PTEZ

Potential for the use of Power to Heat technologies in the transformation of the system district heating sector in Poland

Report by Polish Association of Professional Combined Heat and Power Plants

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Spis treści

1. Executive summary and introduction

Executive summary

INTRODUCTION

- The system heat market in Poland is one of the largest in Europe. System heat is used for heating purposes in 52.2% of households in Poland. At the same time, Polish district heating systems continue to rely mainly on fossil fuels – in 2022, the share of coal in licensed heat generation amounted to 66.2%, gas fuels amounted to 9.3% and RES amounted to 12.6%.

- In accordance with the provisions of the European Green Deal and taking into account the regulations of the "Fit for 55" package, all district heating systems will have to achieve climate neutrality by 2050. The 2023 analysis by the Polish Association of Commercial Combined Heat and Power Plants (PTEZ) indicates that, in Polish conditions, this means that it is necessary to incur capital expenditure for the modernization of the generation, transmission and distribution infrastructure and in the scope of consumer systems at the level from PLN 276 billion to PLN 418 billion (depending on the adopted decarbonization scenario) – a figure that is highly likely to increase i.a. due to parallel works at many jobsites.

- Importantly, the first significant regulatory changes applicable to the existing district heating systems come into force as early as January 1, 2028, which, taking into account the duration of investment processes in the power sector (4–7 years), means that there is little time to plan the decarbonization strategy for individual district heating systems, take the necessary investment decisions, and implement them.

- The regulations of the "Fit for 55" package, combined with the multi-variant economic and technical analysis, allowed to determine the heat generation technologies that can be used to meet the requirements of the climate and energy policy, with particular emphasis on meeting the criterion of an efficient district heating system, which determines the possibility of securing and maintaining public investment aid. The list of these technologies includes i.a. gas sources, biomass sources, geothermal energy, waste heat and Power to Heat technologies. Power to Heat plants, the use of which consists in the use of equipment converting electricity into heat or cold, can make a significant contribution to the decarbonization of district heating, and optimize transformation costs.

- In the system district heating sector, there are two leading Power to Heat technologies:
  - **Heat pumps** – compressor large-scale heat pumps use electricity to increase the parameters of heat taken from the environment (from air, water, soil – the so-called lower heat source) and transfer ("pump") it to supply the district heating system (upper heat source).
  - **Electrode boilers** – directly use electricity to heat water to a specific temperature, therefore they can be used in district heating systems operating at high temperatures – such as those currently used in district heating in Poland.

- Additionally, the Power to Heat technology spectrum includes heat accumulators and seasonal heat storages.

- Across the European, as well as in Poland, there are singular examples of large-scale application of Power to Heat technologies. The most notable of these include the electrode boilers installed by the PGE Group at the Gdańsk Combined Heat and Power Plant (two electrode boilers of 35 MW_t each) and the Szlachęcin project implemented by the Veolia Group (heat pump system of 1.7 MW).

- As for European projects, the largest air-to-water heat pump system connected to a district heating network in Finland was commissioned in June 2023 (11 MW_t), and two electrode boilers with a total power of 100 MW were also commissioned in the same city in 2023.

- Development plans for Power to Heat are very ambitious – they include the Wrompa project implemented by Fortum in Wrocław (12.5 MW_t), a significant expansion of heat pumps (34.2 MW_t in total) in Poznań (Veolia), heat pumps (383 MW_t) and electrode boilers (690 MW_t) in locations where the district heating system is supplied by PGE, as well as other projects that are in the planning phase.

DECARBONIZATION OF DISTRICT HEATING SYSTEMS

- Power to Heat technologies, both heat pumps and electrode boilers in a heat storage system, are one of the key solutions that will enable an economically efficient decarbonization of our district heating systems, while enabling their transformation in a direction compliant with the criteria of an efficient district heating system, the definition of which is specified in the amended Article 26 of the Energy Efficiency Directive (EED).

- This is a conclusion which results from a scenario analysis of the use of Power to Heat technologies in the system district heating sector developed on the basis of a model, the purpose of which was to determine realistic options of development of the system district heating sector. The scenarios were developed in such a way that, when implementing the investment process in several local district heating systems, the requirements of the climate and energy policy and the expectations of the system heat consumers can be met. On this basis, three scenarios of decarbonization of the Polish system

district heating sector were distinguished, including one background scenario, which is based on a failure to meet the requirements of an efficient district heating system for a significant number of such systems in Poland and was used to determine negative effects of the abandoned transformation.

- In **Option A**, the criteria for an efficient district heating system are met mainly through the implementation of investments in RES plants and electrification. **Option B** assumes more intensive development of cogeneration units with the assumption of the necessity to convert natural gas-fired units to decarbonized gases from 2040 onwards, which will depend on the development of the market for these fuels and their availability for the system district heating sector. **Option C** (background scenario) of the report does not lead a significant part of the district heating systems to achieving the criterion of an efficient district heating system, which will result in a gradual search by final consumers for alternative heating solutions and ultimately in abandoning the system heat, which will not always be possible from the perspective of, i.a., technical conditions.

- In the first two options, natural gas is a transitional fuel in the shift away from hard coal. It plays a particularly significant role in the case of the "cogeneration" option (Option B), which will affect Poland's increased total gas demand. In the third scenario (Option C), natural gas is only a supplement to the fuel mix of the district heating sector, giving way to biomass and electrification of heat generation.

- In the background scenario (Option C), decarbonization and compliance with regulatory requirements are implemented by biomass technologies, which results in a significant increase in the biomass fuel demand. The average annual biomass demand in options B and C would be over 4 million tons. Given the potential further tightening of the sustainability criteria for biomass, the difficulties related to the logistics of fuel supply and the availability of biomass on the market, it seems risky to base long-term plans for decarbonization of the entire sector mainly on this source; however, its role in this process cannot be ignored.

- It is only options A and B that guarantee that carbon neutrality is achieved by 2050.

- Additionally, a wider use of Power to Heat means a lower average variable cost of heat generation in the district heating system. In the example presented in the report, this value amounts to PLN 70.6/GJ for the option without Power to Heat technologies and PLN 51.63/GJ for the option covering this type of sources. It should be emphasized that this is an amount corresponding only to variable costs, additionally reduced by revenues from the sale of electricity and does not take into account expenditure or fixed costs of operation of the cogeneration units. However, this is a significant difference showing **a positive impact of Power to Heat on the cost of generation – and, consequently, on the price of district heating.**

- Electrification of individual heating leads to an increase in electricity demand in the range from 7 to 10 TWh. In the analyzed scenarios, the electrification of system district heating took place at different rates, but in all options the maximum demand exceeded 10 TWh. For Option A, the annual electricity demand was more than 15 TWh.

- The analysis shows that **with a wider use of Power to Heat technologies, the system district heating sector will become one of the major consumers of electricity.** The increasing electricity demand resulting not only from the electrification of district heating, but generally from economic and consumer development, will have to be mirrored in the supply of electricity from low- and zero-carbon sources. The development of nuclear power, RES and sources based on biomethane/biogas combustion will play an important role. On the other hand, hybrid district heating systems using heat pumps and electrode boilers coupled with a thermal storage tank will be able to perform the function of stabilizing the national power system, managing surplus electricity from wind and photovoltaic generation.

DECARBONIZATION OF THE NATIONAL POWER SYSTEM

- Under national conditions, the use of electrode boilers promotes integration of RES plants within the power system (i.a. through the possibility of converting and storing surplus electricity as heat).

- The idea of using Power to Heat is to convert electricity during its overproduction by RES plants into heat, store it, and then consume it at the peak of heat demand. Low electricity price in such situations improves the profitability of the Power to Heat plant, lowers the price of system heat while reducing heat generation in conventional units. With the use of Power to Heat, it would be possible to maximize the use of electricity generation by RES plants.

- **Power to Heat technologies will allow surplus electricity from the RES to be managed.** In Poland, as a result of the inability to balance the National Power System, the limitations on operation of the RES plants in 2023–2024 amounted to 421 GWh, and in 2024 in the period from March 1 to May 20, a total of 395 GWh of renewable energy was lost. Electrode boilers or heat pumps installed in district heating systems can increase the potential for using clean electricity.

- The use of electrode boilers may support the fulfillment of national obligations to increase the share of RES in the district heating sector, without the need for an uncoordinated and rushed transition to a low-temperature network, which should take place according to the needs and conditions of specific district heating networks..

COMPLEMENTARY NATURE OF THE ELECTRODE BOILERS AND HEAT PUMPS

- Heat pumps have the potential to replace run-down base-load generating units that use carbon-based fuels for generation. The use of electrode boilers in cooperation with heat storage facilities, in turn, may help to replace peak load back-up units.

- The application and efficiency of a specific Power to Heat technology depends on the type of district heating network. Heat pumps as a heat source are a source of low-temperature heat (approx. 80÷90°C), which requires additional heating of system water from heat pumps in the heating season in high-temperature networks, which prevail in Polish district heating systems. Electrode boilers, on the other hand, can heat the system water up to 160°C. As the process of switching to a low-temperature district heating network entails considerable costs and inconvenience for residents as well, it must be assumed that it will be prolonged. Therefore, it is important that both Power to Heat technologies are treated in a complementary and equivalent manner.

- Electrode boilers are also a solution for large district heating systems, where heat pumps are not sufficient to cover the heat demand and other RES technologies cannot be implemented (in urban areas, biomass supplies or finding space for solar systems are problematic).

REGULATORY RECOMMENDATIONS

- The following issues are key to the widespread use of Power to Heat technologies in the Polish district heating sector:
    - **A new system of operational support** for selected technologies of renewable heat generation from RES electricity, which would be tailored to the specific features of the technologies included in Power to Heat. The decision on the selection of supported technologies should be preceded by analyses on the necessity of granting such aid, on the basis of which it will be determined which technologies and at what stage (investment, operational or both equally) generate the highest costs, and whether they are able to be price competitive without operational support and which support period should be envisaged. The technology selected on this basis will determine the final shape of the new system of operational support.
    - **Introduction of a possibility to classify heat generated in electrode boilers as heat from RES for compliance with the definition of an efficient district heating system.** Electricity from renewable energy sources used for heat generation in electrode boilers should be certified with guarantees of energy origin (or a mechanism based on guarantees of origin) or power purchase agreements (PPAs). The boilers may also be supplied with energy directly from dedicated or local renewable RES plants (direct line), but these cases do not require any additional regulations.
    - **Changes to RES heat tariffs.** The current heat tariff regime fails to reflect the specificities of RES plants, which have high investment costs but do not generate operating costs analogous to those of conventional generation units. Moreover, the current regulations and guidelines of the President of the Energy Regulatory Office do not reward the efforts of energy companies which undertake investments in RES plants.

A BROADER VIEW OF THE DECARBONIZATION PROCESS

- Despite the fact that the purpose of this analysis is only to analyze the potential and conditions of development of specific technologies allowing for heat generation from RES, a key condition for effective implementation of the process of decarbonization of district heating in Poland is that all parties participating in the heat market should be involved in this process, as individual actions implemented depend on each other. The burden of transformation should not only be borne by heat producers, which could result from the basic requirement related to the need to change the energy mix in district heating systems, but also by district heating network operators (adaptation to the change of the heat-carrying medium parameters) or final consumers (activities involving thermal performance improvement of buildings and retrofit of consumer systems), which in total will impact the optimization of decarbonization costs, affecting i.a. the level of heat demand, or will allow for the most efficient transmission and distribution of heat with reduced parameters.

- An important role in the process will also be played by decision-makers, who can largely support the decarbonization of the district heating sector by implementing regulations improving the implementation of investment processes on such a large scale and adapting technical requirements to the applied technological solutions.

Introduction

Meeting climate and energy policy targets poses a range of challenges for the district heating sector. In the first place, it will require the introduction of new zero- and low-carbon technologies to replace fossil fuel-based generating units.
Meeting the new criteria for an efficient district heating system, including increasing the share of RES energy, is a key challenge for energy companies operating in the district heating sector. Also, the price competitiveness of system heat must be ensured. In order to achieve these goals, it is necessary to electrify the district heating sector through the implementation of Power to Heat technologies. Increasing the share of RES energy in district heating systems depends not only on the availability of appropriate technologies, but also on national regulations which should support the decarbonization process of the sector.
Power to Heat technologies include primarily heat pumps and electrode boilers that convert electricity to heat or cold. At the same time, taking into account the specificity of electricity generation related to a large number of weather-dependent RES plants connected to the National Power System, an important role of heat storage is expected.
Responding to the need to decarbonize the district heating sector using RES electricity, the Polish Association of Commercial Combined Heat and Power Plants (PTEZ) prepared an overview

of the potential for the use of Power to Heat technologies in the transformation of the system district heating sector in Poland. In this report, PTEZ experts analyzed:

- the characteristics of the district heating sector in Poland (in Chapter 2);
- available Power to Heat technologies, described their principle of operation and experience with their use (in Chapter 3);
- the regulatory environment in the context of the use of Power to Heat technologies, resulting from EU and national regulations (in Chapter 4);
- market conditions for the use of RES electricity in the district heating sector (in Chapter 5);
- the impact of the Power to Heat technologies on the achievement of the climate and energy policy targets and the functioning of the National Power System (in Chapter 6);
- and developed recommendations for the implementation of RED III and EED, and for regulatory changes in the scope of heat support and tariff systems (in Chapter 7).

The original analysis of the Power to Heat technology scenarios in the system district heating sector was prepared on the basis of a model aimed at determining realistic options of the development of the system district heating sector (for the period 2024–2050). The scenarios were developed in such a way that, when implementing the investment process in several local district heating systems, the requirements of the climate and energy policy and the expectations of the system heat consumers can be met. One of the scenarios is based on the failure to meet the requirements of an efficient district heating system for a significant number of such systems in Poland and it is used to determine negative effects of abandoning the transformation.

2. System district heating in Poland – current situation and challenges faced by the transition

The system heat market in Poland is one of the largest in Europe. The large-scale heat is used for heating purposes in 52.2% of households in Poland[1]. Conducting heat generation activity in sources with total installed thermal power exceeding 5 MW requires a license and is subject to the obligation to approve tariffs by the President of the Energy Regulatory Office (ERO), but in case of cogeneration units, the license obligation applies to all units.

According to the data from the ERO report "Thermal power sector in figures – 2022", licensed companies generated heat in sources of various sizes with a quantitative predominance of small sources up to 50 MW, only eight companies had available power of sources exceeding 1,000 MW. Hard coal has had the largest share in the structure of fuels used to generate system heat for many years. Over recent years, its share has been gradually decreasing in favor of natural gas and renewable energy sources.

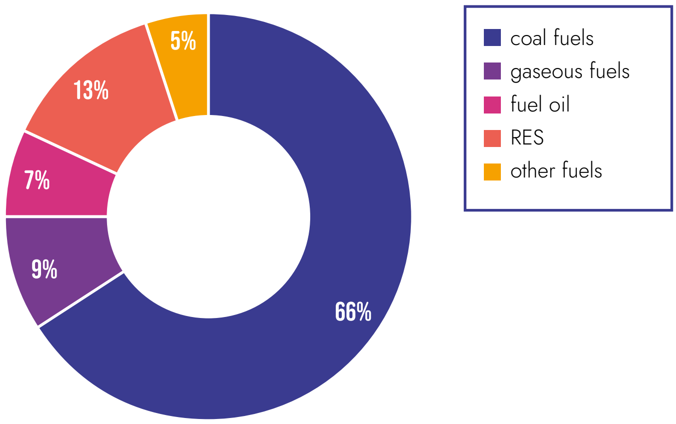
In recent years, there has been a large increase in the price of heat due to higher costs of heat generation, in particular for the purchase of fuel (increase in fuel prices caused mainly by high inflation) and CO_2 emission allowances. However, the increase in heat prices does not translate into an improvement in the economic situation of the district heating sector – since 2019, the profitability level of heat generating sources in cogeneration has been negative.

Heat supplied to customers from district heating and cogeneration units is price competitive compared to alternative, individual and off-system heat sources. The use of modern generation methods, including appropriate environmental

Table 1. Characteristics of licensed district heating in 2022[2]

Item	2022 r.
Number of licensed district heating companies	392
Installed power in MW	53 188
Contracted power in MW	34 924
Length of networks in km	22 578
Employment in jobs	27 772
Total heat sales in TJ	357 703
Heat returned to the network in TJ	265 658
Heat supplied to network-connected consumers in TJ	233 134

Figure 1. Fuel figures (according to energy contained therein) used for heat generation in 2022[3]



1 Statistics Poland, Energy carrier consumption in households in 2021.

2 Own study based on the data of the report "Thermal power sector in figures – 2022" of ERO, Warsaw, October 2023

3 Own study based on the data of the report "Thermal power sector in figures – 2022" of the ERO, Warsaw, October 2023.

protection systems, guarantees high efficiency of energy use, in particular in the cogeneration process (i.e. simultaneous generation of heat and electricity). System district heating is the most effective method of combating the low emission and the problem of energy poverty due to significant possibilities of development of the district heating network and connection of new consumers. Expenditures related to connection of next consumers to the district heating network are generally lower than the construction of individual heat sources, especially in the case of multi-family buildings. The priority of district heating companies is to ensure security and stability of supplies for heat consumers. Moreover, the risk of supply interruptions is minimal and possible failures are quickly resolved.

Today, system district heating faces a number of challenges caused by the need to transform and retrofit in order to meet the requirements of the EU climate and energy policy, mainly in the scope of the European Green Deal and the Fit for 55 Package. In accordance with the conclusions of a 2023 report of the Polish Association of Commercial Combined Heat and Power Plants entitled Assessment of the impact of the decisions of the EU "Fit for 55" Package on the transformation of the district heating sector in Poland, expenditures for adaptation of the system district heating sector in Poland will amount – depending on the adopted scenario – to PLN 276–418 billion. In view of the financial situation of district heating companies and the limited "tolerance" of customers to price increases, the funds for the transition should be obtained with significant support from the State and the European Union.

Despite the theoretical wide availability of low- and zero-emission technologies, it is not obvious to select the optimum option for the implementation of investment projects from the point of view of the security of heat supplies and the amount of generation costs. Technical barriers to the use of state-of-the-art generation methods based on zero-emission renewable energy include in particular: outdated transmission, distribution and reception infrastructure in buildings, as well as inability to place RES sources in the vicinity of the system or difficulties in supplying enough biomass.

Bold investment decisions for strictly regulated parts such as district heating require clear and transparent regulations to keep pace with changing methods of heat generation, transmission and distribution, and to guarantee the long-term stability of the regulatory environment.

An opportunity to meet the objectives related to Poland's and the EU's pursuit of climate neutrality is the broadly understood electrification of district heating. The full or partial use of renewable electricity by Power to Heat plants contributes to a physical increase in the share of green electricity in the district heating sector. On the other hand, the development of this technology may have a positive impact on the management of surplus electricity from renewable energy sources in the national power system. Integration of the national power system with district heating systems in the technical and regulatory area is a prerequisite for successful transformation of the Polish power sector.

3. Power to Heat technologies[4]

3.1. Available technologies and their principle of operation

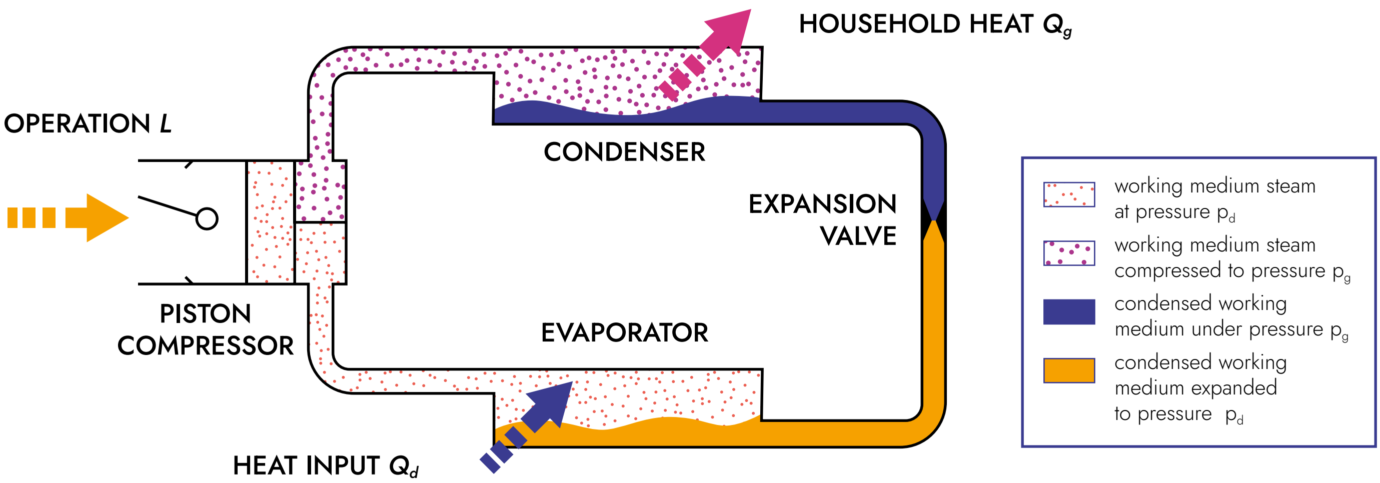
Power to Heat consists in the use of equipment converting electricity into heat or cold. In the district heating sector, there are two leading Power to Heat technologies:

- **Heat pumps** – compressor large-scale heat pumps use electricity to increase the parameters of heat taken from the environment (from air, water, soil – the so-called lower heat source) and transfer ("pump") it to supply the district heating system (upper heat source). Heat pumps are most efficient in low-temperature networks.
- **Electrode boilers** – directly use electricity to heat water to a specific temperature, therefore they can be used in district heating systems operating at high temperatures – such as those currently used in district heating in Poland.

3.2. Heat pumps

Heat pump is a device that transports heat from a lower temperature space from the so-called lower heat source to a higher temperature space – i.e. to the so-called upper heat source, which may be, for example, a district heating network or a heating system of a building. For this purpose, the thermodynamic process cycle (evaporation, compression, condensation and expansion) to which the working medium circulating in the pump is subjected is used. The temperature of the working medium (e.g. cooling medium) after evaporation may be increased by means of mechanical energy (electric compressor heat pump) or thermal energy (absorption/adsorption heat pump – this type of heat pumps does not fit into the Power to Heat mechanism and will not be discussed in the report).

Figure 2. Heat pump compressor station system diagram



4 Information from the study prepared by Energopomiar Sp. z o.o. for Veolia was used in sub-chapters 3.1-3.4.

Examples of lower heat sources that can be used in pumps are: air, water (e.g. rivers, lakes, seawater), municipal wastewater (both treated and untreated); energy accumulated by the ground (collected by an intermediate medium circulating in ground, deep-water or surface heat exchangers), as well as waste heat from various technological processes.
An important aspect of heat pump operation to choose a specific working medium. The relevant substances have different levels of environmental impact, determined, among others, by the Global Warming Potential (GWP).
The key operating parameter of each heat pump is the pump's coefficient of performance (COP), which describes the ratio between the energy transferred to the upper heat source and the electricity supplied to it (or heat in sorption equipment) at specific pump operating points. The COP value of a heat pump depends on the temperatures of the upper and lower source. The higher the temperature of the lower source and the lower the temperature of the upper source, the higher the efficiency of the "heat pumping" process – therefore, the COP value may vary depending on the pump operating parameters and reach values from 1.7 to 5. Pump suppliers usually use SCOP, a seasonal COP factor representing an averaged value. Large-scale heat pumps are characterized by a relatively large thermal power range of equipment – from 1 MW_t to 90 MW_t and more. In district heating applications, solutions can be found in the form of several heat pumps with a common lower heat source operating in parallel or in series, which allows to better match the generation profile with the demand on the district heating side through better flexibility of the plant.
Table 2 summarizes the advantages and disadvantages of heat pumps in the context of application in district heating systems.

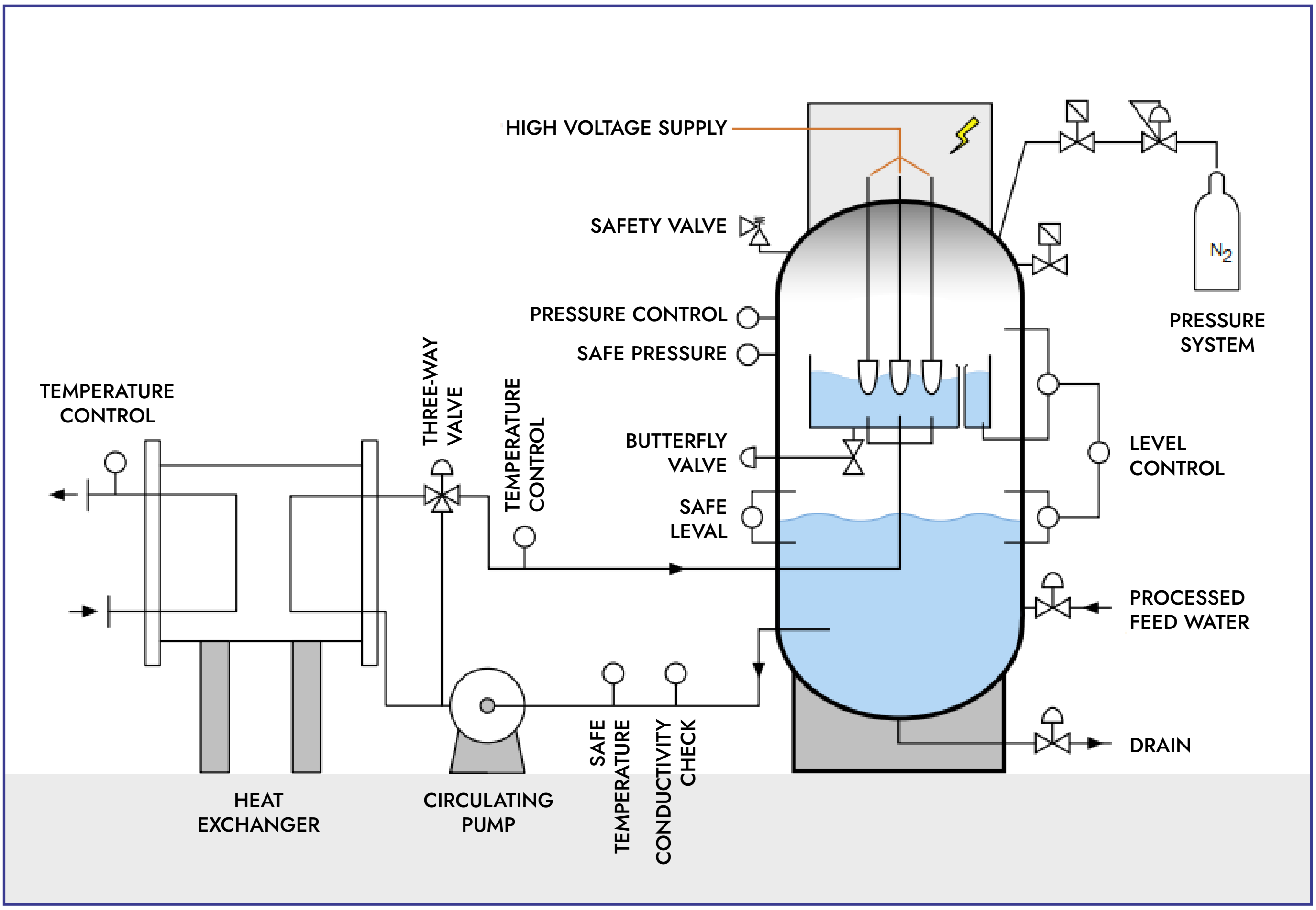
Table 2. List of advantages and disadvantages of heat pumps in the context of application in district heating systems

Advantages	Disadvantages
■ Relatively wide power range ■ High efficiency ranging from 250% to 500% ■ High degree of technology automation ■ High reliability, availability and service life. No long-term overhaul outages, possibility of operation throughout the year ■ Possibility of classifying energy taken from the lower natural heat source (air, water, ground) and wastewater as a renewable energy source or as waste heat if heat is recovered from industrial processes (e.g. heat from the server room) ■ Relatively short construction time (up to 24 months) ■ Possibility of quick change of electric/thermal load – up to 10 MW_e/30 s. ■ No emissions of greenhouse gases and other pollutants generated by systems based on the combustion behavior, no need for costly retrofits with the implementation of stricter emission standards (NOX, etc.) ■ High technological maturity	■ Availability of electrical connection power and usually no location correlation between lower and upper heat sources ■ Usually, the economically reasonable maximum preheating temperature is relatively low, ranging from 80 to 90°C, which may require additional preheating in the heating season to the temperature in high-temperature networks required by the adjustment table. ■ Decrease in efficiency as the temperature difference between the lower heat source and the upper heat source of the water increases in the district heating network (for most heat pumps) ■ Decrease in efficiency at negative ambient temperatures. ■ High capital expenditures, especially for ground pumps ■ Risk of periodic generation reduction due to parameters of the lower heat source, e.g. too low water temperature in the river or too low air temperature ■ For some equipment, operating media are used that are not environmentally inert, and there is a risk that factors with high GWP will be excluded from the market. ■ Economic viability is largely dependent on electricity prices

3.3. Electrode boilers

The operation of an electrode boiler is based on heat generation that accompanies the flow of electricity through properly prepared circulating water. The main component of a boiler is a high-pressure tank filled with water, in which the electrodes to which voltage is applied are properly submerged. The water flowing between the electrodes circulates from the boiler to the heat exchanger in a closed circuit. On the secondary side of the heat exchanger, the heat stream is collected by district water. In industrial electrode boilers, water in the primary circuit is characterized by a high temperature, significantly exceeding 100°C (reaching up to 160°C), so that the boilers can be a heat source in high-temperature district heating networks.
Electrode boilers are designed for operation in the power range of 1–113 MW_t (most often 5–50 MW_t). The high-power ones are used in district heating systems and in the chemical or food industries.
It should be pointed out that, unlike fossil-fired boilers, the efficiency of generation in electrode boilers is practically independent of equipment load. Both at half load and full load, the efficiency is similar and amounts to approx. 99%.

Figure 3. Operation diagram of the hot water generation system in an electrode boiler



Source: https://www.parat.no/pl/products/industry/parat-ieh/

Table 3. List of advantages and disadvantages of electrode boilers in the context of application in district heating systems

Advantages	Disadvantages
■ Wide power range and high flexibility (high load rate) ■ High efficiency above 99%, load independent ■ High degree of technology automation ■ High reliability and availability ■ They do not require a large area for installation (short water cycle) ■ They make it possible to manage surplus electricity from RES ■ Very fast construction time (up to 12 months) ■ No emissions of greenhouse gases and other pollutants that arise from combustion behavior systems ■ No need for costly retrofits with the implementation of stricter emission standards (NO_x, etc.)	■ Possible increase in operating costs (or reduction of the power factor as a result of an increase in electricity prices) ■ Reliance on renewable energy supply and RES electricity prices ■ Availability of connection power ■ Costs related to additional network investments

3.4. Heat storage – cooperation with Power to Heat technologies

Due to high variability and weather dependence of electricity generation from RES and due to the fact that periods of excess electricity from RES are not always correlated with periods of heat demand, as well as due to economic aspects related to the variability of electricity prices, the concept of using Power to Heat technologies for decarbonization of the sector envisages a significant use of heat storage facilities. Heat storage facilities are classified as short and medium-term (daily, weekly) and long-term (seasonal).

3.4.1. Short-term heat storage – heat accumulators

A heat accumulator is a suitably insulated non-pressure, usually steel above-ground tank that uses heat stratification, which involves natural temperature stratification inside of the tank. Layers of hot water with the temperature usually up to approx. 95–98°C are located in the upper area and the layers of colder water, with the temperature of return water from the municipal district heating network, in the lower area of the tank. Therefore, the accumulator filling level depends on the location of the water layer in which the highest temperature difference occurs. During the filling process, water coming from heat exchangers of other heat sources is pumped to the upper part of the tank. Feed water of the tank replaces cold water from the bottom of the tank, which is discharged to the return water pipeline. The discharge process is analogous to the above, except that the direction of the hot and cold water flow is reversed.

In district heating systems, heat accumulators have the potential to cooperate with electrode boilers. An accumulator is able to store the heat generated in a boiler during the period of excess electricity from RES present in the national power system. Moreover, the accumulator operation contributes to obtaining electricity from the spot or balancing market at a favorable price (low or even negative) regardless of the moment of heat demand, which improves the economics of using the Power to Heat technologies.

Table 4. Heat accumulators in Poland[5]

Location	Height, m	Diameter, m	Volume, m^3
Siekierki CHPP	47	30	30 400
Białystok CHPP	37	21	13 000
Generating Power Plant Bielsko-Biała CHPP1	65	21	20 000
Kraków CHPP	48	23	20 000
Poznań CHPP	63	24	24 000
Toruń CHPP	42	20	13 000

Table 5. List of advantages of heat accumulators in the context of application in district heating systems

Advantages[6]
■ Ability to balance the heat sources load at variable heat demand ■ Ability to cover instantaneous peak heat demand ■ Ability to increase instantaneous peak power of the source ■ Increasing the equipment operation flexibility, electricity and heat generation efficiency and availability ■ Heat generation costs reduction ■ Ensuring heat supply in emergency situations ■ Enabling heat sources operation in periods when the heat demand is lower than the equipment technical minimum ■ Making electricity generation independent of the heat demand profile (this may have an impact on limiting the costs of failure to meet the generation plan, i.e. the participation in the balancing market) ■ Maximization of electricity generation in cogeneration systems in case of high electricity prices on the market and, at the same time, low heat demand. ■ Use of accumulator water to cover water losses in the district heating network ■ Possibility of maintaining the static pressure in the network in case of unexpected shutdown of network pumps (gravitationally) until the static pressure pumps are switched on

5 Own study based on data of power companies

6 Nie identyfikujemy większych, istotnych wad funkcjonalnych magazynów ciepła

3.4.2. Seasonal heat storage

The purpose of the seasonal storage is to accumulate heat during periods when heat is available in excess (e.g. in the summer) to be able to use it during periods of increased demand (during the heating period). The model operation of the seasonal heat storage is as follows: in late spring and summer, when a large quantity of electricity from RES (e.g. from photovoltaic cells) is commonly available, storage loading takes place. Heat can be obtained directly from solar collectors, electrode boilers or heat pumps, which during this period have a high coefficient of performance (COP) and may be supplied by relatively cheap electricity from RES plants during periods of surplus production in the National Power System. Then, in autumn and winter, when the heating season begins, heat is collected from the storage by flowing cold water, which is heated by the accumulated energy. Heat losses range from several to a dozen percent per month, depending on the storage technology used, size, location, surrounding environment and soil conditions.

Seasonal heat storages have been developed and tested since the 1980s in countries such as Denmark, Germany and Austria. Four large-scale heat storage technologies with different values of thermal capacity, efficiency as well as charging and discharging rates are currently being developed. The selection of a specific technology is mainly influenced by local conditions. In practice, heat can be stored in hot water or in the ground, but phase-change materials can also be used for this purpose. Table 6 lists the types of seasonal heat storages.

Table 6. Types of seasonal heat storage

Type of storage	Aboveground water tank	Water tank in the ground trench	Ground battery	Battery in the aquifer
English name and abbreviation used	Tank Thermal Energy Storage (TTES)	Pit Thermal Energy Storage (PTES)	Borehole Thermal Energy Storage (BTES)	Aquifer Thermal Energy Storage (ATES)
Storage potential	60–80 kWh/m³	30–80 kWh/m³	15–30 kWh/m³	30–40 kWh/m³
Specification	Aboveground or partially underground water tank	A water tank formed in a cavity excavated in the ground, filled with water or water and gravel	Storing heat in the ground, e.g. in a volume of rocks, sand, soil, by supplying and collecting heat through boreholes	Storing heat in aquifers, access through two boreholes

Table 7. Summary of the advantages of seasonal heat storages in the context of application in district heating systems

Advantages	Disadvantages
▪ Use of electricity from RES generated during the period of lower heat demand ▪ Increase of energy security ▪ Reduction of heat generation costs	▪ High total capital expenditures ▪ Large area required for installation ▪ Relatively high heat losses through the upper cover of the storage (PTES)

3.5. Selected Power to Heat technology experiences in Poland and in the European Union

3.5.1. Completed projects:

Electrode boilers at Gdańsk Combined Heat and Power Plant

Two electrode boilers in PGE Energia Ciepła Gdańsk Branch with a power output of 35 MW_t each, supplied with electricity. The electrode boilers have two functions:

- peak load back-up that guarantees the security of heat supply in the event of increased demand at low temperatures;
- enabling additional heat generation through participation in balancing of the National Power System. In 2023, the electrode boilers operated for 453 hours while performing this function. This solution allowed the Gdańsk Combined Heat and Power Plant to avoid burning more than 1,500 tons of coal and reduced its CO_2 emission by almost 3,200 tons.

In 2023, electrode boilers operating for the needs of district heating, including balancing of the National Power System, operated for 1,312 hours and produced more than 100 TJ of heat for the residents of Gdańsk, which statistically corresponds to the demand of approx. 3,500 households.

Szlachęcin Project

Veolia, in cooperation with the local water supply and sewerage company Aquanet, commissioned a district heating system in Szlachęcin (Wielkopolskie Voivodeship), using the synergy of high-efficiency cogeneration and heat pump recovering heat from wastewater.

Heat is obtained simultaneously from two sources: from a heat pump with a lower source in the wastewater, supplied with energy from high-efficiency cogeneration and from the cogeneration system at the wastewater treatment plant. Its installed electric power is 1 MW, of which 700 kW is used to supply the heat pump and the surplus is fed to the National Power System. The new plant partly replaced the existing traditional coal-fired district heating plant in Bolechów, making the entire system run on renewable energy in 62%. It also made it possible to reduce CO_2 emissions by 5,142 tonnes per year (a reduction by 54%). In addition to reducing carbon dioxide emissions and coal consumption (3,400 tonnes per year), the solution also contributes to reducing emissions of sulfur dioxide (by 17.6 tonnes per year, a drop of 71%), nitrogen compounds (8.6 tonnes, 56%) and dusts to the atmosphere (1.8 tonnes, 70%), as well as reducing the temperature of wastewater, which is discharged to the Warta River following treatment.

The heat pump system has the following parameters:

- thermal power – 1.6 to 1.7 MW,
- lower source power output – 1.07 MW,
- lower source temperature – 20/8°C,
- electric power demand – 660 kWe,
- COP – 2.58,
- heat output – 38,345 GJ/a.

3.5.2. Projects in progress

Espoo (Finlandia)

Use of Power to Heat technology in Espoo (Finland) as an example of decarbonization of the entire district heating system. Fortum, in cooperation with the city of Espoo (a city with a population of more than 300 thousand, i.e. at the level of population of Lublin or Bydgoszcz), is implementing the Espoo Clean Heat project[7], which assumes achieving climate neutrality in 2029. Power to Heat technologies supplement the biomass-fired heat generating plant. Additionally, artificial intelligence ensures optimization of operation of several heat sources with balancing of demand in the district heating system while ensuring maximum energy savings.

Specification of the Espoo district heating system:

- Heat generation is more than 2 TWh.
- In 2014, almost 100% of production came from fossil fuels (it was based on hard coal – 72%, natural gas – 27% and oil – under 1%).
- By 2025, it is planned to completely abandon the use of coal.

7 Espoo Clean Heat | Fortum

Espoo Clean Heat projects include:

VERMO PROJECT – completed project

The largest AWHP plant in Finland (air-water heat pumps connected to the district heating network). It was commissioned in June 2023 with the following parameters:

- thermal power: 11 MW,
- supply temperature up to 95°C.

The advantage is the simultaneous production of heating and cooling to increase efficiency. The technology is easy to scale and has the capability to gradually increase power to 150 MW.

Vermo project

SUOMENOJA PROJECT – completed project

The site currently has five generating units, including two gas turbines. It includes a total thermal power of 600 MW and electricity generation of 350 MW. The last coal-fired unit was closed in April 2024 (one year earlier than originally planned). The retrofit covers:

- heat pumps with total power output of 65 MW (the largest – 25 MW), lower source: treated wastewater and seawater;
- 800 MW (20,000 m^3) heat storage to make production more flexible;
- 100 MW (2 x 50 MW) electrode boilers, commissioned in 2023

Suomenoja project

MICROSOFT DATA CENTER WASTE HEAT MANAGEMENT PROJECT – project in progress

The world's largest project to use waste heat from data centers. The project assumes the introduction of waste heat from server cooling to the existing district heating network. Construction works were commenced in 2023 and are expected to last until the end of 2025.

The project includes, among others, the construction of:

- heat pumps (both water-to-water and air-to-water),
- two electrode boilers,
- heat storage (with a capacity of approx. 20,000 m^3).

The project will cover 40% of total annual municipal heat demand and 100% of the summer demand and reduce CO_2 emissions by 400,000 tons per year.

Use of Power to Heat technology with Wrocław as an example of such use – "Wrompa" project

Fortum, in cooperation with Miejskie Przedsiębiorstwo Wodociągów i Kanalizacji in Wrocław, is implementing, on the premises of the Port Południe wastewater pumping station, an investment project consisting of a heat pump named "Wrompa". System pump characteristics:

- It uses raw wastewater as the lower source.
- Thermal power is 12.5 MW_t.
- Planned: investment cost – approx. PLN 110 million, to be commissioned: Q4 2024.
- The project was co-financed in the form of grants from the European Economic Area Financial Mechanism in the amount of PLN 18 million and from the state budget in the amount of PLN 3 million.

The pump will supply up to approx. 5% of the annual demand of the district heat customers. With the use of a heat pump, it is estimated that the generation of thermal energy from fossil fuels will be reduced by 36 thousand GJ per year (it will also allow to avoid the emission of almost 35 thousand tons of CO_2 and other harmful substances – SO_2, NO_x and dust);

Projekt „Wrompa"

3.5.3. Planned projects

The table below presents selected projects planned for implementation by power companies being members of the Polish Association of Combined Heat and Power Plants.

Table 8. Selected planned Power to Heat projects.

City	Plant Owner	Type/technology of the plant	Lower source for heat pump	Thermal power of the plant (installed) [MW]	Heat generation (planned) [GJ/year]	Commissioning date (planned)	Type of power supply
Poznań	Veolia Polska	Heat pump	Raw wastewater	2,2	46 714	Q4 2026	grid electricity
Poznań	Veolia Polska	Heat pump	Treated wastewater	32	800 000	Q4 2028	grid electricity
Poland[8]	PGE Energia Ciepła	Heat pumps	River water / municipal wastewater / air / ground	383	n.d.	2027–2035	grid electricity / auxiliary electricity
Poland[8]	PGE Energia Ciepła	Electrode boilers	-	690	n.d.	2022–2030	grid electricity / auxiliary electricity

8 As part of projects consisting in decarbonization of generation sources, PGE Energia Ciepła S.A. is currently analyzing the potential of applying the Power to Heat technology in its sites. The values listed in the table are approximate and may change during further analytical studies.

4. Regulatory environment in district heating with a view to using the Power to Heat mechanism

4.1. European Union climate and energy policy

To meet the EU's climate and energy objectives (European Green Deal and Fit for 55 package), the sector will have to face a series of decarbonization challenges and it will be required, in particular, to introduce new zero- and low-carbon technologies that will replace the existing fossil fuel-based generation assets. In the existing market and legal conditions, renewable heat in Poland is generated largely based on certified biomass (which meets sustainability criteria). As EU regulations aim to reduce the role of this fuel in the power sector, it is necessary to explore other sources of renewable energy that will enable continuation of the process of "greening" the district heating. According to the Carbon-Neutral Poland 2050 analysis prepared by McKinsey & Company[9], for Poland to meet the environmental objectives in the area of district heating and cooling, the share of renewable energy in final energy consumption in 2030 should exceed 35%.

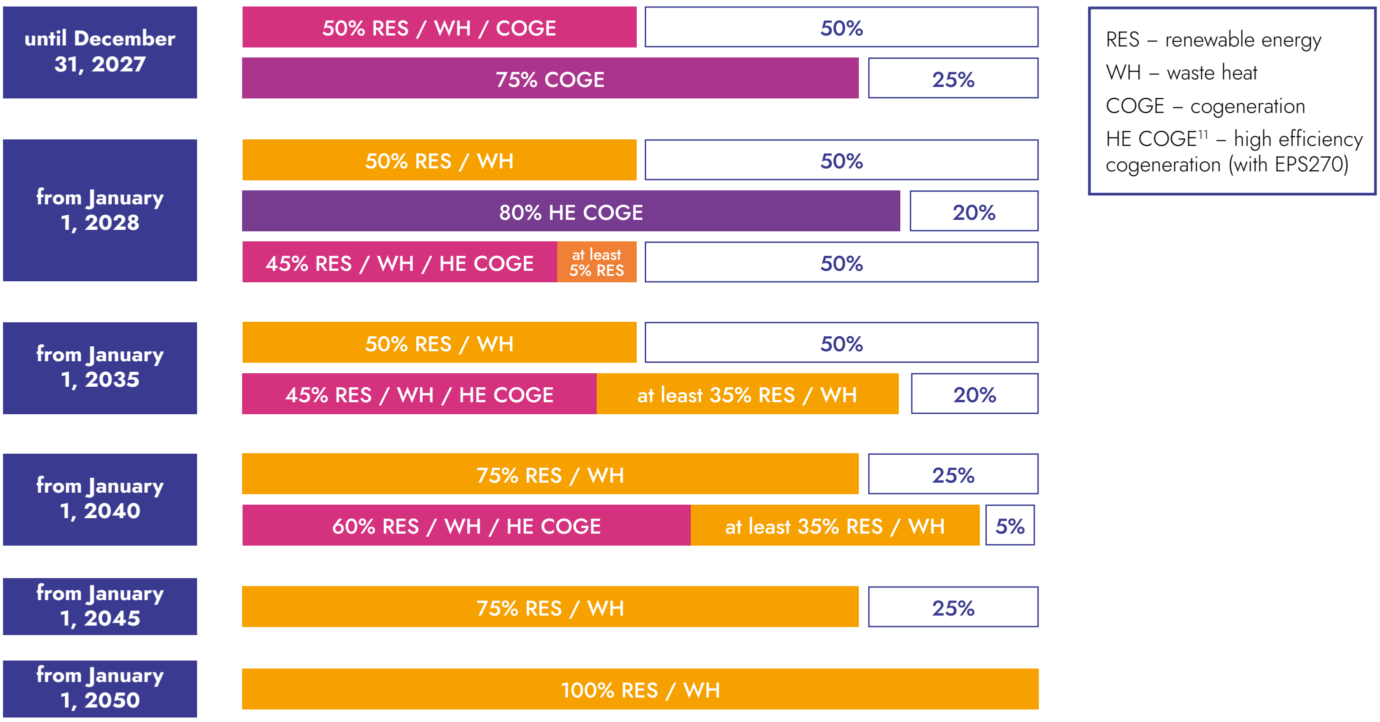
One of the key solutions in this area will be electrification of district heating with the involvement of the Power to Heat technology. This sub-chapter discusses the key conditions for the use of Power to Heat from the perspective of EU regulations.

9 Carbon-Neutral Poland 2050, McKinsey & Company, 2020; Green Horizons: Poland heading towards a sustainable future, Kearney; 2024

Energy Efficiency Directive

In the revised Energy Efficiency Directive (hereinafter EED), a significant change is the new definition of an efficient district heating system, which assumes target shares of renewable sources, waste heat and cogeneration in individual years until 2050, when zero-emission district heating systems are expected). As defined in Article 26 of the EED, efficient district heating systems shall meet the following criteria:

Required heat shares from efficient district heating systems (Article 26 of the EED)[10]



Moreover, the Directive allows for the establishment of an alternative definition of the district heating system based on greenhouse gas emissions from the district heating system per heat unit without indicating individual shares of heat sources. The maximum values of greenhouse gas emissions per unit of heat supplied to consumers in individual years are as follows:

- from January 1, 2026: 150 g/kWh,
- from January 1, 2035: 100 g/kWh,
- from January 1, 2045: 50 g/kWh,
- from January 1, 2050: 0 g/kWh,

10 own study based on EED

11 from 2028, high-efficiency cogeneration shall mean cogeneration units that meet the emission performance standard (EPS) of direct carbon dioxide, which was determined at 270 g CO_2/kWh of generated energy, but it will apply to units that are either new or were substantially refurbished after the transposition date, i.e. October 11, 2025. For cogeneration units operating before the entry into force of the amended Directive, it is possible to derogate the application of the ENP until January 1, 2034, provided that such units develop an emission reduction plan to reach the threshold of 270 g CO_2 per 1 kWh by January 1, 2034.

The above-mentioned criteria, as part of the definition of an efficient district heating system, set a clear direction in terms of increasing the role of RES in district heating systems. In view of the above, it should be stated that it will be necessary to increase the share of renewable energy and waste heat in district heating systems, which may be executed, among others, by using the Power to Heat technology.

Directive on promoting the use of energy from renewable sources

The amended Directive on promoting the use of energy from renewable sources (hereinafter: RED III Directive) introduces a new Europe-wide binding target of at least 42.5% share of energy from renewable sources in gross final energy consumption in 2030 and an additional indicative target of 2.5% share of energy from renewable sources in gross final energy consumption in 2030. The amended Article 23 also sets new nationally binding targets for the entire heating and cooling sector (combined individual heating and district heating) assuming an annual increase in the share of renewable energy sources by 0.8 pp in the period 2021–2025 and by 1.1 pp per year in the period 2026–2030, with non-binding additional targets agreed for Member States.

For district heating, as one of the sectoral objectives, Article 24 sets an indicative target, assuming an average increase in the share of energy from renewable sources at 2.2 percentage points per year in the 2021–2030 period.

From the point of view of the implementation of Power to Heat technology in district heating, the possibility of including electricity from renewable energy sources for the purpose of achieving the objectives for district heating, as introduced by Article 24, is key. A similar possibility was introduced by Article 23 (general objective for heat), but its use will be limited only to heat pumps due to efficiency requirements. This change should be treated as a formal basis for using Power to Heat as an action leading to an increase in the share of renewable sources in district heating. RED III also regulates the accounting of renewable energy from heating heat pumps.

Energy Performance of Buildings Directive

In relation to the above directives, the Energy Performance of Buildings Directive (hereinafter EPBD) refers to buildings as final consumers of heat, which are expected to be zero-emission in 2050.

The EPBD establishes a zero-emission building definition that all new public buildings will have to meet from January 1, 2028 and all other new buildings from January 1, 2030. The definition indicates that a zero-emission building does not burn fossil fuels and its total annual primary energy consumption is covered by the following possible energy sources:

- renewable energy produced on site or nearby,
- renewable energy from energy community,
- from efficient district heating systems in accordance with the criteria in the recast EED,
- carbon-free energy source from the grid – in accordance with the applicable general requirements for decarbonization of these sources (e.g. RES, but also nuclear power sector).

Additionally, if due to economic and technical conditions none of the above methods of power supply is available, Member States will be able to set a national standard for zero-emission buildings, which permits the approval of the use of other energy from the grid. Through the requirements set for the zero-emission building, it can be concluded that the use of Power to Heat technology is justified, with the help of which heat will be supplied through efficient district heating systems. Moreover, the EPBD strengthens the requirements for reduction of energy consumption in buildings and also forces further reduction in the scope of renovation and thermal upgrading of buildings. The above issues will affect the market environment for district heating, limiting the demand for heat on the part of consumers. On the other hand, the gradual reduction of heat temperature in buildings provides the possibility of development for Power to Heat. Electrification of district heating with the use of high efficiency will also contribute to reducing energy consumption in buildings.

The aforementioned amendments to the directives require, at the time of preparation of the report, implementation into national law.

4.2. National legislation in the context of the use of Power to Heat technology

National legislation allows heat produced from renewable electricity to be classified as green heat if it is produced in the same renewable energy plant. The plant within which electricity from the RES is generated and then used to generate heat in that plant meets the requirements of the definition of a renewable energy source plant, provided for in Article 2 section 13 of the RES Act[12]. This is due to the fact that electricity and heat are produced in a plant where energy is produced from renewable energy sources and, consequently, heat is produced from a renewable energy source plant.

Two legal acts came into force in 2023, which may constitute a starting point for the process of decarbonization of district heating using renewable energy sources based on Power to Heat technology:

- Act of July 28, 2023 amending the Act – Energy Law Act and certain other acts (Journal of Laws, item 1681) – it implements into the national law the Directive (EU) 2019/944 of the European Parliament and of the Council of June 5, 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU;
- Act of August 17, 2023 amending the Act on Renewable Energy Sources and certain other Acts (Journal of Laws, item 1762) – implements Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources ("RED II Directive").

The above legal acts introduced into the Polish law regulations concerning:

1. redemption of the guarantees of origin

the amendment to the RES Act introduces, among others, changes in Chapter 5 of this Act, which refers to the guarantees of origin. The changes in this respect are aimed at implementing Article 19 of the RED II Directive by introducing guarantees of origin for heat or cold generated from renewable energy sources in renewable energy source plants. As regards the redemption of the guarantees of origin, the Act allows for the redemption of the guarantees of origin for the purposes of the energy conversion process, which should be understood as a technological process resulting in the generation of derivative types or carriers of energy, in the form of electricity, heat or cold, biomethane, renewable hydrogen, biogas or agricultural biogas. The issuance of a guarantee of origin for a given derivative energy type or energy carrier is preceded by the redemption of the existing guarantee of origin for that type or energy carrier;

2. RES Power Purchase Agreements (PPA)

regulations concerning purchase agreements for the electricity from renewable energy sources are included in the Act – Energy Law (Article 5 section 2d). This implements Article 2 (17) of RED II. The above provision of the Act – Energy Law defines the essence of this agreement and the methods of its performance. The PPA may be concluded directly between the generator (within the meaning of Article 2 point 39 of the RES Act) and the consumer. Technical performance of such an agreement is possible in two ways:

- electricity supply on the basis of a transmission or distribution service agreement, if the parties to that agreement have previously been connected to the National Power System,
- electricity supply through a direct line

3. direct line

changes introduced by an amendment to the Act – Energy Law in the scope of the direct line are aimed at increasing its availability for consumers. The main changes involved:

- definitions – in a way that better achieves the objectives laid down by the EU legislator, while clearly distinguishing the concept of direct line from self-production systems,
- elimination of the obligation to obtain the consent of the President of ERO for its construction and replacing this regulation with the obligation for the entity intending to construct a direct line to obtain an entry in the register.
- introduction of a solidarity fee covering fixed costs not covered by other components of the tariff, quality fee and capacity fee, with respect to which the obligation to pay was imposed on entities using the direct line. All energy generated or surplus in relation to self-consumption in the generating unit is delivered to the consumer via a direct line.

Under the current legal status, national regulations do not provide the possibility to support energy companies in meeting the criteria for declaring the district heating system effective, using the Power to Heat technology. In view of the above, it is necessary to introduce a regulatory solution to increase the use of electricity from renewable energy sources for the production of renewable heat, allowing to include as renewable energy also heat or cold generated from electricity from RES supplied from the National Power System or PPAs using the process of redemption of the guarantee of origin, for the purpose of recognizing a given district heating or cooling system as an energy-efficient system.

12 Act on Renewable Energy Sources (Journal of Laws of 2023, item 1436)

4.3. Financing of investments in Power to Heat technologies – review of systems, aid schemes and commercial support

Public support systems for Power to Heat technology in district heating are mainly intended for projects in the field of development of renewable energy sources. There are mechanisms supporting the investment phase (investment aid) and systems relating to the operational phase relating to the operation phase of a given unit (operating aid).

4.3.1. Support systems in European Union Member States

There is a series of instruments in the European Union to support projects in the field of RES plants in district heating (including heat pumps). Table 9 shows the types of support instruments in the Member States concerned.

Table 9. Types of support instruments for RES sources and efficient energy generation for district heating systems in EU Member States[13]

Grants (subsidies)	Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Ireland, Italy, Luxembourg, Lithuania, Slovakia, Slovenia, Spain
Preferential loans	Belgium, Germany, Poland, Slovenia
Tax incentives	Bulgaria, Denmark, Lithuania, Netherlands, Sweden
Premium Tariff solutions	Finland, Netherlands

Examples of support systems that support the "greening" of district heating are presented in Table 10.

13 Overview of District Heating and Cooling markets and regulatory frameworks under the revised renewable Energy Directive, annexes 3 to 5, European Commission 2022, pp. 20-22.

Table 10. Overview of selected support instruments for selected EU Member States[14]

Member State	Availability of investment support	Availability of operational support	Implemented solutions / additional information
Czech Republic	YES	NO	Investment aid for the construction of generating sources, including large-scale heat pumps for the district heating sector, provided for under the scheme financed from the Modernisation Fund.
Denmark	YES	NO	Investment support for large-scale heat pumps. Support is targeted at district heating companies where at least 5% of current heat production comes from coal, petroleum products or natural gas. A district heating company may apply for reimbursement of up to 5 million krones (approx. 650,000 EUR) for each large-scale heat pump construction project.
Estonia	YES	NO	Financial support from the European Union for energy transition.
Finland	YES	YES	Financial support for large-scale heat pumps and electric boilers in the district heating network. The mechanism provides for a 15% return on investment for the construction of heat pumps for plants above 1 MW.
France	YES	NO	The "District Heating Fund" is intended for the development of projects based on Renewable Energy Sources and the recovery of waste heat, including investment expenditures for the extension of the district heating network and projects for the construction of large-scale heat pumps.
Germany	YES	YES	(Investment and operational) support system intended for development of district heating systems based on RES or waste heat. The value of the support under the entire aid scheme is approx. EUR 3 billion – funds from the special investment fund for energy and climate.
Sweden	YES	NO	Reduction of taxes on electricity for heat pumps supplying the district heating network or sale of cold to large IT companies such as the data centers.

Particular attention should be paid to the support scheme for district heating systems, which operates in Germany, covering both investment and operating aid[15]. The above-mentioned scheme provides for three modules:

- support for the development of feasibility studies and transition plans;
- system support for investment and operating costs;
- investment aid, on an individual basis, for investments in RES sources (including heat pumps) and service lines.

Investment aid under the above-mentioned scheme concerns both the construction of generating plants using solar systems / solar collectors, heat pumps, geothermal (deep) sources, biomass and the construction of new sections of district heating networks as part of systems based on RES sources or waste heat at least in 75%. The maximum amount of co-financing, in the form of a non-refundable subsidy, for a project may amount to 40% of the net investment costs, but not more than EUR 100 million (it applies both to system support and connection of new facilities, in which e.g. co-financing of heat pumps is also planned). Investment support may be granted for 4 years, with an option to renew it. The operating aid in turn covers production using solar collectors and electrically driven heat pumps (with a COP of at least 2.5). The support of this type lasts for 10 years of operation of a given unit. This scheme is expected to run until August 30, 2028.

14 Own study

15 State Aid SA.63177 (2022/N) – Germany; Federal support for efficient heat networks, Brussels, 2.8.2022, C (2022) 5548 final.

The Czech aid scheme for the construction of generating units for district heating systems, which was approved by the European Commission in December 202[16], is also worth mentioning. This mechanism (financed by the Modernisation Fund) is intended, among others, for projects in the field of RES and high-efficiency cogeneration plants and waste-based projects in order to replace the existing heat sources supplying district heating systems. Support in the form of grants shall be conditional upon achieving a reduction of CO_2 emissions by at least 20% and a reduction of non-renewable primary energy consumption by at least 10%. In order to obtain co-financing, applicants must present a gap analysis for the financing of the investment project. The scheme, with a budget of €1.2 billion (€400 million/year), is expected to run until January 14, 2026. It should also be noted that projects to support investments in the RES sector for district heating (including in the context of decarbonization of this sector) have been taken into account by some EU Member States (e.g. Austria, Croatia, Denmark, Finland, Poland, Slovenia) in their National Recovery and Resilience Plans (NRRPs)[17].

4.3.2. Polish investment support schemes for heat from RES

In the case of Poland, projects in the scope of construction of RES units for the needs of district heating may receive investment support from a series of schemes financed from EU funds or national funds. The main forms of aid consist in preferential loans and grants, the key information on the main sources of investment support is set out in the table below. Detailed information on the issue in question is presented in the list that forms one of the appendices to this report[18].

16 State Aid SA.103821 (2022/N) – Czechia Support scheme for the production of heat in district heating under the Modernisation Fund, Brussels, 16.12.2022, C (2022) 9680 final.

17 The National Recovery and Resilience Plans are published on: https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility/country-pages_en.

18 The compiled summary covers only schemes/instruments supporting investment projects. The list does not cover research and development and innovation projects which may be co-financed from other sources, such as in particular: European Funds for Modern Economy Programme (FENG), national resources of the National Center for Research and Development (NCBR), LIFE Programme, Horizon Europe Programme. The table presents the status of cases at the end of March 2024.

Table 11. Overview of key schemes/sources of investment support for projects in the field of heat generation from RES in Poland[19]

Name of the scheme.	Scope of support	Form of support	Budget
European Funds for Infrastructure, Climate, Environment 2021–2027 (FEnIKS)	High-efficiency cogeneration projects (in particular RES-based cogeneration) and energy storage. Investment projects in heat-generating RES plants, including sources based on heat pumps. For heat generating plants, the minimum capacity of the plants eligible for support shall be: ■ **biomass:** over 5 MW_t, ■ **solar radiation:** over 0.5 MW_t, ■ **geothermal energy (including heat pumps):** over 0.5 MW_t, ■ **biogas:** over 0.5 MW_t.	Mixed instrument (comprising a loan and a grant within one operation)	EUR 1.72 billion (the entire planned allocation under Measure FENX02.01 District heating infrastructure and FENX 02.02 RES development was taken into account, with the reservation that a large part of the funds will be allocated to other types of projects in the field of district heating and RES).
Priority Programmes of the National Fund for Environmental Protection and Water Management (NFOŚiGW): "Cogeneration for District Heating" / "Poviat Cogeneration" (funds from the Modernisation Fund).	Sources of high-efficiency cogeneration, including those based on RES and waste heat. Heat storage may be part of the project scope.	A grant or a preferential loan.	PLN 4 billion (the budget of both Programs was taken into account).
Priority Programme of the National Fund for Environmental Protection and Water Management (NFOŚiGW) "RES – heat source for district heating" (funds from the Modernisation Fund)	Investments in the construction and/or conversion of sources with a total installed power of at least 2 MW_t where energy from the following sources is used to generate thermal energy: ■ heat pumps, ■ solar collectors, ■ geothermal energy. Energy storage may be an element of the project scope.	A grant or a preferential loan.	PLN 2 billion
NFOŚiGW Priority Programme "Energia Plus" (Energy Plus)	projects concerning the construction or conversion of generating units with their connection to the distribution/transmission network, which use RES energy, among others, for energy generation.	Preferential loan	PLN 4 billion (budget of the entire Programme).
National Recovery Plan (B1.1.1 Investments in heat sources in district heating systems)	Projects in the scope of construction of heat sources for the needs of district heating systems.Investments in RES plants and heat pumps may be co-financed.	Subsidy	EUR 300 million

In Poland, there is no operational support model for heat generation from the Power to Heat technology, which would allow to improve the profitability of the implemented projects and reduce the cost of energy generated in these sources. The instrument provided for in the Act on Renewable Energy Sources is an obligation for companies transporting/distributing district heat to purchase heat generated in a RES plant, whereas in the case of heat generated in a RES plant using heat pumps, the obligation to purchase refers to heat being energy from renewable sources.

Energy companies operating in the district heating sector may benefit from an auction system for renewable sources. Its design makes it possible to obtain operational support for biomass plants; however, the lack of interest in participation in auctions is caused by the insufficient level of support and excessively dynamic changes on the biomass market. Another system dedicated to district heating is the support system for high-efficiency cogeneration, operating on the basis of the Act on promoting electricity from high-efficiency cogeneration. This system makes it possible to obtain support in the process of high-efficiency cogeneration, which in the case of "greening" the district heating can only cover biomass-fired cogeneration units.

Moreover, it should be noted that the capacity market operating in Poland under the Capacity Market Act, due to its specificity, cannot effectively support the increase of the share of RES in district heating.

19 Own study

4.3.3. Financing of investments in Power to Heat technologies by banks

The assessment of the district heating sector in recent years may have been posing a challenge for the banks. On the one hand, it is a regulated sector with quite high entry barriers, which should affect the stability of revenues. On the other hand, the sector is generally not a "high-margin" one, and, in times of market turbulence, it has proved particularly sensitive to dynamic changes in energy carrier prices, resulting in a significant deterioration in financial performance and liquidity. Moreover, the tariff mechanism makes it difficult for district heating companies to make up for losses generated in crisis years, which affects the long-term deterioration of the ability to indebt. An additional factor that may have a negative impact on the possibility of debt financing of new investment projects is their high capital intensity (in relation to the value of the existing assets, revenues and results of the borrower). District heating projects often show a financial gap and may therefore be beneficiaries of aid schemes (in the form of grants or preferential loans), which significantly improves the profitability and "bankability" of the project and reduces the risk of an unacceptable increase in tariffs.

Detailed rules of financing investment projects in the district heating sector, together with an example describing the bank perspective for the project of construction of a new generation mix in the district heating system for a city of approx. 100–150 thousand inhabitants, taking into account Power to Heat technologies, are presented in Appendix No. 3 to the report.

5. Market conditions

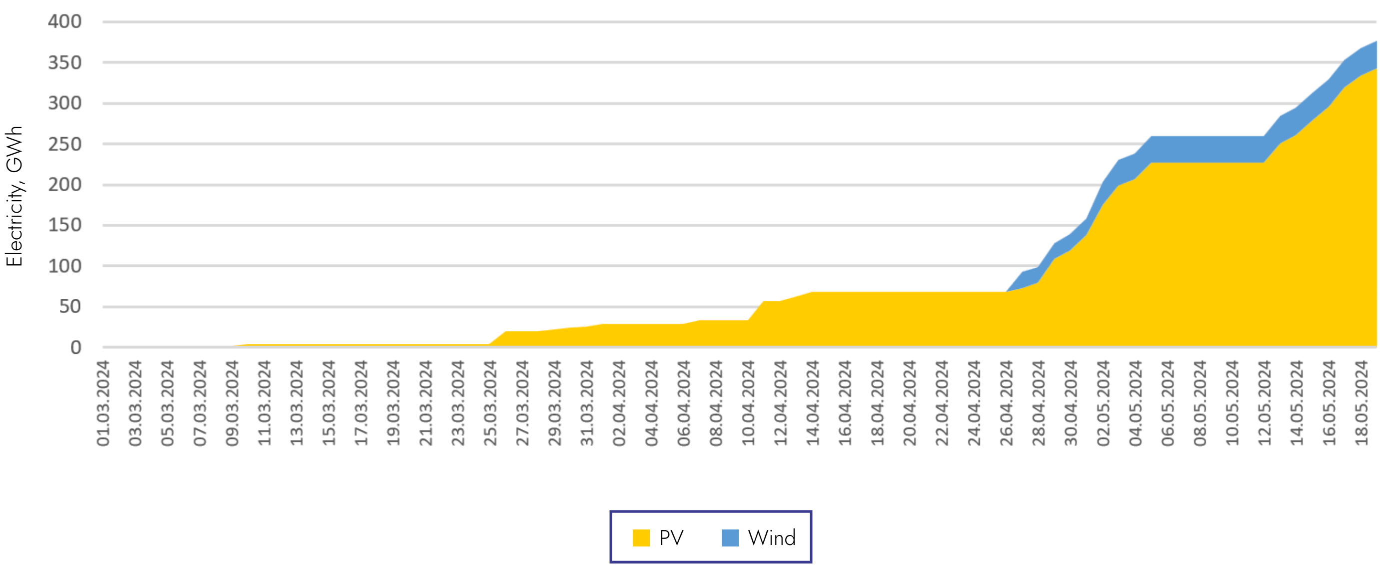
5.1. Use of electricity for district heating purposes

5.1.1. Balancing of the National Power System by district heating

To meet the EU's climate and energy policy commitments to achieve net zero emissions by 2050, a profound change in electricity generation technology and adequate management of the growing volume of electricity from RES is needed. At the same time, the uncontrollable large-scale and intermittent nature of the operation of weather-dependent RES systems generates fluctuations in the power balance understood as the balance between supply and demand. When the energy in the National Power System is too high in relation to the current demand, there occurs a situation when the Transmission System Operator (TSO), i.e. the Polskie Sieci Elektroenergetyczne, decides to reduce the capacity. Actions consisting in: reducing to a technical minimum the operation of coal-fired and gas-fired power plants, starting-up pumped storage hydro power plants in the pumping mode, emergency energy export to neighboring countries (cross-border exchange between operators) and, if this is not sufficient, ordering the wind farm or solar farm operators to shut down some of their plants.

In Poland, as a result of the inability to balance the National Power System, the limitations on operation of the RES plants in 2023—2024 amounted to 421 GWh, and in 2024 in the period from March 1 to May 20, a total of 395 GWh of renewable energy was lost. Figure 4 shows the cumulative reductions of the RES plants in the first months of 2024 based on PSE announcements.

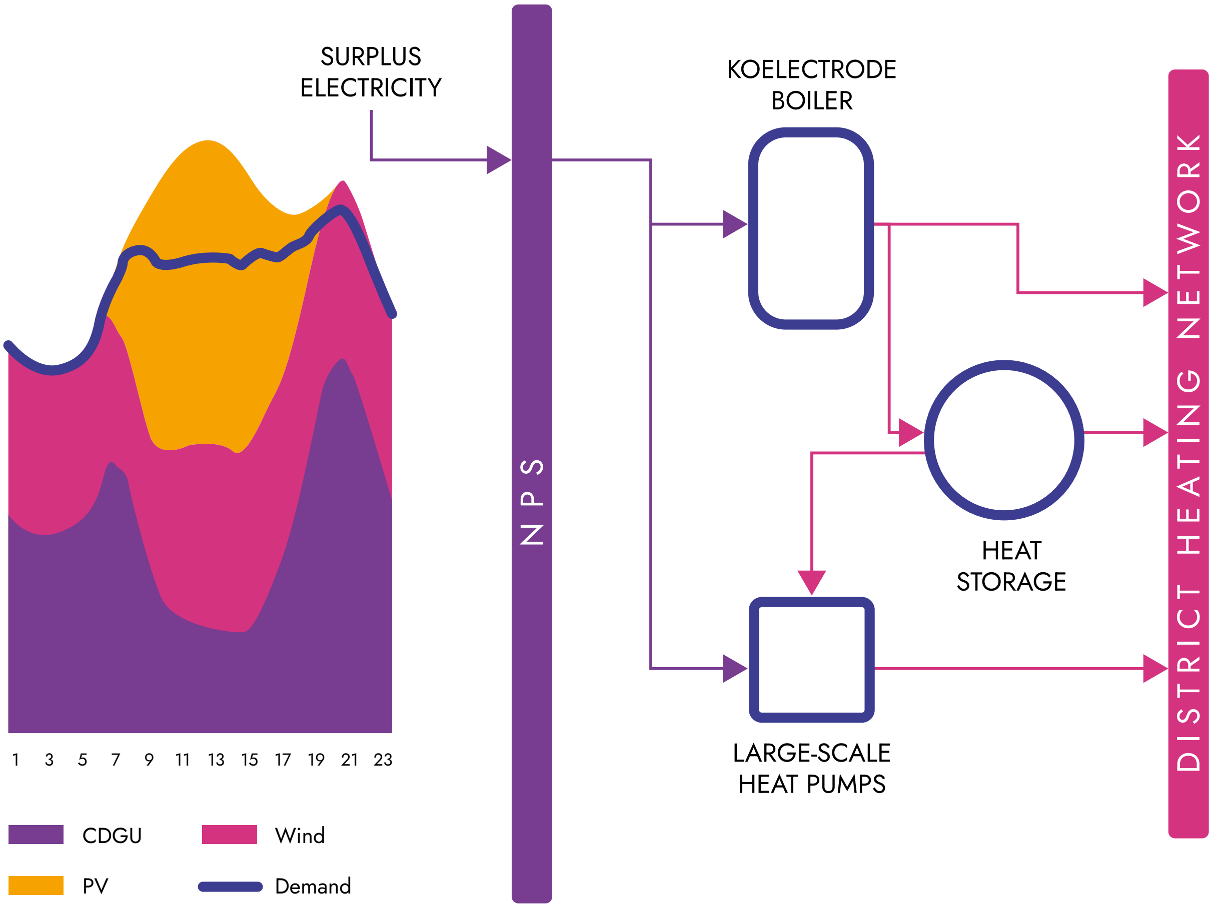
Figure 4. Cumulative size of RES reduction in the period from January 1 to May 20, 2024



One possible solution to prevent the situation described above is the cooperation of the National Power System with district heating systems through the use of Power to Heat technology, with which it would be possible to maximize the use of electricity generation by RES plants without jeopardizing the security of the National Power System. The idea of using Power to Heat technology is to convert excess electricity during its overproduction by RES plants into heat, store it and then consume it at the peak of heat demand. Low electricity price in such situations improves the profitability of the Power to Heat plant, lowers the price of system heat while reducing heat generation in conventional units.

At the same time, attention should be paid to the impact of the implementation of the Fit for 55 package on the National Power System, taking into account the district heating sector. With the fulfillment of the climate and energy policy commitments, the district heating will become not only an important generator (in cogeneration units), but also an important consumer of electricity (Power to Heat plants).

Figure 5. Power to Heat and NPS Cooperation Ideogram



5.1.2. Power to Heat development conditions relative to transmission infrastructure

Due to limited physical connection possibilities, as well as the lack of available connection capacity in a given location, high costs of connection and the condition of power networks in Poland, there may be risks related to difficulties in connection of the Power to Heat system to the National Power System. The introduction of new generating units may additionally affect the network load and require adaptation of the existing infrastructure. System constraints, such as line capacity caused by aged infrastructure, are important challenges in the process of issuing connection conditions by electricity distributors.

The costs of connection of individual systems, usually to the medium voltage (MV) network, will vary greatly depending on the location and condition of the distribution infrastructure in a given area. Both power generation and consumption units must ensure proper integration with the system in order to ensure stability and power balance. Moreover, following the introduction of new generating units, gradual decommissioning of the existing operating units based largely on hard coal combustion will take place, which results from the regulatory conditions. Due to the need to ensure continuity of heat supplies to consumers, this process must start with the construction of new heat sources, temporary operation in parallel with the currently operating sources, gradual phase-out of coal-fired units until they are completely replaced with new generating units. This creates additional difficulties in the process of obtaining the conditions for connection to the power network for the Power to Heat plant.

In order to enable the development of the Power to Heat technology, close coordination of activities between the power system operators is required. The cooperation in the scope of flow management, dispatching the capacity of units and handling the challenges of energy transition is a necessary element to enable the connection of larger capacities in Power to Heat.

5.2. Impact of the Power to Heat technology on the district heating infrastructure

5.2.1. Conditions of district heating networks in the context of the increase in the share of the Power to Heat plant

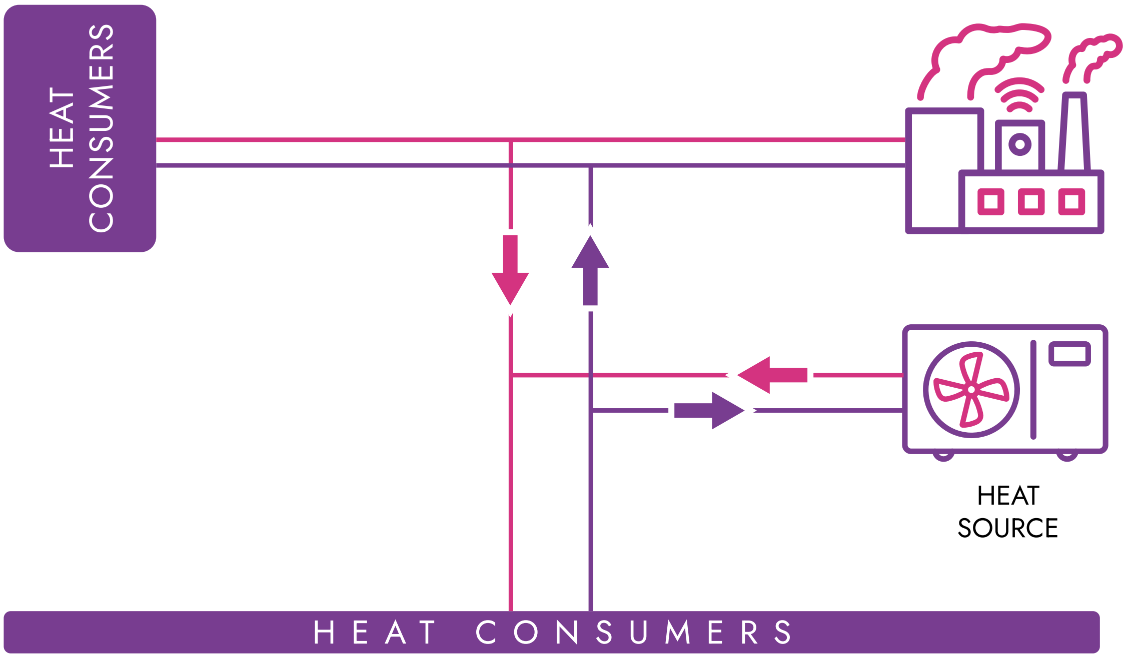
Each district heating system is characterized by design parameters, including but not limited to: heat source supply and return temperature tables (source control table), heat station supply and return temperature tables (node control table), supply and return pressure, heating water flow rate. The vast majority of district heating systems in Poland were designed assuming that the supply temperature will be approx. 150°C under design conditions. Introduction of the pre-insulated pipe technology resulted in the possibility of lowering the heating medium supply temperature to the level of 120–135°C. Thermal performance improvement operations, replacement of district heating stations, observed climate changes and development of low-temperature heat sources make it justified to further reduce the supply temperature. However, further reduction of the heating water parameters will involve an increase in the flow rate proportional to the decrease in the network temperature. The condition necessary for the implementation of the latest generation of low-temperature district heating networks is the adjustment of district heating station units and adaptation of indoor systems in buildings for operation under low temperature regime.

If electrode boilers are connected to the network, which are a high-temperature source capable of maintaining the supply temperature within the entire range of the heat source control table, then a possible profile of operation of the new source in a given location will be obtained. The high-temperature source does not interfere with the temperature parameters included in the temperature tables of heat sources and consumers, so there is no need to adjust these parameters in the system and, consequently, no additional expenditures are required for the retrofit of the district heating network. Such an assumption is justified, especially as the most probable location of the electrode boilers will be the existing combined heat and power plants or district heating plants.

The issue gets complicated when a low-temperature heat source is to be connected to the high-temperature district heating system – a large heat pump with a power output of several to several dozen mega watts. An example of the connection diagram is shown in Figure 6.

Due to very individual types of necessary changes in the district heating system, the task of which is to connect such a source, the estimated costs of these changes will be very diversified. The costs of performing district heating works for the heat output system from the renewable energy source plant based on heat pumps depend on the scale of the source (larger pipework diameters compared to conventional solutions) and directly on the location (distance from the district heating network, e.g. if the lower heat source consists of municipal wastewater). It should be noted that in the cost structure and the schedule of district heating works, it is very important to obtain approvals of the site administrators, costs of easement and the scope of possible performance of works on the available sites.

Figure 6. Connection diagram for low temperature source "return – supply"



5.2.2. The role of district heating network digitalization in the implementation of Power to Heat solutions

The process of digitalization of district heating networks in the implementation of Power to Heat solutions may be one of the key factors for optimal integration and efficient use of these technologies. The ability to respond to changes on the electricity market will be important both on the supply and demand side. The report indicates issues related to synergies resulting from cooperation of the Power to Heat plant with conventional cogeneration units. Tools allowing to manage the balance of temporary district heating capacity through continuous monitoring of the level of heat demand in district heating networks and quick response on the load side of generating units will allow to increase the efficiency and capacity of generating units, including Power to Heat plants. Taking into account the scale of investment challenges, the digitalization of the networks may contribute to determining the optimum level of peak capacities necessary to be installed in the decarbonization process of a given district heating system. The use of algorithms based on historical data and analysis of current data will allow to forecast heat demand and adjust production depending on changes in weather conditions or prices of energy carriers.

From the point of view of heat consumers, digitalization systems can also play an important role. Providing end-users with data related to heat consumption, remote control of the level of heat comfort in public and residential buildings allow to build consumer awareness consisting in monitoring demand-side efficiency, consequently also affecting the amount of heat demand.

Due to the volatility of energy markets, these technologies enable suppliers to accurately assess both the current and future state of the network. This allows to take decisions on battery charging and discharging times and use the network as a buffer to reduce peak demand by anticipating future changes based on reliable data.

5.3. Relationship between Power to Heat plants and cogeneration units

Currently, coal-fired cogeneration units are dominant in large district heating systems, which significantly affect the security of heat supply to final consumers. Due to the generation of electricity, before the intensive development of the RES, they also played an important role in the mix of technologies of generating units supplying the National Power System. The new emission limit for high-efficiency cogeneration (based on fossil fuels) of 270 g of CO_2 per kWh, set out in Annex III of the EED, which, for new units, is to apply after the implementation of the provisions of the Directive into national legal orders (the deadline for transposition of these provisions is October 11, 2025; however, existing units will be able to obtain a derogation from this limit – until January 1, 2034), will force the replacement of coal-fired cogeneration units by natural gas-fired cogeneration units. The role of gas-fired cogeneration units cannot be neglected especially in large district heating systems, where due to the need to install large capacity sources, the possibilities of using RES systems are limited, and the scale of potential investments together with their logistics and hydraulics of the district heating network does not allow to fully quickly divide it into separate systems with the possibility of supplying low-parameter sources based on heat pumps.

Additionally, it should be remembered that the volume of heat from high-efficiency cogeneration will allow to maintain the status of an efficient district heating system until 2045; however, it should be noted that from 2035 it will not be possible to obtain/maintain the status of an efficient system solely based on the share of high-efficiency cogeneration – in the case of systems based on cogeneration sources, it will be necessary to ensure the share of RES or waste heat at the level of at least 35%, which will of course force a significant increase in the share of heat from RES in district heating systems.

The time perspective indicated above is a deadline for power companies to develop business models, learn and develop Power to Heat technology and properly train the personnel to manage and operate the equipment. By then, however, RES plants will have to cooperate with existing cogeneration units, often those for which the return on investment period has not yet expired or those supported by State aid schemes. The current system of support for electricity from high-efficiency cogeneration, based on the Act on promoting electricity from high-efficiency cogeneration, may be a factor encouraging energy companies to invest in cogeneration units (especially in sources with installed power capacity up to 50 MW_e). Energy companies will therefore face a major challenge: in the first period of requirements related to the increase of heat generation from the RES, its generation may not be economically justified compared to the operation of operationally supported gas cogeneration units.

The perspective of 2035, referred to above, must involve a change in the systemic thinking about the role of individual generating units in the system, as well as the development of effective solutions in the scope of support tools aimed at increasing the share of RES in district heating. This should mean, first of all, redefining the support model through aid schemes so that RES plants become as soon as possible price-competitive compared to cogeneration units, and cogeneration units are able to guarantee the stability of heat supplies to heat consumers. Alternatively, it is possible to introduce solutions that would allow to cover the stranded costs that may occur due to the gradual reduction of the capacity utilization time for these cogeneration units.

Moreover, the location of the Power to Heat systems in the area of the existing generating plants allows the use of the existing infrastructure – plots, buildings, water preparation station, as well as the power and district heating network. With this solution, investment costs can be reduced and investments in Power to Heat infrastructure can be accelerated. An equally important aspect is the possibility of training and using the personnel operating cogeneration units to operate the Power to Heat plant. This is important, because it will allow the management and operation of more Power to Heat plants in the future without the need for personnel changes.

5.4. Business model of a company using Power to Heat plants

Organizational Model

Despite the possibility of implementing a classic business model based on investments in own generating assets – used in the case of cogeneration units, the development of Power to Heat forces a wider optics of management decisions related to a different market, regulatory environment and a wider range of investment project stakeholders.

The business model for new RES assets may be based on their inclusion in the direct assets of the Company or, if the conditions of a given project so require, creation of a special purpose vehicle or joint venture together with other stakeholders. Taking into account the characteristics of heat generation from RES plants, the SPV model may be particularly useful for projects based on heat recovery from various types of plants owned by public administration authorities or companies other than an energy undertaking. Alternatively, M&A transactions may be used if there is a desire to acquire new technologies or increase market share.

Power to Heat technologies can be a solution to a series of challenges in the district heating and power sector described in detail in this report.

Customers

In vertically integrated markets, where one entity is responsible for heat generation and distribution, all entities connected to the municipal district heating network are customers. In other cases, the heat producer's customer is a distributor who purchases the generated heat and transfers it to final consumers and individual customers connected directly to the generating unit. Compared to conventional generating units, an important consumer of services provided by a district heating company using Power to Heat technologies is the power system operator to which the balancing service may be provided.

Distribution channels

Access to the customer is ensured through development of modern district heating networks and power lines. Commercial and promotional measures are required to increase sales or reach new customers. It is important to build customer awareness of the benefits of providing heat from efficient district heating systems. These activities should be undertaken by various stakeholders: government, local government, heat producers and distributors. Technical barriers to reaching the customer include a long distance from the district heating network and heat distribution units or an internal system of the building which prevents transmission and distribution of low-temperature heat.

Revenue sources

The main stream of revenues of the district heating company is the fee for sale, transmission and distribution of heat. The interests of the generator (investor), distributor and final consumers in the long term may be protected by concluding long-term agreements for the purchase/sale of heat and a properly conducted process of planning the scope of the investment project. Selling heat from sources above 5 MW of installed capacity is subject to the approval of tariffs by the President of ERO (proposals of changes in the tariff of Power to Heat units are described in chapter 7 of this document).

An additional important stream of revenues should be the remuneration for balancing services, i.e. reduction of electricity consumption in situations where there is electricity shortage in the power system and for taking off electricity at the moment of its oversupply.

Operational support for selected Power to Heat technologies should also be a source of revenue, because, by providing an additional stream of revenues, it will encourage energy companies to implement such projects, improving their competitiveness compared to less efficient individual solutions. The proposal of the basic assumptions of the support mechanism is described in Chapter 7.

Cost structure

The catalog of significant cost items depends on the type of analyzed Power to Heat technology (electrode boilers compared to heat pumps using different lower energy sources). Typical cost items for Power to Heat are shown below:

- **Depreciation** – unit capital expenditures (CAPEX) for the Power to Heat technology are usually lower than for cogeneration units due to the fact that Power to Heat solutions, in particular electrode boilers, are characterized by lower technical complexity. In the case of sources based on geothermal energy, the expenditures related to drilling are significant;
- **Costs of electricity consumption** – depending primarily on the efficiency of the Power to Heat plant (coefficient of performance (COP)), mix of generating units in the national power system and the company's policy of price security. In order to optimize costs in the long term, e.g. PPAs may be applied or own sources of electricity generation (e.g. PV systems) and energy storage may be used;
- **Water intake costs** – in the case of heat pumps with a lower source in water, it is necessary to pay fees for water services;
- **Fixed costs** – costs of employees' remuneration, costs of overhauls and maintenance of the plant, taxes and fees;
- **Other costs** – in plants using wastewater or waste heat, there are costs related to lease of the site for installation of heat pumps and remuneration for business partners.

The competitiveness of the Power to Heat plant in the long term will depend primarily on the relation of electricity prices to natural gas and biomass prices, and the possibility of reducing capital expenditures as a result of technology development or introduction of new support programs. An opportunity to reduce the cost of heat generation from the Power to Heat plant is to implement the planned investment projects in the power sector, in particular to reduce the use of coal fuel in electricity generation in favor of renewable energy sources.

Necessary resources for business

In order to implement the investment project, it is necessary to provide service lines to the power system and district heating network. Location conditions enabling the use of the ground source, e.g. surface water, underground water, municipal wastewater or waste heat from industrial processes, are crucial for the investment in heat pumps. Depending on the type of the ground source, other consents will be required, in particular administrative consents, e.g. environmental decisions, as well as commercial agreements to ensure access to such a source. Investments in Power to Heat technologies are capital intensive, and the support programs described in chapter 4 help to finance the investment projects to a certain extent. Recommendations for new support programs necessary for the development of Power to Heat technology are described in chapter 7. Power to Heat technologies are not yet common in Poland, therefore energy undertakings should educate employees and increase their expertise.

Key partners

The development of Power to Heat projects, due to their interdisciplinary nature, entails a need for a dialog between stakeholders, which are:

- **energy producers** – implementing investment projects and providing energy and services to customers, therefore expecting return on investment guaranteeing the company's profitability;
- **local government administration** – responsible for ensuring the security of heat delivery to residents;
- **government administration** – determining the legal framework for business activities and strategic directions of development of the power sector;
- **district heating network operators and generating unit operators** – responsible for delivery of heat with parameters compliant with the adjustment table and development of distribution infrastructure;
- **Water supply and sewerage companies** – as regards the use of wastewater as the ground source in heat pumps; power system operators – cooperating with heat producers in the scope of system management (balancing) and responsible for development of new connection capacities;
- **contractors** – whose purpose is to gain profit from the performance of the agreement and to ensure occupational safety for employees;
- **industrial plants, data centers (waste heat suppliers)** – having energy that can be used by the district heating system;
- **financing institutions** – providers of necessary public or private funds, expecting the achievement of specific environmental objectives and return on the invested capital.

6. Analysis of the impact of Power to Heat technology on the achievement of climate goals and the National Power System

The dynamic development and popularization of electric heating will contribute to the achievement of climate goals, leading to the reduction in fossil fuel consumption and CO_2 emissions, while increasing the share of electricity in final energy consumption. The thermal needs of residential buildings in 2050 will be met mainly by renewable sources and Power to Heat technologies.

Heating electrification will be developed at the first stage in the new construction industry and then in the existing one through thermal upgrading and replacement of heat sources. In district heating, the development rate will depend on the specificity of district heating systems, including technical conditions available for specific locations of heat generation and currently used generation technologies. Coal sources with high emissions and high environmental costs will be replaced first.

6.1. Methodology and key assumptions adopted for the analysis

The scenario analysis of Power to Heat technology in system district heating was prepared on the basis of the district heating model developed by PTEZ experts, the purpose of which was to determine realistic options of district heating development. The scenarios were developed in such a way that when implementing the investment process in a series of local district heating systems, the requirements of the climate and energy policy (excluding the background scenario) and the expectations of the system heat customers could be met. One of the scenarios was developed as a background scenario – it does not allow for meeting the requirements of an efficient district heating system for a significant number of such systems in Poland and it is used to determine negative effects of the abandoned transformation.

The proposed district heating model translates the most efficient configuration of generating units, minimizing the prices of system heat for final customers while meeting the requirements specified in the definition of an efficient district heating system. The multi-option analysis was performed for the period 2023–2050. Modeling of the future mix of the district heating system in Poland was carried out. As part of the calculations, heat markets were not divided due to their size – the district heating system as a whole is modeled. The data concerning the current district heating condition was based on the information contained in the reports of the Energy Regulatory Office and the Energy Market Agency (Agencja Rynku Energii). The starting point adopted for the analysis is the volume of system heat reported as sold to the network for final customers[20]. The system heat demand in a given year depends, i.a., on weather conditions and, consequently, on the duration of the heating season, in order to eliminate the risk of disproportionate deviations in historical data. Averaged data of 2020–2023 were assumed as initial values.

Macroeconomic, market and technical assumptions adopted for the heat market model are based on national and international references, as well as on the most recent data held by PTEZ Members. The analysis adopts the set of assumptions which were prepared by PTEZ Members in April 2024. The scenarios used proven technologies for which operational experience exists in Europe. Technologies prior to the commercial implementation stage or prior to obtaining appropriate process certification were not taken into account.

20 "Heat power engineering in numbers – 2022", Energy Regulatory Office 2023

Table 12. Assumptions of the analyzed technology costs[21]

Technology	Fuel	Overall efficiency [%]	CAPEX[22] [mPLN/MWe]	CAPEX [mPLN/MWt]	OPEX [% CAPEX]
Coal-fired cogeneration	hard coal	85%	15	N.A.	5%
Coal-fired boilers (WR)	hard coal	85%	N.A.	1,8	5%
Gas-fired boilers	natural gas	95%	N.A.	0,93	1%
OCGT	natural gas	82%	8,4	N.A.	3%
CCGT	natural gas	86%	9	N.A.	3%
Gas engines	natural gas	85%	8,15	N.A.	5%
Oil-fired boilers	natural gas	95%	N.A.	0,8	0,5%
Biomass-fired boilers	biomass	85%	N.A.	3,8	5%
Biomass-fired cogeneration	biomass	85%	15	N.A.	5%
Heat pumps	ambient energy and electricity	320%	N.A.	5,5	0,65%
High temperature geothermal energy	ambient energy	-	N.A.	11,4	2%
Electrode boilers	electricity	99%	N.A.	0,7	0,5%
Municipal Waste-to-Energy Plants	waste	85%	90	N.A.	5%
Heat storage	electricity	-	N.A.	2,5 tys/m^3	N.A.

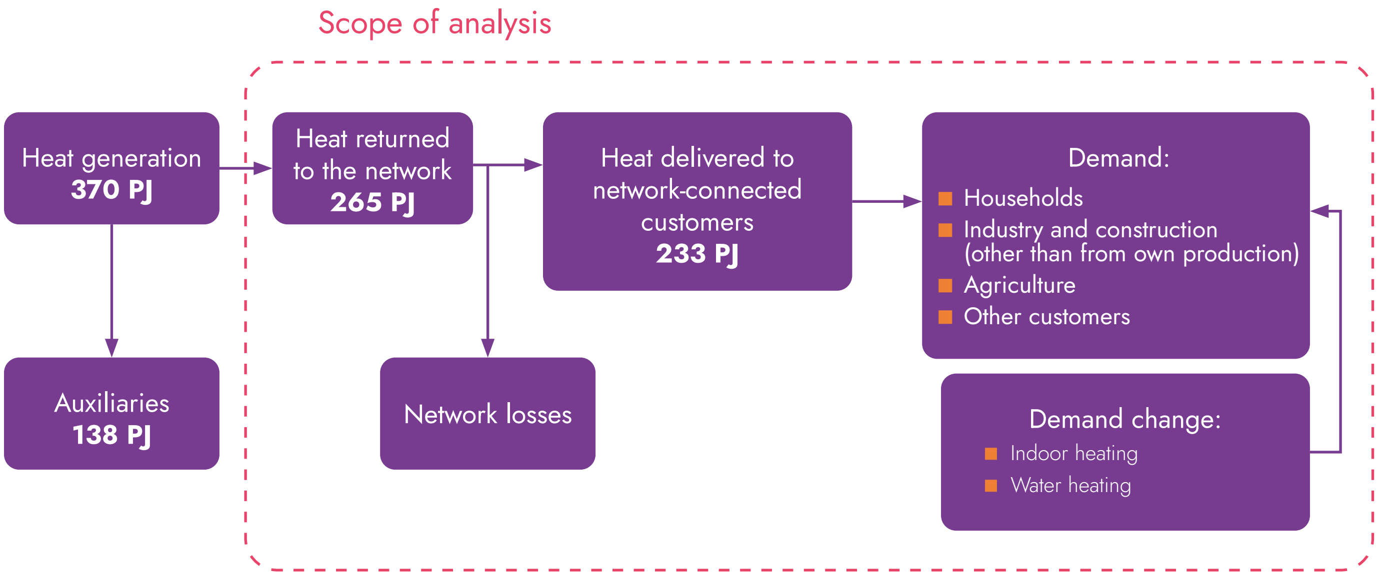
6.2. Heat demand – analysis of energy performance of buildings and its impact on the system district heating sector

Over the last decade, total district heat consumption among customers connected to district heating systems decreased by 16% and amounted to 233 PJ in 2022. The analysis assumes "greening" of heat delivered to the district heating network and then to final customers. The modeling does not apply to heat intended for production processes and included in the use for auxiliaries. Households with a demand of 157 PJ have been a significant part of the demand, consistently for years. Therefore, they constitute, in terms of change in fuel structure and impact on system heat, the main area of interest of the report and were analyzed in more detail than other categories of customers.

21 PTEZ data

22 Fixed prices of 2023 were assumed.

Structure of licensed heat generation and consumption in 2022[23]



The following can be distinguished as the main reasons for changes in heat demand:

a) Demographic change, population decline and decrease in the number of households

Changing population may have a significant impact on heat demand. Adverse demographic trends have been observed in Poland over the past years. The number of births has been steadily decreasing in recent years. The positive migration balance maintained in Poland since 2016 has so far not reversed this trend. As a result thereof, the population in Poland has been decreasing almost continuously since 2012.

Population forecasts prepared by the Statistics Poland (GUS) clearly indicate a decrease in the population in Poland from the current 37.7 million to 35.3 million in 2040 and 30.9 million in 2060 . The working age population will decrease, the demographic load factor and demographic aging will increase. However, there is an increase in the foreign migration balance. A change in population will affect the number of households, which will translate into a changing heat demand on the part of buildings. By 2030, we can see an increase in their number, with the number of people per household decreasing. This will be effected under the assumption of a further improvement of the country's economic standing and a positive foreign migration balance. After 2030, with a significant decrease in the number and structure of the population and the creation by then of a sufficient base of single- and multi-family buildings, the number of households will decrease.

b) Thermal upgrading, new construction, low-emission buildings[25]

Renovation of public and private buildings will be one of the most important challenges of energy transition. One of the main areas of action in this scope will be the progressive decarbonization in the construction sector. Lower emissions can be achieved by developing energy-efficient construction or upgrading the existing resources to reduce final energy consumption. It is estimated that there are over 14 million buildings in Poland, which are characterized by significant

23 "Heat power engineering in numbers – 2022", Energy Regulatory Office 2023

24 Polish Regional Development, Statistics Poland (GUS)

25 Long-term building renovation strategy

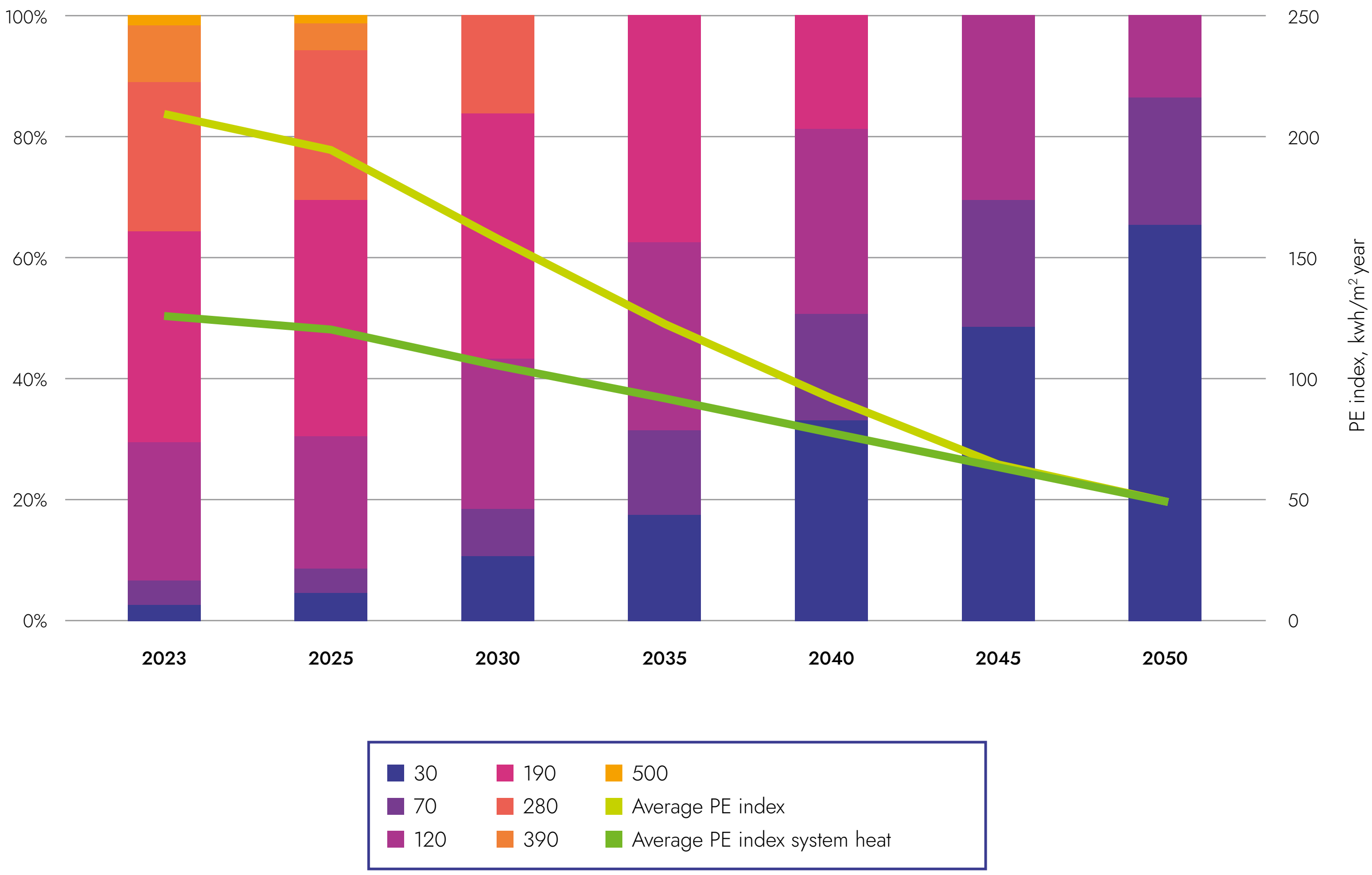
diversification of the energy performance index resulting from the period of their handover for operation.

Due to the long-term policy of renovation and improvement of energy performance of residential and public buildings implemented in Poland, it should be assumed that the primary energy consumption index per m^2 of surface area (PE index) will gradually decrease. In accordance with the recommended scenario included in the Long-term building renovation strategy, by 2050, 65% of buildings should reach PE index not higher than 50 kWh/m^2 year (currently, only 1% of the building surface area meets this index).

On the basis of information on fuel consumption in households for heating purposes, the PE index for residential buildings using system heat was calculated. It is mainly located in urban centers where the dynamics of change and development of new construction are higher than the country average. Buildings connected to the district heating network are generally characterized by higher energy performance (lower PE index) than the remaining part of the existing buildings. For this reason, achieving the objective of the average PE index in domestic system district heating can be achieved with a lower impact on the decrease in heat demand.

A wide-ranging, nationwide building renovation initiative will require significant capital expenditures that will lead to increased energy performance. From the point of view of customers, lower energy demand in buildings translates into lower costs relating to heating bills and, for individual sources, lower sensitivity to changing prices of raw materials – hard coal and natural gas.

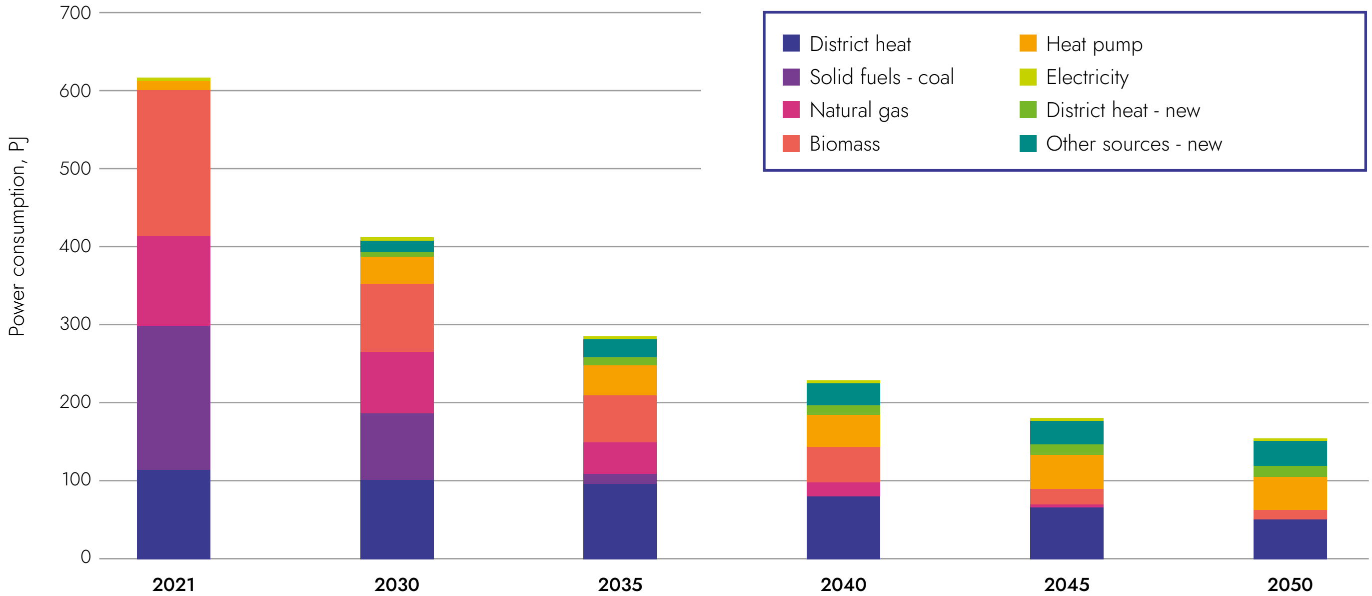
Figure 7. Average PE indices of buildings and share of these buildings



c) Change in heat demand as a result of source replacement and thermal upgrading.

Difficulties in ensuring uninterrupted delivery and the volatility of coal and natural gas prices contributed to quicker transformation in the sector of smaller customers. The increase in the share of clean and low-carbon technologies in households will be stimulated by both legal solutions (standards, technical conditions, creation of a greenhouse gas emission allowance trading system, e.g. for buildings – the so-called ETS-bis), as well as technological changes and availability of aid funds. According to the available data, 52.2% of households use district heat, 32.8% solid fuels – mainly hard coal and wood, 14.6% natural gas and only 5.5% chose electricity[26]. According to the latest data, the number of installed heat pumps in Poland amounted to more than 600 thousand pieces (as of 2023)[27]. In the analysis of the heat generation technology in the entire district heating sector, it was assumed that the heating needs of buildings would be met mainly by electrification, system heat or temporarily by natural gas. Taking into account the impact of thermal upgrading and new buildings, the system heat consumption in households may decrease from approx. 170 PJ to 140 PJ in 2050. The change in the district heat consumption for domestic hot water heating is due only to the connection of new buildings.

Figure 8 Change in the method of room heating in households



The factors described above will affect the change in the system heat demand. It is assumed that in other sectors: industry, agriculture, other smaller customers, the demand decreases mainly due to the progressing thermal upgrading. The improvement in performance contributes most to the decrease, while in the overall balance, the impact of connecting new buildings and changing the heat source is not sufficient to increase the district heat demand. By 2050, the demand may deteriorate by up to 95 PJ. Such trajectory was assumed in further analyses of "greening" through Power to Heat of the district heating system.

26 Household fuel consumption in 2021, Statistics Poland (GUS)
27 Polish Organization for Heat Pump Technology Development

Figure 9. Change in the method of domestic hot water heating in households

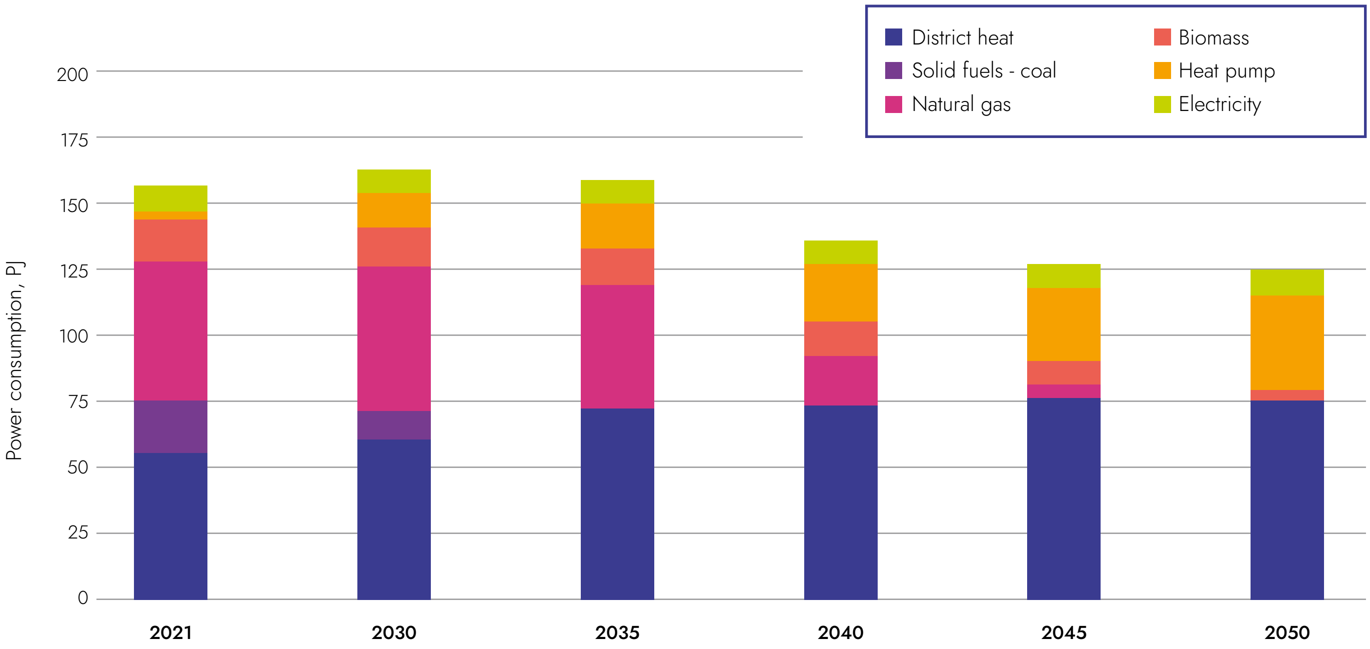
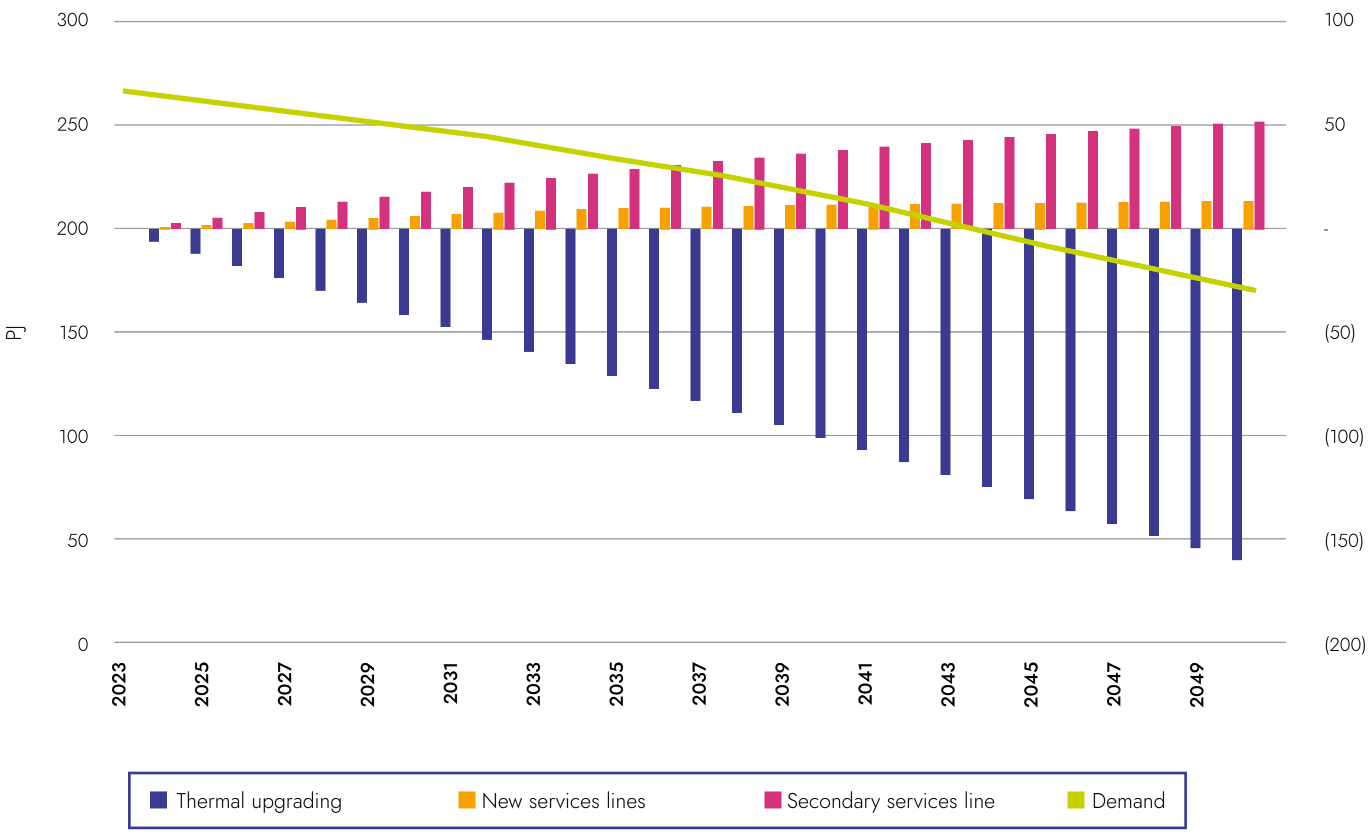


Figure 10. System heat demand trajectory by 2050



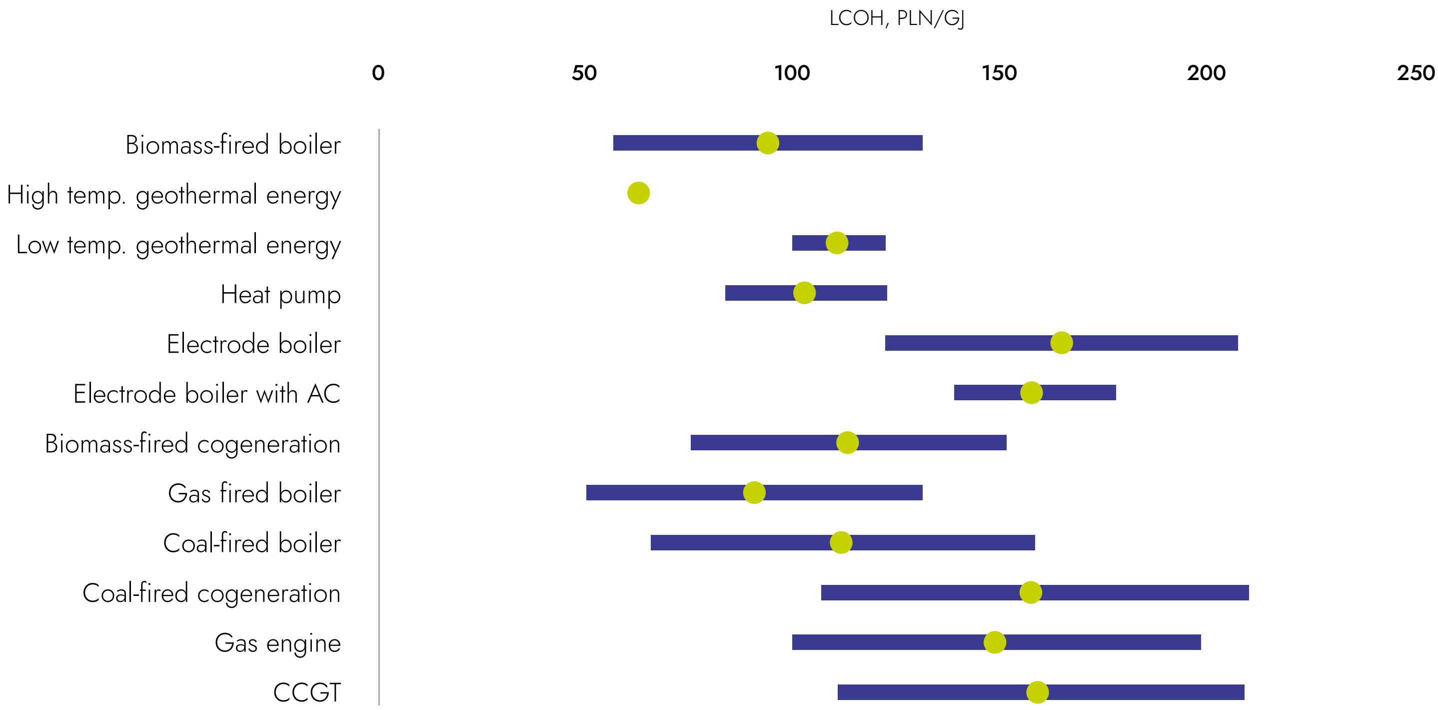
6.3. Comparative analysis of system heat generation costs – LCOH comparison

Ensuring adequate thermal comfort is a basic household need and one of the objectives of energy undertakings. Power to Heat technologies, due to their high efficiency, are an environmentally friendly solution which, at the level of heat generation costs, may be competitive for alternative solutions.
For the purposes of this report, the supply of heat to buildings was compared using the so-called levelized cost of heat (LCOH) for individual technologies. Using the indicator, we can calculate the average cost of delivery of 1 GJ of heat taking into account capital expenditures, fuel costs, capital costs, inspection and service costs throughout the life cycle of the investment project.

$$\text{LCOH} = \frac{\text{Total costs (investment, operating costs)}}{\text{Total heat generation}} = \text{PLN/GJ}$$

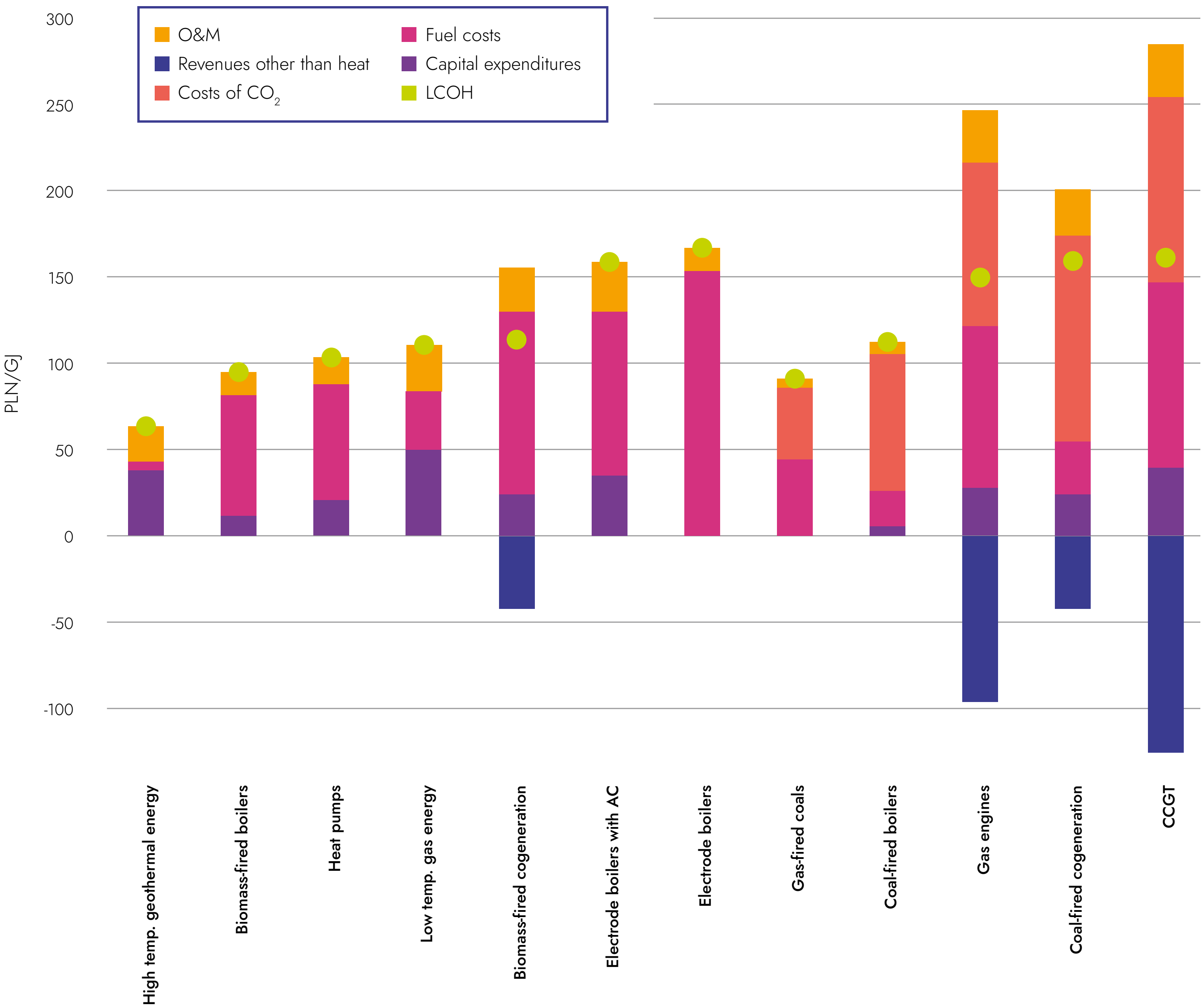
The main impact on price parameters covers the situation in the hard coal and natural gas markets as well as the CO_2 emission allowances market. These areas are characterized by high variability, which in consequence increases the risk of investment in fossil fuel-based heat sources. In the case of renewable sources, the greatest challenge comprises the changing interest rates affecting capital costs and weather conditions determining the performance of the plant. The assumption is that LCOH for individual technologies is calculated for the operation of the unit in the base of the district heating system for 2030. At the same time, it should be noted that some technologies, i.e. electrode boilers, will operate in the system as peak-load back-up sources, which will reduce the LCOH of these units.

Figure 11. LCOH for individual technologies taking into account sensitivity to fuel price change in 2030



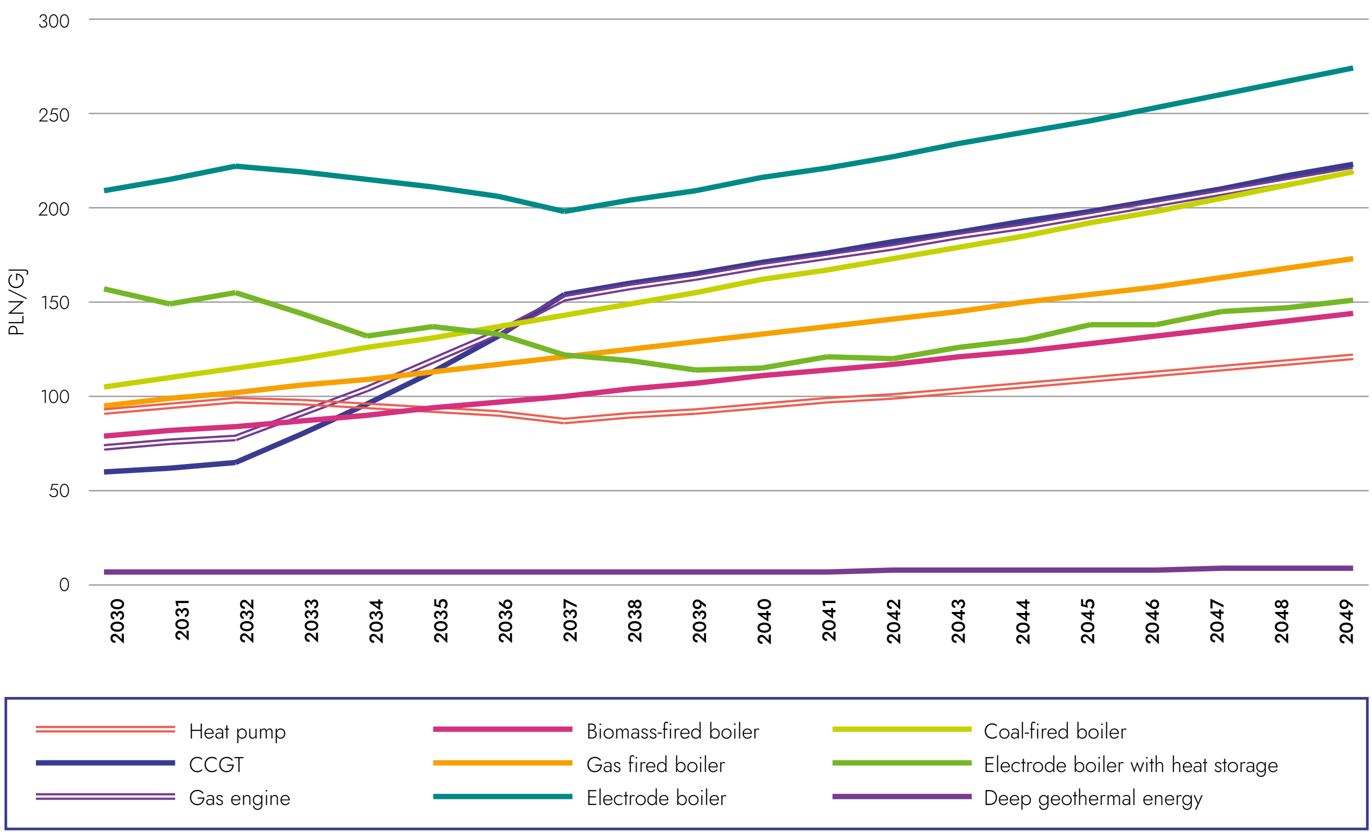
The lowest sensitivity to changing key price parameters (such as the price of natural gas, CO_2, coal, biomass and electricity) is typical of the technologies based on heat pumps and shallow (low-temperature) geothermal energy and deep (high-temperature) geothermal energy. Electrode boilers are resistant to environmental costs – they are not directly associated with the combustion of fossil fuels, and their operation is assumed at the moment of low electricity prices. Electrification of heating, under appropriate market conditions, is an attractive alternative to other technologies for the generation of district heat.

Figure 12. LCOH structure – status as of 2030



Among the green technologies, the lowest LCOH is observed for geothermal energy, heat pumps and biomass-fired boilers. Among them, technologies of heat pumps and biomass-fired boilers involve much lower capital expenditures. However, it is worth remembering that the choice of technology should depend on the availability and price of fuel and risk assessment. It is also worth emphasizing that the capital expenditures of the heat pump involve lower operating costs for the generation of a heat unit in relation to the cogeneration units.

Figure 13. Forecast of volatile costs for individual technologies



For the assumptions and forecasts of raw material prices adopted in the report, the costs of variable heat generation in cogeneration technology are lower than in RES technologies by 2034. In consequence, there is an undesirable situation in which, in the absence of operational support, RES technologies will be displaced from the basis for covering the heat demand. We estimate that at the time of preparation of this report, the amount of operational support for heat pumps, which guarantees base operation, is approx. PLN 35/GJ. A significant difference in volatile costs for electrode boilers without and with a thermal storage tank is also important, which is associated with the volatility of RES electricity prices and the use of surplus renewable electricity. For this technology, the heat storage increases the use of the electrode boiler power. After 2035, LCOH for electrode boilers with a thermal storage tank is lower than for cogeneration technologies, which supports the construction of electrode boilers together with a thermal storage tank. Biomass technologies are also characterized by low volatile costs over the years. However, such investment projects in the long term may involve uncertainty as to the recognition of biomass as an environmentally sustainable heat source with high greenhouse gas and dust emissions. An additional obstacle to large-scale biomass use may comprise the availability of fuel of appropriate quality, the need to develop logistics and storage.

6.4. Transformation of the fuel mix in system district heating.

As part of the analysis, a forecast of the generation mix in the system district heating sector in 2023–2050 was prepared for all district heating systems in Poland. The model lays down the generating unit stacks including them into the demand resulting from the heat profile in a given year. All scenarios assume the use of Power to Heat technology, although this occurs at different rates.

The maximum capabilities of the Power to Heat technology were assumed at the level of:

- 5 GW for heat pumps;
- 10 GW for electrode boilers.

The emissions of the power sector and the percentage share of renewable energy in the system were adopted in accordance with the scenarios of Poland's achievement of net zero-carbon emission in 2050[28]. It was assumed that the operation of electrode boilers mainly takes place at times of peak demand for system heat, but also at times when there are renewable energy surpluses in the power system. In accordance with chapter 5.4, the current share of energy from RES at times of surplus energy is 55% on average. Therefore, it can be assumed that with the transition of the power sector, this share will increase systematically until the full share of renewable sources in heat generation is achieved.

Table 13. Assumptions concerning the average CO_2 emission by the NPS for the forecast share of RES energy

	2023	2030	2040	2050
RES % in electricity generation	27%	35%	71%	79%
RES % with the use of Power to Heat	55%	70%	95%	99%
Average emission by the NPS, tCO_2/MWh		0,43		0,1

The assumption for building the technology mix in the analyzed model was to meet the criteria included in the definition of an efficient district heating system and other requirements resulting from the final decisions of the Fit for 55 package. The results show that in some scenarios it may be difficult to meet these assumptions.

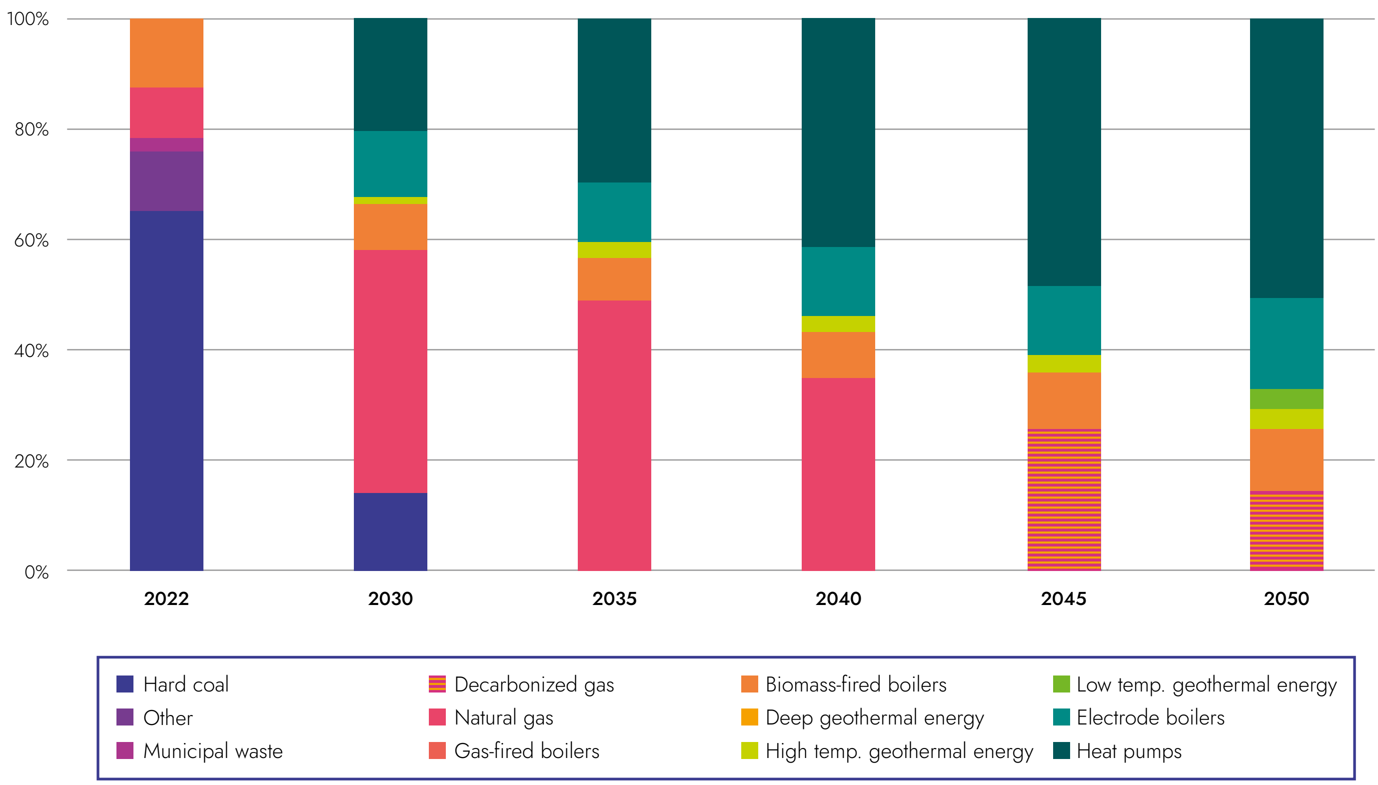
The analysis was carried out for the following scenarios (options):

28 Carbon-neutral Poland 2050; McKinsey; 2020

Option A – Power to Heat

The main scenario assuming the fastest development of Power to Heat technology – reaching 1 GW of installed capacity of heat pumps and 2 GW of electrode boilers already in 2030. Ultimately, in 2050, the power output of heat pumps is 5 GW and the power output of electrode boilers is 10 GW. The scenario also assumes the fuel change (conversion of burners to burners that will be technologically prepared for combustion of green fuels) after 2040 for gas technologies to technologies using biogas, biomethane or hydrogen. It was assumed that not all district heating systems will abandon coal combustion in accordance with regulatory requirements, therefore coal generation continues in 2030, and the share of waste is also negligible (due to uncertainty as to the use of waste for energy purposes). The development of high-temperature geothermal energy up to the level of 200 MW was assumed.

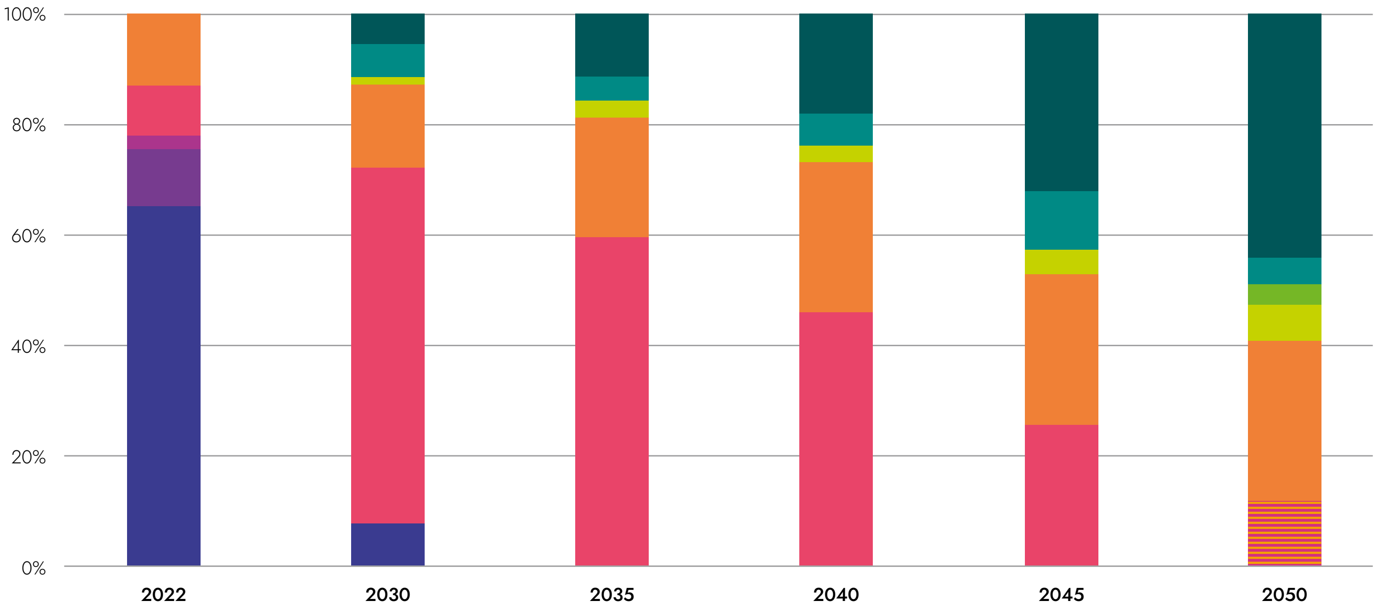
Figure 14. Structure of heat generation in Option A



Option B – Gas-fired cogeneration

The scenario is focused mainly on the substitution of hard coal by natural gas. It was assumed that gas-fired cogeneration will be maintained in the system as long as the regulatory conditions allow for it, with possible fuel change to zero-carbon gases after 2045. Power to Heat appears in 2030, but it is a smaller share of both capacity and production compared to Option A – 500 MW of heat pumps and 2 GW of electrode boilers. Ultimately, in 2050 there will be 4 GW of heat pumps and 6 GW of electrode boilers. Option B assumes a greater dispersion of sources and the use of deep (high-temperature) and shallow (low-temperature) geothermal energy with a heat pump and a more intensive development of biomass cogeneration. Assumed development of high temperature geothermal energy up to 350 MW.

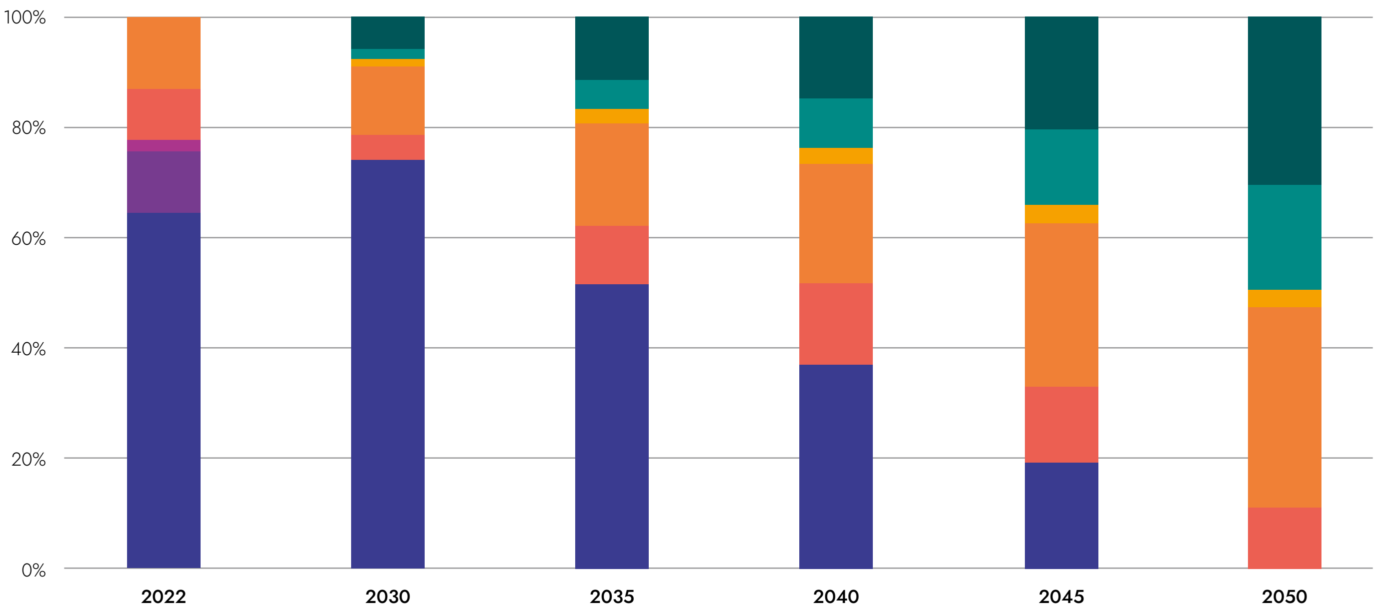
Figure 15. Structure of heat generation in Option B



Option C – Coal

Option C is a reference scenario and shows a mix of a district heating system relatively long based on fossil fuels – both coal and natural gas. The Option does not assume that all control conditions are met, coal-fired boilers are in operation by 2045. This is a conservative approach to the transformation of heat sources and limited access to funding sources, which in turn translates into inefficient district heating systems. The scenario assumes a greater emphasis on the development of technologies based on biomass and biogas.

Figure 16. Structure of heat generation in Option C

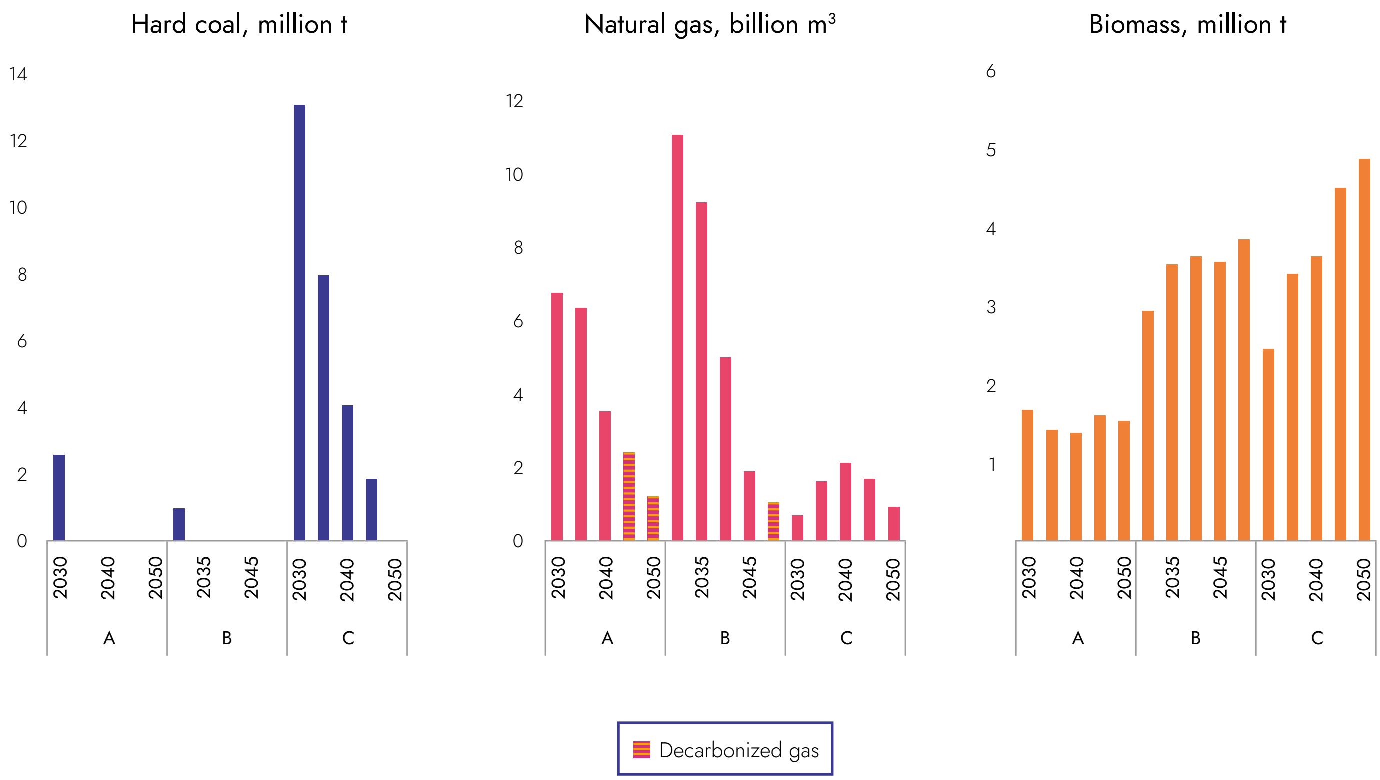


6.4.1. Fuel consumption

All options include the decrease in system heat demand.

In the first two options, natural gas is an important part of the fuel consumed, which results from the fact that it is a transitional fuel in the process of transition from hard coal. In particular, it plays a significant role in the case of the "cogeneration" option (Option B), which will affect the increased total gas demand of Poland, and thus the need to increase its delivery and ensure its availability. In both Options A and B the share of natural gas decreases, which is related to the increasing share of Power to Heat and biomass in heat generation. Additionally, after 2040 (A) or after 2045 (B), the fuel is changed to decarbonized gases. In the third scenario (Option C), natural gas is only a supplement to the fuel mix of the district heating sector, giving way to biomass and inevitable electrification.
In the "coal" scenario (Option C), decarbonization and compliance with regulatory requirements are implemented by biomass technologies, which results in a significant increase in the biomass fuel demand. In the Power to Heat (A) Option, the biomass demand does not change over time and averages 2 million t per year. This is mainly due to the rate of electrification and introduction of decarbonized gases into the generation mix. The average annual biomass demand in the "cogeneration" option (Option B) and "coal" option (Option C) would amount to 4 million tons, which is within the estimated biomass supply potential. In both options, production is based on natural gas and coal for a long time, so biomass is added to bring the production closer to the requirements of the Fit for 55 package. Given the regulatory uncertainties treating biomass as a sustainable heat generation technology, the difficulties associated with the logistics of fuel delivery and the availability of biomass on the market, it seems risky to base long-term decarbonization plans for the entire sector mainly on this source.

Figure 17. Fuel demand in individual Options

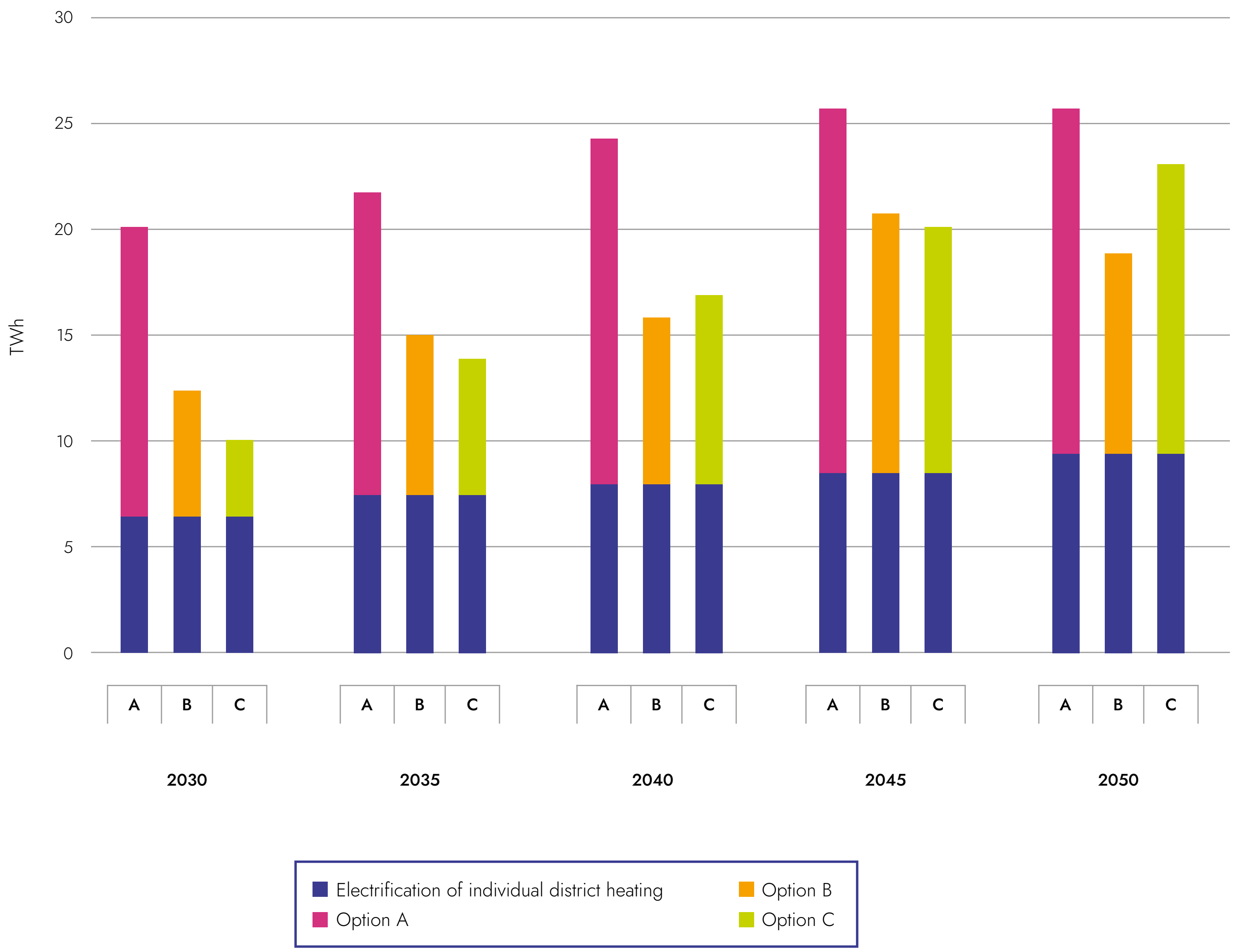


6.4.2. Electricity consumption by Power to Heat units

Figure 18 shows the demand for electricity used in district heating, for both system heat and for households. The introduction of individual heating electrification leads to an increase in electricity demand in the range from 7 to 10 TWh. In the analyzed scenarios, the electrification of system district heating took place at different rates, but in all options the maximum demand exceeded 10 TWh. In the case of Option A assuming the fastest decarbonization of system district heating in accordance with the requirements of the Fit for 55 package, the annual energy demand amounted to more than 15 TWh (in 2023, electrode boilers in Poland consumed less than 0.5 TWh).

Electrification of the system and individual heat sector will proceed, and future planning of the power system should take into account the resulting needs. It will be necessary to upgrade the energy infrastructure, including transmission and distribution networks, in order to increase the network connection capacity in areas where heat-generating plants are located.

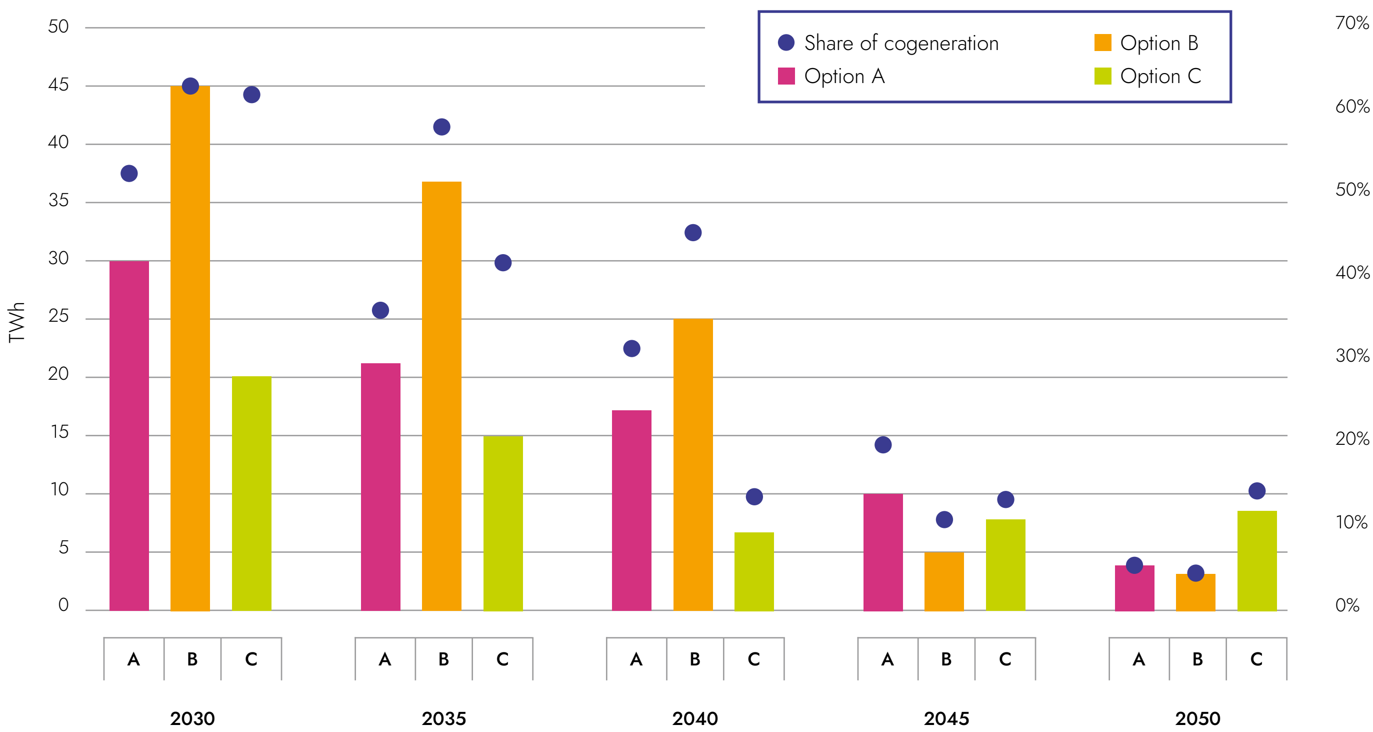
Figure 18. Electricity demand (TWh) in system district heating and heating



6.4.3. Electricity generation

In the process of district heating decarbonization, in order to abandon fossil fuel combustion to increase electrification, it is important to take into account the decreasing volume of electricity generated by the district heating sector. This will result from a gradual transition from cogeneration technologies, especially those based on natural gas and coal. The only cogeneration units will be those based on decarbonized gases, which will depend on the availability of such fuels on the market. Cogeneration will need to adapt better to the increasing dynamics of price volatility, and one of the potential solutions is to optimize operation with thermal storage tanks. In accordance with diagrams below, the cogeneration technology will be replaced by other cheaper technologies, which will also reduce the volume of electricity generated by them. It is worth emphasizing that after 2045 the prevailing share of heat from high-efficiency cogeneration will not allow for meeting the requirements of an efficient district heating system.

Figure 19. Electricity generation (TWh) in individual Options

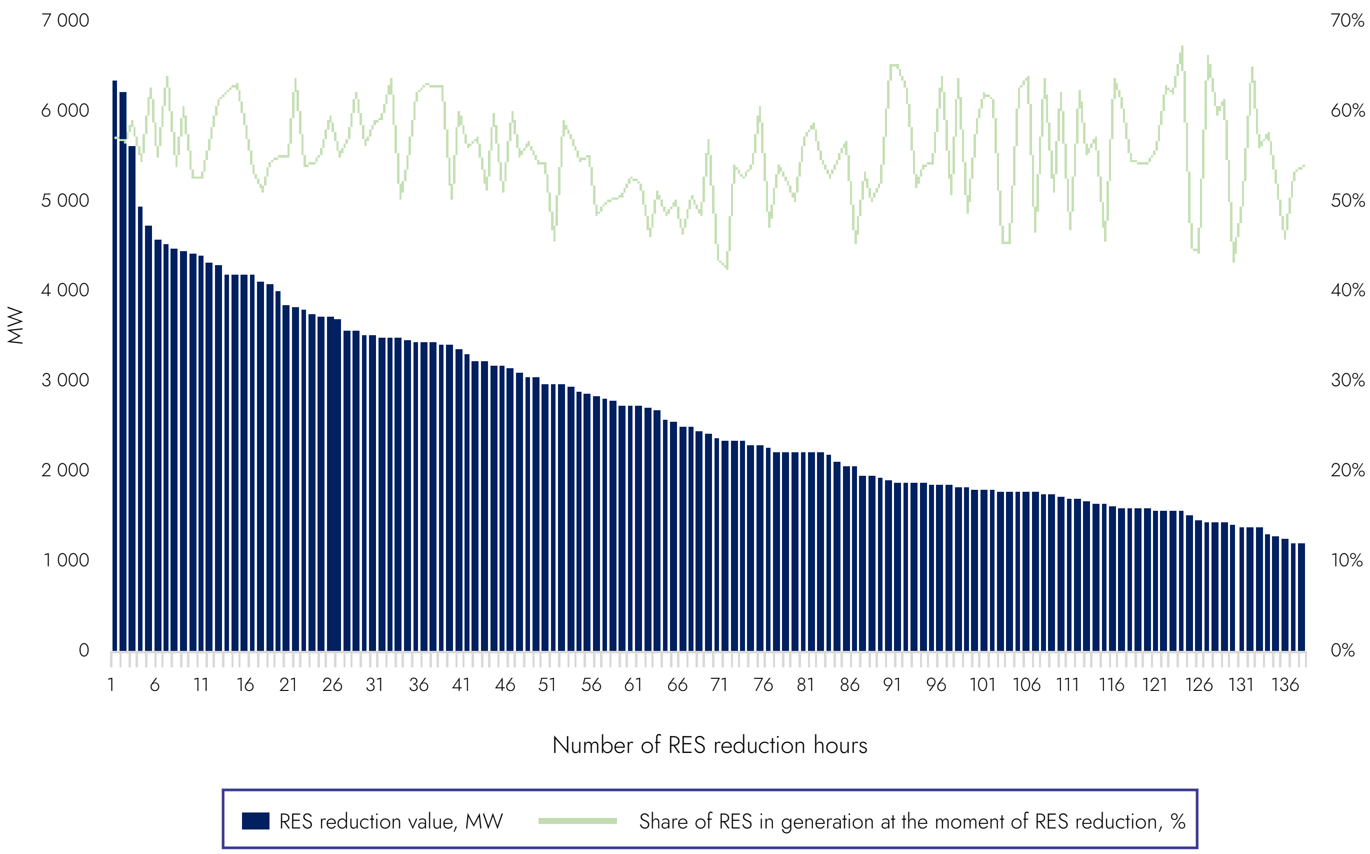


The national energy policy should take into account the significant decrease in electricity generation from the district heating sector presented in figure 19 in order to fully secure the needs of the economy, households and electrified district heating.
The analysis shows that the district heating sector will become one of the largest consumers of electricity, which entails some opportunities, but also consequences. The increasing electricity demand resulting not only from the electrification of district heating, but generally from economic and consumer development, will have to find a mapping in the supply of energy from low- and zero-carbon sources. The development of nuclear power, RES and sources based on biomethane/

biogas combustion will play an important role. On the other hand, hybrid district heating systems based on heat pumps and electrode boilers coupled with a thermal storage tank will be able to perform a stabilizing function of the National Power System, managing surplus energy from the production of wind and photovoltaic power plants.

Starting from 2023, significant levels of reduction in renewable sources are observed in the Polish power system – caused by the surplus of simultaneous production of wind farms and photovoltaic farms. The diagram below shows the power values of all reductions that occurred so far (from the beginning of 2023 to May 20, 2024) in the NPS. The use of Power to Heat technology, i.e. electrode boilers, could already today significantly lower the levels of these reductions and cover the system heat demand. Additionally, the average share of RES in electricity generation during reduction hours was 55%. In the future, an increase in the installed capacity of RES and, consequently, a higher share of RES in the national energy mix and a more severe reduction in renewable sources should be expected. The connection of the district heating and power sectors through the use of Power to Heat technology will support balancing of the National Power System, which will allow for avoiding the phenomenon of reduction in electricity generation from renewable sources, which is detrimental to consumers.

Figure 20. RES power reduction in the period from the beginning of 2023 to May 20, 2024 based on the announcements of Polskie Sieci Elektroenergetyczne.



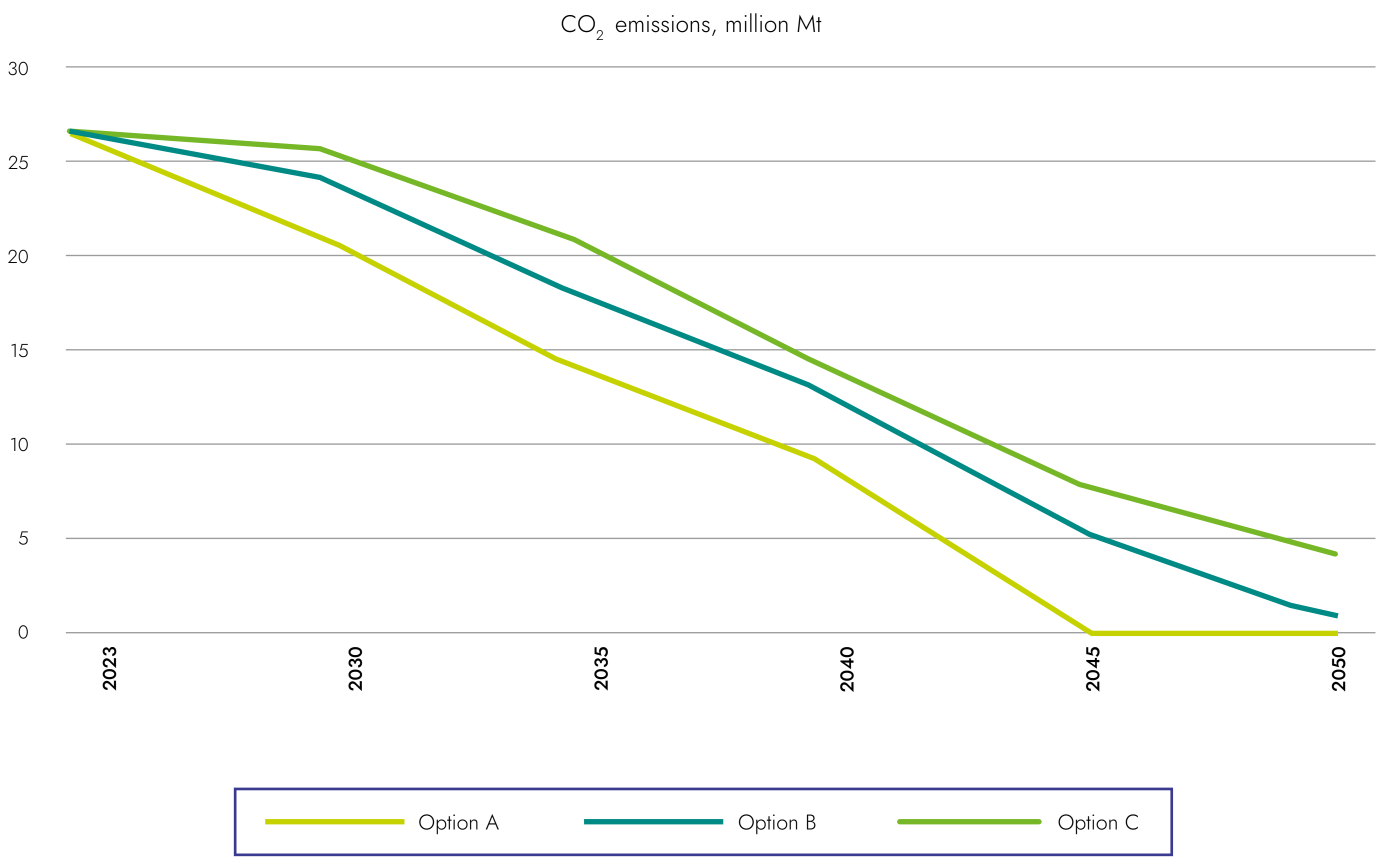
6.4.4. Emissions – emission reduction path

The fastest decarbonization of district heating is carried out in scenario A – efficient electrification reaching the highest values of installed capacity, and as a result thereof, a significant share of heat generation from heat pumps and electrode boilers (Option A) allows for reducing emissions in the district heating sector in a significantly more efficient manner than in other scenarios. Emissions in scenarios B and C are similar, but significantly higher than in scenario A, which is mainly due to two factors:

- **1. In Option C – coal** – in the generation mix, mainly district heating boilers remain as coal-fired units ultimately, which reduces the share of coal-fired cogeneration and electricity generation from coal, as a consequence, it reduces the volume of CO_2 emissions.
- **2.In Option B – gas option** – there is a significant share of gas-fired cogeneration, which, due to the high cogeneration rate of electricity and heat, affects a larger volume of CO_2 emissions than would be the case for heat generation without electricity.

Among the analyzed scenarios, Option A leads to neutrality already in 2045.

Figure 21. Impact of the change in the generation mix on CO_2 emission in individual options.

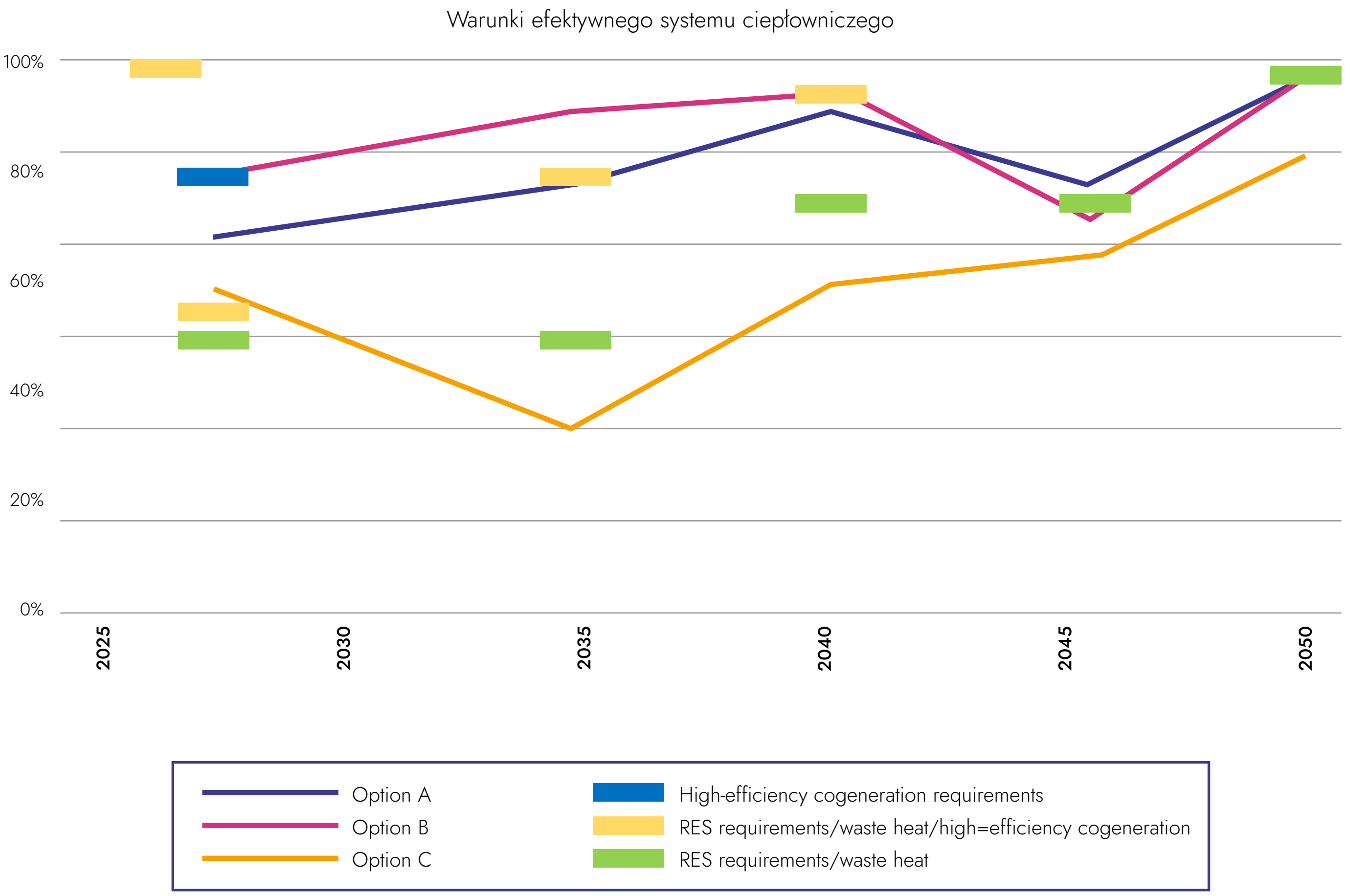


6.4.5. Meeting the conditions of an efficient district heating system

Meeting the new, strict criteria for an efficient district heating system by district heating systems in Poland will be one of the most important challenges of the transition. As shown in the analyzed scenarios, the achievement of these requirements by most district heating systems is possible, but requires radical actions. In each scenario, Power to Heat technologies can play a significant role in complying with these criteria.

In Option A, the criteria for an efficient district heating system are met mainly through the implementation of investments in renewable sources and electrification. Option B assumes more intensive development of cogeneration units, however, it is worth noting that from 2045 these units should use renewable fuels, which will mean the need to change fuel of natural gas-fired units to decarbonized gases. This will depend on the development of the market for these fuels and their availability for the district heating sector. Option C (background scenario) of the report does not lead a significant part of the district heating systems to achieving the criterion of an efficient district heating system, which will result in a gradual search by final customers for alternative heating solutions and ultimately in abandoning the system heat, which will not always be possible from the perspective of, i.a., technical conditions. Diagram 22 shows how the options allow for meeting the criteria of an efficient district heating system. Horizontal designations correspond to the required shares of heat from individual sources – RES or waste heat or high-efficiency cogeneration – for the purpose of achieving the volume criterion for efficient district heating systems.

Figure 22. Fulfillment of the conditions for an efficient district heating system on the basis of individual Options on national scale



6.4.6. Example of operation of the unit with the Power to Heat system – hourly production duration curves

In order to illustrate the cooperation of Power to Heat solutions with other generating units, the operation of a sample large district heating system was simulated in 2035. The analysis shows how the cooperation of Power to Heat equipment with other generating units and thermal storage tank typical for future district heating systems in actual expected economic conditions would proceed (changing during the year, week and day).

INPUT DATA AND CALCULATIONS

The input data for the simulation were:

- assumptions concerning fuel prices, emissions and other volatile costs for 2035,
- heat demand path of one year with hourly resolution,
- electricity price path for one year with hourly resolution,
- overhaul plan of individual pieces of equipment during the year.

The simulation consisted in optimum selection of generating units and power from/to the thermal storage tank so as to cover the set heat demand for each hour of the year at the minimum cost understood as the sum of fuel and emission costs and purchase of electricity less the revenue from electricity generated as part of cogeneration. The costs of equipment start-ups and their models were taken into account and a proprietary optimization tool was used, a more detailed description of which is included in the publication available in the Polish periodical "Energetyka Cieplna i Zawodowa" 2/2023[29].

The generating units included in the model comprised:

- Electrode boiler with power output of 60 MW_t
- Heat pump with power output of 90 MW_t and COP=3
- 3 gas-fired water boilers, 105 MW_t each
- Gas engine system with total power output of 152 MW_t
- Biomass-fired power unit with power output of 90 MW_e
- BC100 gas-fired power unit with power output of 205 MW_t (after conversion)
- 1500 MWh thermal storage tank (corresponding to approx. 30,000 m^3)

SIMULATION RESULTS

The simulation results in optimal hourly operating paths of the Combined Heat and Power Plant in one entire year for two alternative sets of equipment: a complete set of units mentioned in the previous paragraph and the same set of units without the heat pump and the electrode boiler.

29 Use of proprietary optimization models to analyze the profitability of investment projects relating to cogeneration, electric or solar sources and heat accumulation in district heating systems, Michał Leśko, ECiZ 2/2023.

Timelines

Figures 23 and 24 show the operation of the combined heat and power plant in exemplary 72 winter hours, in the option with and without Power to Heat technologies, respectively. The discrepancy between the total power output of the generating units and the demand results from the thermal storage tank operation, the charging level of which is also shown in the diagram. Within 3 days, there are significant changes in the selection of equipment. The reason is the volatility of electricity prices. Due to relatively low energy prices compared to fuel prices and taking into account COP=3, the heat pump operates throughout the analyzed period in the base, minimizing power output only in a few hours at the highest prices. During the first hours, at low electricity prices, the demand is covered by the operation of the biomass-fired power unit and the electrode boiler. Only after the increase in the electricity price above approx. PLN 400/MWh for a longer period of time, the BC-100 power unit and gas engines are started up. The electrode boiler is shut down and the thermal storage tank is charged with heat from the cogeneration, which is cost-effective at these prices. In the low price period lasting several hours, the power output of the BC-100 power unit is reduced and gas engines are shut down (their start-up cost is much lower than for BC-100). After a permanent decrease in energy prices (in the center of the diagram), the BC-100 power unit is shut down. Apart from the biomass-fired power unit and heat pumps, heat is delivered by gas engines, gas-fired water boiler and electrode boiler as well as gradually discharged thermal storage tank. The contributions of these devices are adjusted to the electricity prices and due to the low cost of start-ups (especially of the electrode boiler, but also of the engines), their optimum operation is characterized by significant changes.

The operation of a combined heat and power plant without Power to Heat technologies (fig. 24) during the same 3 days would be rather similar, but due to the lack of a heat pump in the base and the lack of an electrode boiler in the low price periods, cogeneration sources would operate longer and less in line with the electricity prices.

Figure 23. Exemplary 3 days of winter operation of the system with Power to Heat technologies

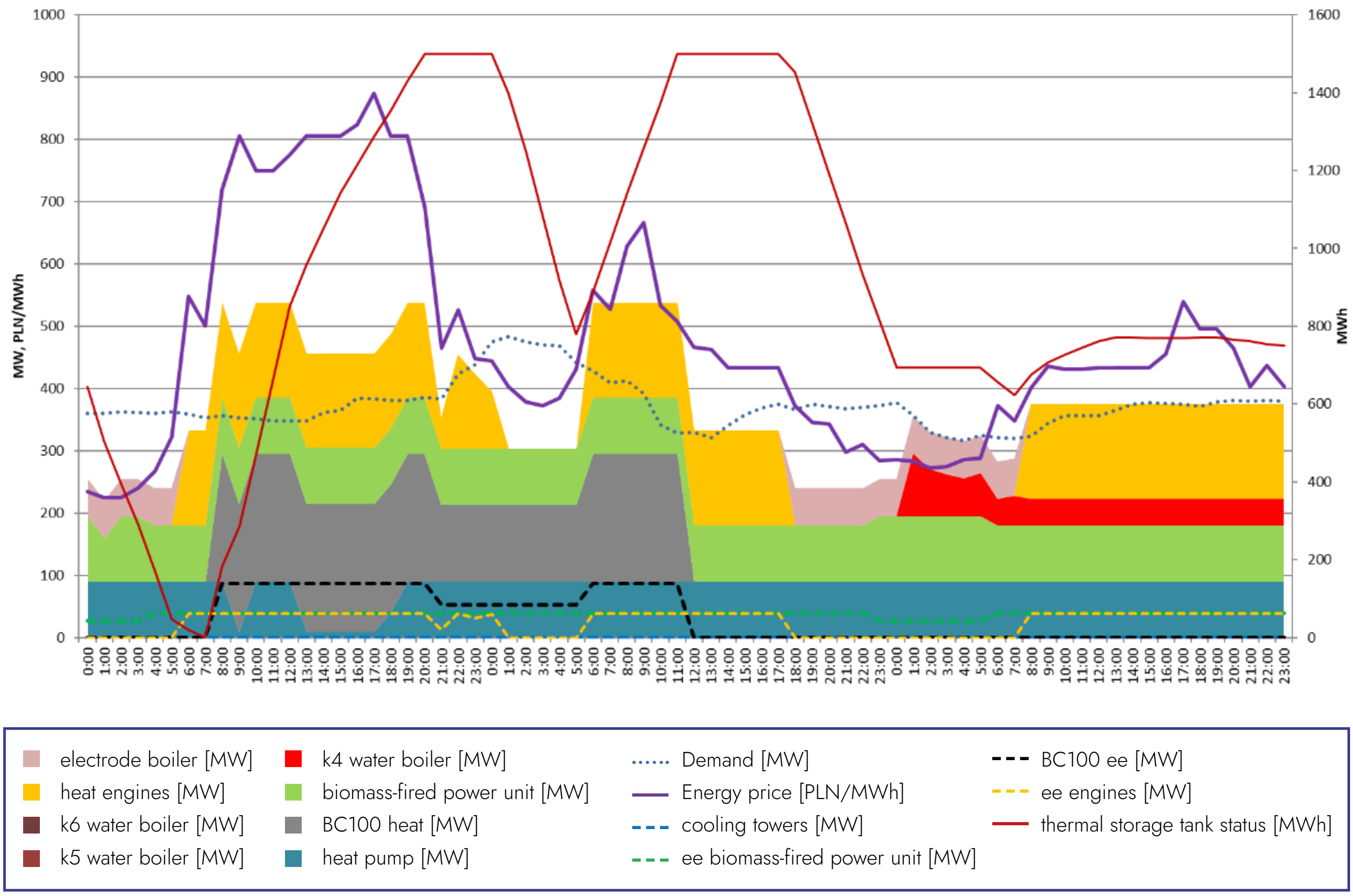
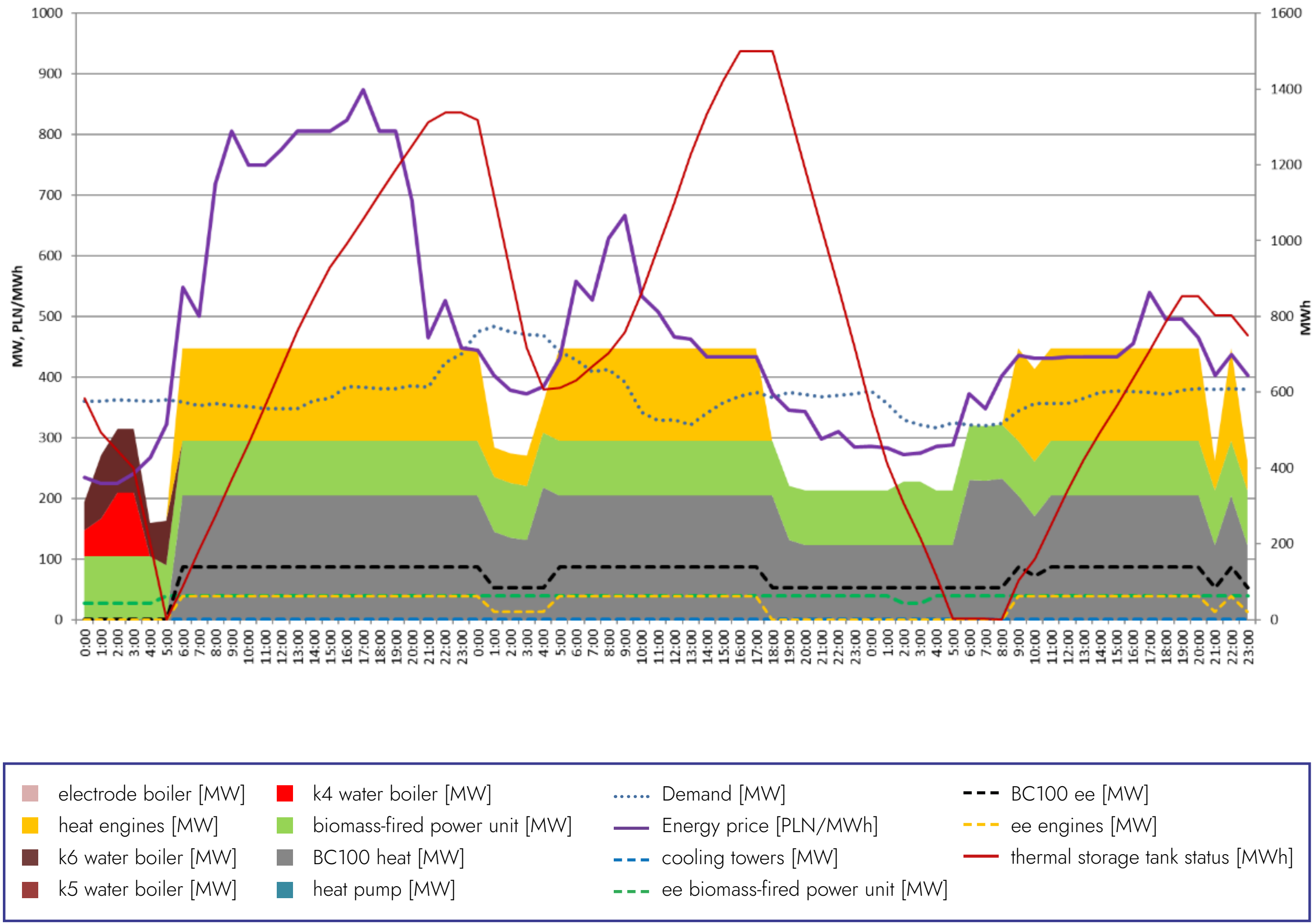


Figure 24. Exemplary 3 days (the same) of winter operation of the system without Power to Heat technologies



On the other hand, in the summer period (figures 25 and 26), the difference between the option with and without Power to Heat technologies is very noticeable. The heat pump is the primary source operating with power output slightly below demand. The missing heat is delivered to the system from the thermal storage tank. During electricity price peaks, gas engines are started and heat from them is used to recharge the thermal storage tank. Moreover, in the case of significant and multi-hour price peaks, the heat pump is shut down and the biomass-fired power unit is started.

In the option without Power to Heat, the role of engines is the same, but the source operating in the base is the biomass-fired power unit, which operates in cogeneration even during low electricity price periods. The power output of this source is controlled, but to a limited extent, which results in relatively high electricity generation at low electricity prices.

Figure 25. Exemplary 3 days of summer operation of the system with Power to Heat technologies

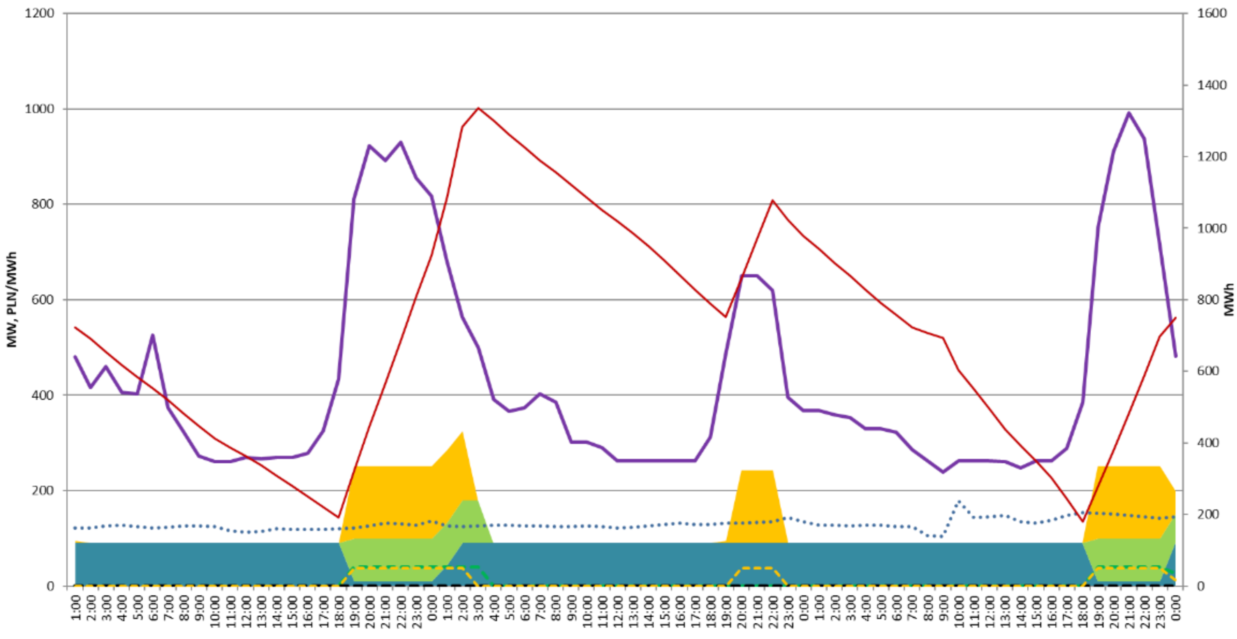
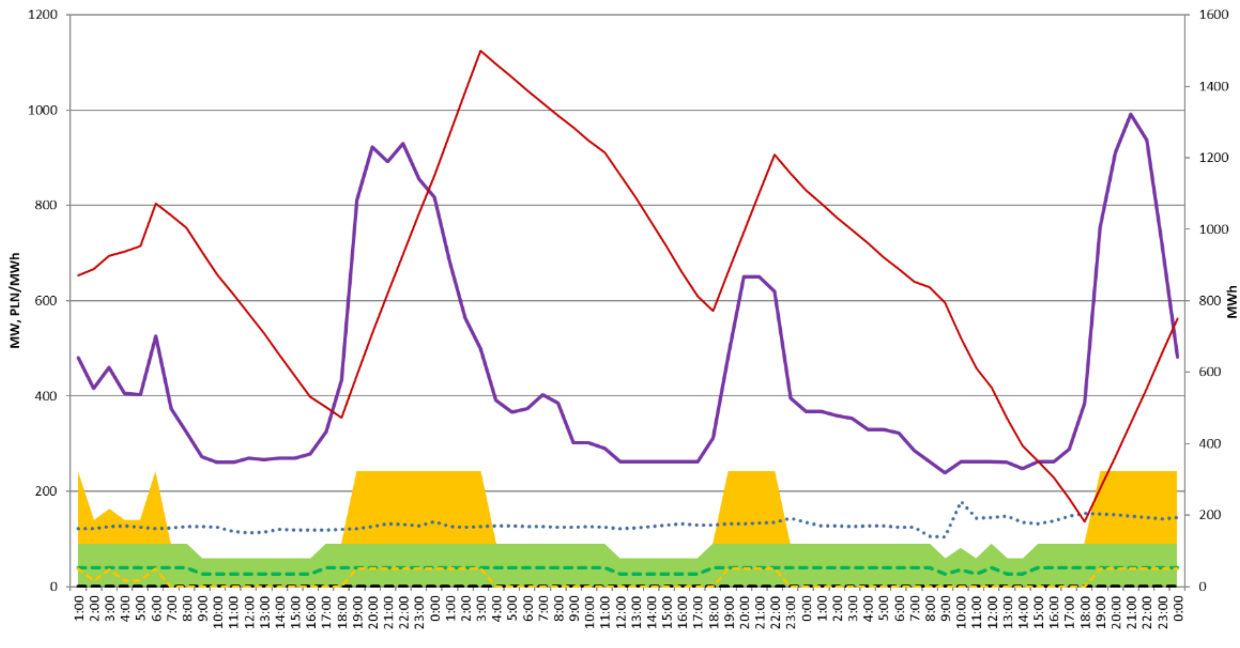
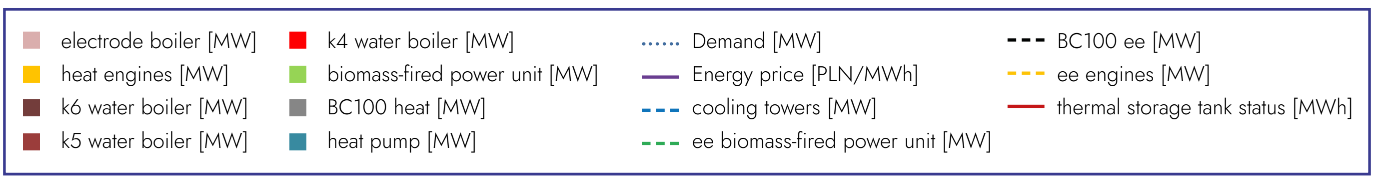


Figure 26. Exemplary 3 days of summer operation of the system without the Power to Heat technologies





Organized chart

Directly based on the results of the analysis, the organized charts were prepared for the option with and without Power to Heat technologies (figures 27 and 28, respectively). There are significant differences between the chart obtained in this manner and the usually presented organized charts as a result of theoretical considerations. Firstly, the total power output of individual sources in a given hour is almost never equal to the demand – this results from the thermal storage tank operation. Secondly, the operating areas of the individual sources in the chart are divided – the operation hours are adjacent to the shutdown hours. The greater the dependence of the unit operation on energy prices (and not only on heat demand), the more visible this effect, limiting the legitimacy of using organized charts in modern district heating systems.

Statistically, the heat pump acts as the primary source, partially replacing the biomass-fired power unit in summer, and mainly replacing the BC-100 power unit in the heating season. Regardless of the option, gas engines start up throughout the year, depending on electricity prices. In addition, water boilers and an electrode boiler are used during the heating season. Power to Heat technologies significantly reduce the share of gas-fired water boilers. Firstly because the additional power output in the heat pump makes it possible to cover peak demand without the use of water boilers and secondly because at low electricity prices, they are replaced by an electrode boiler.

Figure 27. Organized chart based on simulations for a system with Power to Heat technologies

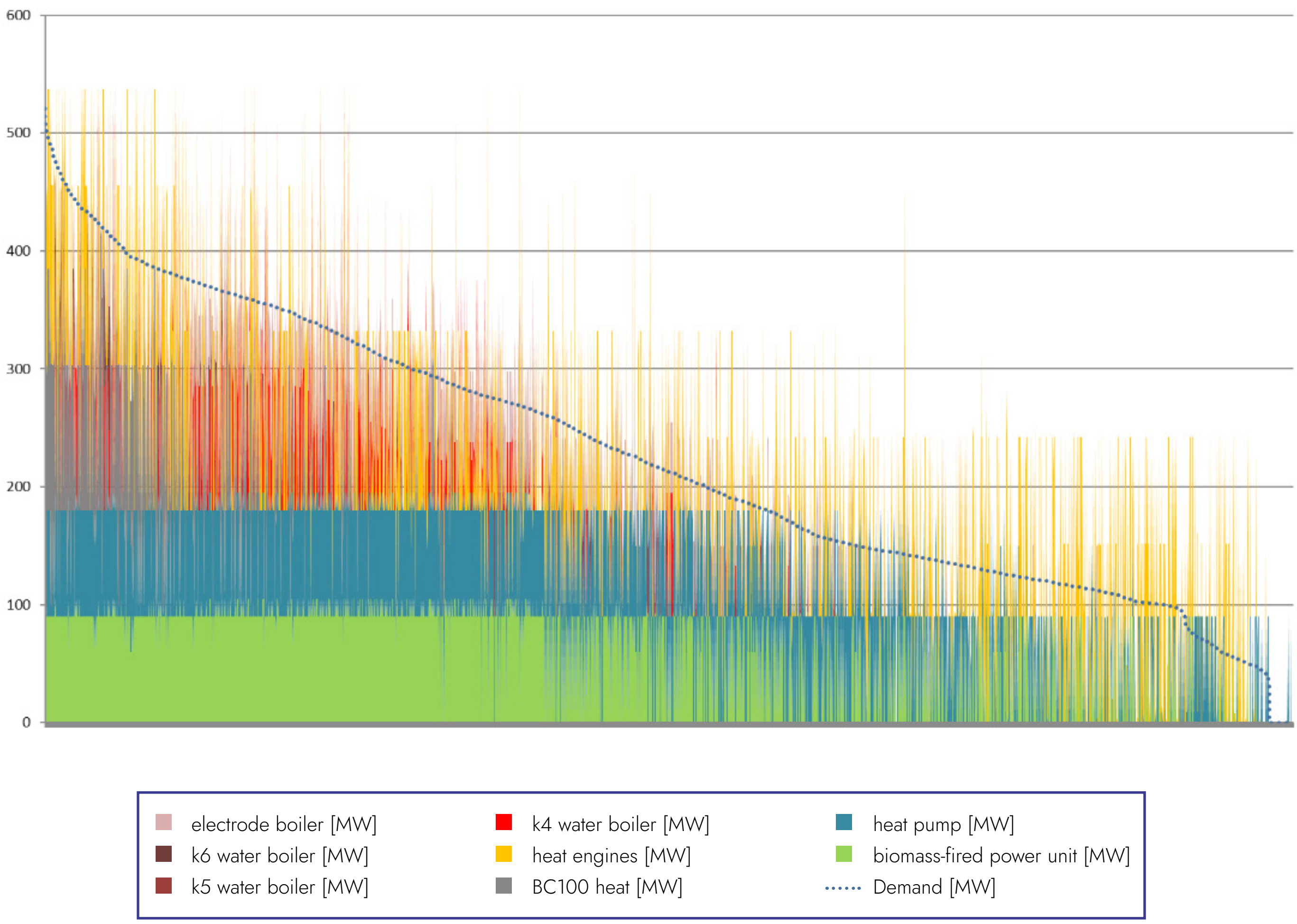
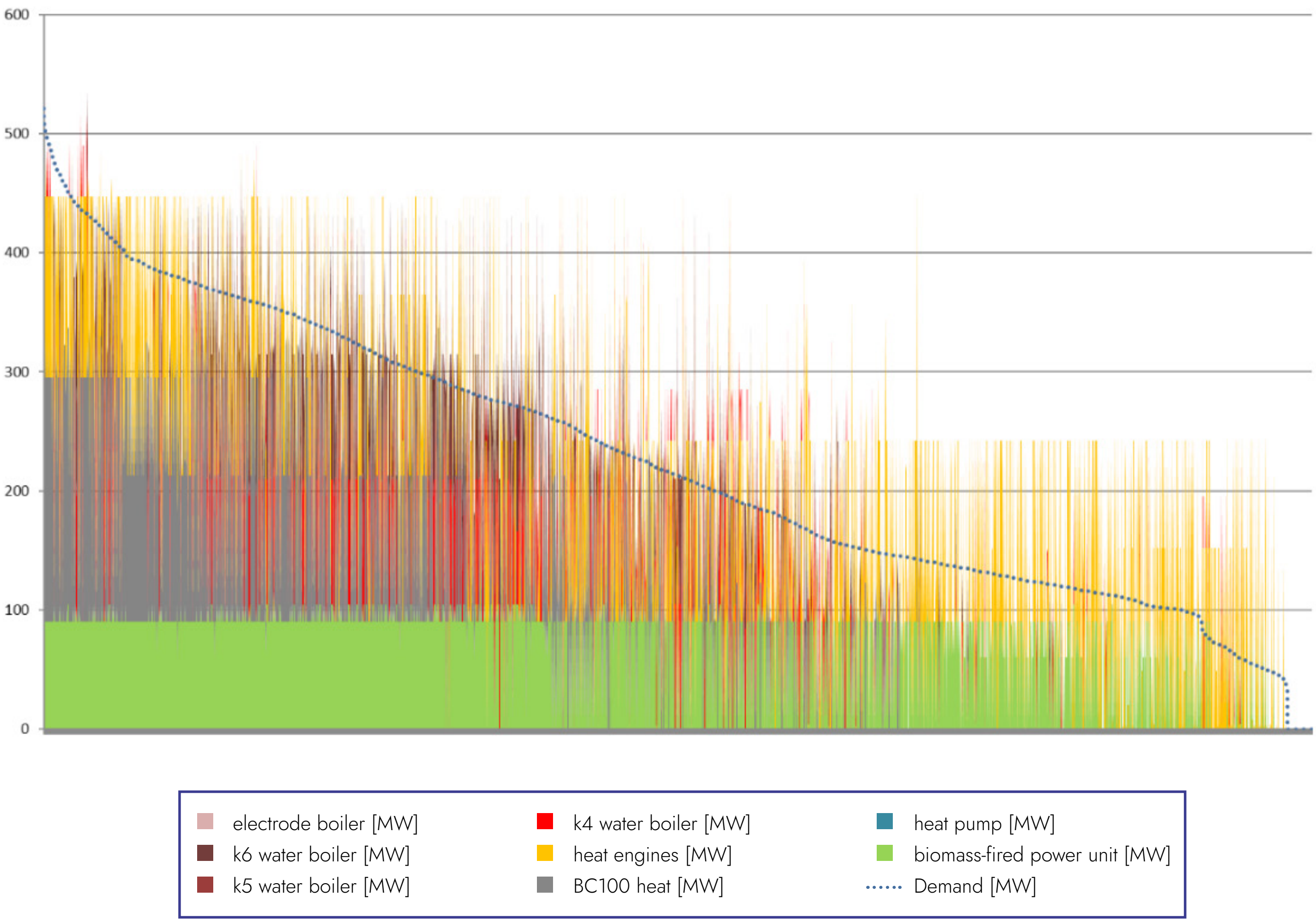


Figure 28. Organized chart based on simulations for a system without Power to Heat technologies



Economic results

In order to quantify simulations of the system operation with and without Power to Heat technologies, the total economic results for both options were compared. The addition of Power to Heat sources to the system resulted in a significant decrease in the use of gas-fired water boilers (by 68%) and BC-100 power unit (by 63%), with a slight decrease in the use of gas engines (by 18%) and biomass-fired power unit (by 14%). This confirms that Power to Heat technologies allow (with economically optimal operation of the system) for avoiding the least efficient sources based on fossil fuels.

The simulation with hourly resolution allows for examination of the prices at which individual generating units operated. The average price at which electricity generated in gas engines was sold was PLN 654.76/MWh for the scenario without Power to Heat and PLN 694.91/MWh for the scenario with Power to Heat technologies. As it can be seen, even in the option without Power to Heat sources, due to the optimum use of the thermal storage tank, this value is more than ⅓ higher than the average price per year. However, the use of Power to Heat in district heating allows for even better adjustment of engine operation to prices (mainly replacing engines during periods where they would have to be used due to heat demand even despite long-term low electricity prices). On the other hand, the average price of electricity at which the heat pump was operated amounted to PLN 402.50/MWh, and the average price of electricity at which the electrode boiler was operated amounted to PLN 277.98/MWh. These values are much lower than the average energy price per year, for both the heat pump (although it operated with variable power output as much as 6,998 hours per year) and for the electrode boiler (which operated for 2,285 hours per year). They show the potential to use low electricity prices. If price volatility on the DAM is more significant in the future, this potential will be even greater. These effects are visible in the final average variable cost of heat generation in the system. In the analyzed example, this value amounts to PLN 70.6/GJ for the option without Power to Heat technologies and PLN 51.63/GJ for the option covering this type of sources. It should be emphasized that this is an amount corresponding only to variable costs, additionally reduced by revenues from electricity and does not take into account expenditures or fixed costs of operation of the combined heat and power plant. Therefore, in both cases, it is lower than the LCOH calculated for the technologies used. Nevertheless, the difference is significant and shows the benefits of the Power to Heat technology implementation. Provided that expenditures are incurred, which are high especially for heat pumps, Power to Heat sources allow for significant reduction in variable costs, which contributes to stabilization of heat prices for consumers. At the same time, the share of renewable energy or waste heat in the district heating system is significantly improved.

6.5. Main conclusions and summary

The conducted analysis, showing the transformation of the entire district heating sector, was aimed at estimating the global potential of Power to Heat technology development in Poland. The analysis indicates that the mix of technologies used in individual options will be diversified, but electrification fits well into each scenario and may significantly facilitate the decarbonization of system district heating. In large district heating systems located in urban agglomerations where there are no locally occurring RES in sufficient quantities (possibility of using biomass, geothermal energy) or there is a difficulty in availability of space for construction of such plants, the potential to use Power to Heat technologies, such as an electrode boiler or heat pumps supplied with renewable electricity, will be greater.

a) Impact of Power to Heat technologies on heat prices

The structure of capital expenditures and operating expenditures is reflected in heat prices, which is important from the point of view of the customers of system district heating. Technologies with a relatively high share of capital expenditures with a limited share of fuel costs (such as heat pumps or electrode boilers) i have ultimately the advantage of ensuring greater predictability and price stability. The low share of fuel costs in the heat price results in the creation of a specific type of shield against turbulence on the raw material markets, including the CO_2 emission allowance market. Investments in heat generation sources with a lower share of operating costs are therefore beneficial from the point of view of both the investor and the heat consumers.

b) Recommended direction of district heating decarbonization

As shown in the report, Power to Heat technologies (heat pumps and electrode boilers) are a desirable direction of development of district heating. Technologies based on energy conversion are able to effectively cooperate with other technologies used for heat generation (e.g. gas- and biomass-fired units), both in the options assuming the most dynamic transformation (Options A and B), and in the scenario of the longest possible maintenance of hard coal in district heating systems (Option C). The conducted analysis allows for concluding that in order to meet the requirements of the climate and energy policy, it will be necessary to use the Power to Heat technologies in the full range of possible process solutions.

Solutions relating to district heating electrification are known and used worldwide, and consequently, this experience can be extrapolated to Poland, adapting them accordingly to the conditions of district heating systems. Taking into account the current market conditions, availability of Power to Heat technologies and EU regulations, it seems most appropriate to apply the technologies described in the report, thus giving space for the development of new solutions supporting the decarbonization of the district heating sector.

The use of Power to Heat technologies provides adequate time reserve for possible fuel change and use of decarbonized gases for production. This approach was proposed in Option A, which allowed for the achievement of almost zero emissions already in 2045. Ultimately, Power to Heat technologies should be supplied as much as possible from renewable energy to enable district heating systems to meet the criterion of an efficient district heating system.

The confirmation for the selection of Option A as the optimum option for district heating decarbonization is the example of cooperation of Power to Heat technologies in an actual configuration included in chapter 6.4.2, which shows the decisive impact of instantaneous electricity prices on the system operation. Power to Heat technologies allowing for much better use of the potential of electricity price volatility than flexible cogeneration sources alone. The thermal storage tank is an important element of the optimization. Ultimately, Power to Heat sources allow for a significant decrease in the average variable heat generation cost in the system, but one must not forget the high expenditures (especially in the case of heat pumps) necessary to achieve this effect.

7. Recommendations – key to development

Bearing in mind the EU regulations applicable to Power to Heat technologies currently in effect (described in chapter 4), the Polish Association of Combined Heat and Power Plants developed recommendations on how to implement the regulations of the Fit for 55 package, aimed at accelerating the increase in the share of renewable energy in system district heating. The proposals contained in this chapter were preceded by a detailed analysis of:

- the wording of the previous versions of the directives included in the Fit for 55 package in relation to those currently applicable,
- national regulations to adapt them to EU regulations.

7.1. Implementation of directives of the Fit for 55 package

The key issues regulated in the new directives, which have an impact on Power to Heat technologies, are indicated below, together with suggestions on how to implement them into national legislation.

7.1.1. EED

From the point of view of system district heating, the changes introduced by the revised EED, which refer to Power to Heat, are as follows:

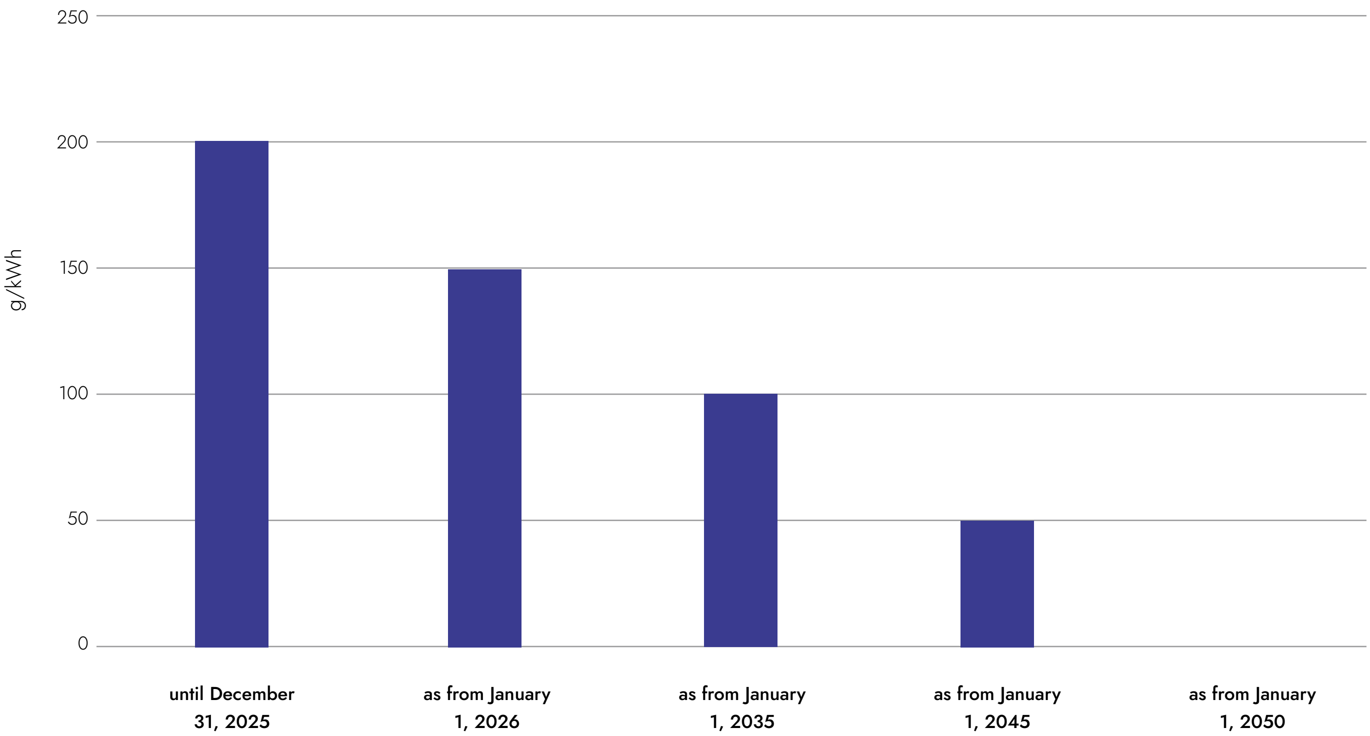
- change in the criteria for recognition of the district heating or cooling system as an efficient district heating or cooling system,
- new criteria for high-efficiency cogeneration.

Change in the criteria for an efficient district heating system:

- replacement of the current criteria for the qualification of a district heating or cooling system as efficient within the meaning of the new definition introduced by Article 26 section 1 of the revised EED (valid within individual time frames). It should be noted that the new criteria for declaring the district heating system efficient are more stringent than those currently in force. As of January 1, 2028, one of the criteria provides for the share of high-efficiency cogeneration at the level of min. 80%, which must meet additional requirements (i.a. as regards the emission rate below 270 g CO_2/kWh of total generated heat and electricity), whereas as from 2045 until becoming an efficient district heating system, no significant role of high-efficiency cogeneration is expected.

- The introduction of alternative criteria for declaring a district heating or cooling system efficient, i.e. based on Article 26 sections 2 and 3 of the EED, provides for the possibility of introducing alternative criteria for declaring a given system efficient, which are based on the amount of greenhouse gas emissions from the district heating and cooling system per unit of heat or cold delivered to consumers.

Figure 29. Required greenhouse gas emission thresholds per unit of heat or cold delivered to consumers from a given district heating system, allowing for considering a given system as an efficient district heating or cooling system



In order to introduce alternative solutions, it seems justified to specify the methodology of converting emissions into a unit of heat delivered to consumers. Those rules should, in the opinion of PTEZ, be consistent with those used for the greenhouse gas emission trading scheme.

Under the EED, the decision on the solution should be made by the Member States. In this context, implementation providing for application of different criteria to district heating systems could be considered. Therefore, it is recommended that the selection between the paths for achieving the definition of an efficient district heating or cooling system be based on the application of an energy undertaking engaged in the transmission or distribution of heat or cold in a given district heating system for the use of an alternative method for the system in the area of operation of that undertaking, which would be assessed by the President of ERO or the Minister of Climate and Environment as the Minister competent for energy. Such a solution seems to be the most appropriate, given the high level of knowledge of the undertaking in question as to the feasibility of meeting alternative criteria.

In order to implement the above provisions into national law, it is necessary to amend the national criteria for an efficient district heating system. An appropriate place for introducing a change in this respect is Article 7b section 4 of the Energy Law.

New criteria for high-efficiency cogeneration

For the purposes of implementation of the criteria for declaring the district heating or cooling system efficient, additional conditions were also introduced, specifying the conditions for energy generated in high-efficiency cogeneration in order to participate in the fulfillment of the definition of an efficient district heating system.

The new criteria for energy generated in high-efficiency cogeneration reflect the path indicated by the EU, aimed at decarbonizing the district heating sector, i.a., using Power to Heat technologies. Setting the EPS index at the level of 270 kg of CO_2 per 1 MWh (for fossil fuel sources) becomes a kind of entry point in the context of the possibility of meeting the definition of an efficient district heating system (only by 2045) and will be important from the point of view of public financing.

The currently applicable criteria for the definition of high-efficiency cogeneration have been implemented into the national legislation in the definition of high-efficiency cogeneration included in Article 3 point 38 of the Energy Law. In view of the amendments made to Annex III of the EED, it is necessary to remove the current criteria from the definition of high-efficiency cogeneration and to include them in the substantive provisions, and to add new ones which are introduced by Annex III.

Individual criteria need to be specified, including:

- Determination of the method of calculation of the emission criterion for high-efficiency cogeneration (EPS 270);
- Definition of non-strict terms, such as "construction" and "substantial retrofit" of the generating unit;
- Derogation for cogeneration units in operation before October 10, 2023 from EPS 270 until January 1, 2034, provided that they have a phased emission reduction plan to reach a value not exceeding the threshold of 270 g CO_2 per 1 kWh by January 1, 2034 and that they notified that plan to the relevant operators and competent authorities.

7.1.2. RED III

From the point of view of system district heating, the changes introduced by the revised RED, which refer to the Power to Heat mechanism, are as follows:

- increasing the share of energy from renewable sources and from waste heat and cold in district heating and cooling systems.
- the possibility of including, as part of the increase in the share of energy from RES in heating and cooling systems, electricity generated from renewable sources and subsequently used in those systems (Article 24(4), second and third subparagraph of the Directive).

Therefore, the above allows to classify heat or cold generated from electricity from RES for district heating systems as heat or cold from RES[30].

Table 14 Method of implementation of new criteria for high-efficiency cogeneration

A cogeneration unit generates energy from high-efficiency cogeneration if:	
1.	the unit carbon dioxide emission factor from this fossil fuel-fired cogeneration unit is not higher than 270 kg of CO_2 per 1 MWh of heat or cold, electricity and mechanical energy generated in the cogeneration process
2.	the retrofit did not result in an increase in the use of fossil fuels other than natural gas, compared to the annual average consumption for the three previous calendar years prior to the date of commencement of the refurbishment – in the case of substantial refurbishment
3.	the unit does not use fossil fuels other than natural gas – in the case of construction of a new cogeneration unit or substantial refurbishment by 2030.

30 More information on EU regulations is included in Chapter 4 of this report.

Therefore, when implementing these provisions, it is recommended to:

- by supplementing Article 7b of the Power Law Act, include a provision allowing to classify as energy from renewable sources also heat or cold generated from electricity from renewable energy sources, including electricity purchased on the basis of PPAs or directly – in the case of connection of an electricity source through a direct line, for the purpose of classifying a district heating or cooling system as efficient. The qualification should be confirmed by the redemption of the guarantees of origin issued for electricity generated in renewable sources, with possible modifications of the mechanism allowing for verification that a specific volume of electricity from RES was used for heat generation. Taking into account the fact that the use of electricity from RES to generate heat or cold, subsequently classified as heat or cold from RES, constitutes the energy conversion process referred to in Article 120 section 7 of the RES Act, the redemption of the guarantees of origin should take place under the rules for energy conversion provided for in the aforementioned provision. Such a solution will prevent the inclusion of guarantees of origin issued for electricity from RES used to generate heat or cold in the balance of redeemed guarantees of origin referred to in Article 124 section 7 of the RES Act;
- supplement the scope of the report to the ERO on activities aimed at maintaining or achieving the criterion of an efficient district heating system with heat or cold generated from RES electricity generated in the energy conversion process – specification of the catalog of information taken into account by an energy undertaking holding a license for heat transmission or distribution in the report submitted by March 31 each year to the President of the ERO and the Minister competent for energy, concerning the district heating or cooling system, so that it does not raise any doubts that it includes the percentage of energy from renewable energy sources, specifying the type of renewable energy source, including heat or cold generated from electricity from renewable energy sources.

In order to stimulate investment in RES in the district heating sector (including the use of Power to Heat technologies), solutions should also be introduced at the national level to simplify administrative procedures for obtaining required consents and permits (especially in the scope of environmental impact assessment as well as building permits). In the current legal state, there are no such solutions, and RED III provides for simplifications envisaged only for heat pumps in the identified and designated area of accelerated development of energy from renewable sources. Moreover, it would be essential to launch as soon as possible a national contact point for renewable energy sources referred to in Article 160a of the RES Act of February 20, 2015.

7.2. Launch of the Power to Heat technology support system

The system district heating sector faces the already started decarbonization process, which largely assumes the use of a transitional fuel, i.e. natural gas. The evolving regulatory environment at the EU level (i.e. the Fit for 55 package) forces energy undertakings to constantly transform, which, if it meets the requirements of this package in the area of decarbonization of the system district heating sector, will require expenditure at the level from PLN 276 billion to PLN 418 billion by 2050[31], depending on the adopted decarbonization scenario.

Particular responsibility for meeting the EU targets of "greening" the system district heating sector lies with energy undertakings generating heat, which are or will be investing in constructing new or upgrading existing heat sources, which is necessary to meet new criteria for an efficient district heating system. This means that these undertakings will have to bear the costs of further investments, this time in RES plants. As it results from the contents of this report and analyses carried out for it, the technologies that may support the fulfillment of the criteria of an energy-efficient system:

- are limited in terms of availability and feasibility,
- have a higher LCOH than cogeneration units (they are not price competitive),
- increase the level of heat prices and rates in end-user tariffs.

Considering the above factors, a comprehensive approach to decarbonization of the system district heating sector is needed. A comprehensive approach means essentially creating a new ecosystem for the emerging renewable heat market. Energy undertakings participating in the decarbonization process should be able to benefit from the widest possible range of aid programs, which will improve the competitiveness of zero- and low-emission technologies in the district heating sector. Moreover, the tariffs should be at a socially acceptable level, but at the same time enable energy undertakings to cover the costs of their operations.

7.2.1. Power to Heat technologies with an operational support system

In the first place, it is justified to introduce a new operational support system for selected renewable heat generation technologies based on electricity from RES. Apart from biomass- or biogas-fired cogeneration units, in the RES auction system or in the mechanism of support for electricity from high-efficiency cogeneration, RES technologies in the district heating sector cannot participate in operational support systems in place in Poland. The situation is different in the EU Member States, which have successfully introduced aid schemes and thus support the decarbonization of the district heating sector (detailed description in Chapter 4). The decision on the selection of supported technologies should be preceded by analyses on the necessity of granting such aid, indicating also which technologies and at what stage (investment, operational or both equally) generate the highest costs, and whether they are able to be price competitive without operational support and which support period should be envisaged. The technology selected on this basis will determine the final shape of the new system of operational support.

Basic assumptions of the mechanism:

- Beneficiaries: energy undertakings operating in the system district heating sector;
- Conditions for providing support: recruitment; application submitted to the ERO; demonstration of the financial gap;
- Duration of support: the period of support will depend on the supported technology, it should be e.g. 10–15 years; support would be paid in regular intervals (e.g. quarterly); the amount should be indexed annually (based on the inflation rate); the performance of the system should be regularly verified by the ERO on its basis and adjusted to changing market conditions;

31 Report by the Polish Association of Commercial Combined Heat and Power Plants "Assessment of the impact of the decisions of the EU Fit for 55 Package", May 30, 2023.

- System financing: currently applicable co-generation or RES fee or revenue earned by Poland on the sale of CO_2 emission allowances in auctions.

The proposed support will constitute State aid and will therefore have to be granted in accordance with the conditions for the admissibility of that aid, as defined in the 2022 Climate, Energy and Environmental Aid Guidelines (hereinafter CEEAG). According to the said regulations, operating aid for activities related to heat generation from renewable energy sources requires notification to the European Commission and its acceptance prior to granting the aid. It should be noted here that, in order for the European Commission to accept the proposed aid, it must declare it compatible with the EU market.

7.2.2. Additions to investment programs

The analysis of investment support programs available in Poland for the district heating sector, as juxtaposed with the growing need to implement investments in technologies supporting decarbonization of the Polish district heating sector, in particular Power to Heat, indicates the need to modify or take into account new elements of the aid programs.

The expected level of co-financing for Power to Heat technology development projects should correspond to the maximum allowable State aid intensity for RES of 45% of eligible costs plus SME bonus (+20% or 10%). In the case of geothermal energy, the level of support for technical documentation and exploratory borehole should be 60% + SME bonus (+20 or 10%). It would be reasonable to use different forms of support: grants, soft loans, or grants and soft loans (under one instrument), with non-repayable support as a priority.

Table 15. Proposal to supplement aid programs for Power to Heat technologies

Investment support[32]	Project type	Źródło finansowania	Uwagi
Thermal energy storage	Construction/extension of storage facilities without the requirement to include simultaneous construction of a generating source in the scope of the application	FEnIKS	Allocation of more aid to storage-only projects under the Program
		Modernization Fund	The need to create a new Program for thermal energy storage projects.
Electrode boilers	Construction and/or conversion of a RES-powered power generation unit	Modernization Fund	Necessity to agree with the EIB and the EC on the possibility of granting co-financing (e.g. extension of the scope of support in the "RES for district heating" program).
		Energy Transition Fund	Necessity to create a program for electrode boilers
"Small" RES	Program supporting investment in the construction and/or conversion of sources with total installed capacity below 2 MW_t, implemented as part of the district heating system, with installed thermal capacity as of the day of submission of the application below 50 MW	FEnIKS	Financing source depending on the technology and installed capacity
		Modernization Fund	
Geothermal wells	Preparation of technical feasibility documentation for district heating projects and conducting geothermal drilling exploration (searching for a suitable heat pump location)	Polska Geotermia plus. Part 1) Deep geothermal energy	Transfer to the obligatory types of projects: "Execution of the first exploratory borehole". Supplementing the Program with a technical documentation component.
Construction of large-scale electricity storage facilities	Construction of large-scale electricity storage systems integrated with the transmission network, including: support and control systems, energy storage modules (e.g. containerized battery systems), inverters, transformers, auxiliary infrastructure.	Modernization Fund	The organization of the program is in the final phase. The program must be launched as soon as possible.
Increasing the overall efficiency of the district heating and/or domestic hot water systems	Co-financing for activities consisting in upgrading the district heating/domestic hot water systems and heat distribution units Co-financing for implementation of telemetry systems in district heating networks and digital systems for optimization of operation of district heating networks and sources connected to them.	FEnIKS	The measure is aimed at increasing the efficiency of using Power to Heat sources by improving the efficiency of the system operation (minimizing heat losses in the plant) and striving to reduce the operating parameters of the system.

An additional source of support may be funds available under the Energy Support Fund (NRP). As there are currently no specific areas of support under the Fund, it seems necessary to supplement it with a system district heating component. Investment support for RES heat generation, distribution and storage projects will constitute State aid and must comply with the Union eligibility conditions laid down in Commission Regulation No 651/2014 of 17 June 2014 declaring certain categories of aid compatible with the internal market in application of Articles 107 and 108 of the Treaty (GBER) or in the CEEAG.

32 Various forms of support possible: grants, soft loans, grants and loans under one instrument.

7.3. Other regulatory changes, including renewable heat tariffs

An crucial issue in the context of the possibility of developing Power to Heat technologies in district heating systems is that of setting heat tariffs. The current heat tariff regime fails to reflect the specificities of RES plants, which have high investment costs but do not generate operating costs at the level of conventional generation units. It should also be emphasized that the current regulations and guidelines of the President of the ERO do not reward the efforts of energy companies which undertake investments in RES plants.

Table 16. Regulatory change proposals

Recommendation area	Change proposal
1. Additional component of the capital cost formula	The formula indicated in Release of the President of the Energy Regulatory Office No. 65/2022 on the principles and method of determining and taking into account in the heat tariffs of the return on capital (cost of capital) for 2023–2025 should include a bonus for heat generation from RES sources at the level of min. 2% multiplied by the RES heat volume in the overall heat generation
2. Additional component of the equity capital cost formula	The cost of equity capital should be modified in such a way as to enable heat generators to calculate an investment intensity premium. In the calculation of the reinvestment bonus for heat generation, it should be allowed to include capital expenditure within e.g. 5 years from the cost being actually incurred. Currently, the guidelines of the President of the ERO do not reflect the profile of investment expenditure of heat generators (significant point-type investments), rewarding, as part of the investment premium formula structure, implementation of investments of energy undertakings involved in heat distribution.
3. Power to Heat technology WACC	Coverage of the justified costs of business activity of energy undertakings in the scope of construction, upgrade and connection of generating units being renewable energy source plants should be remodeled so as to provide them with an opportunity to achieve higher values than the statutory minimum, thus giving a development impulse for renewable sources. We propose to adopt the minimum WACC for Power to Heat technologies at the level not lower than 7% plus the premium for heat generation from RES in accordance with proposal No. 1 from the table.
4. Exemption of heat pumps up to 20 MW from tariff approval requirement	Taking into account the expected level of increase in the share of renewable sources in the district heating sector, it is necessary to consider introducing preferential operating conditions for such units, in particular as regards exemption of heat pumps up to 20 MW from tariff approval by the President of the ERO.
5. Tariff regime for heat storage facilities (daily and seasonal)	The role of heat storage (daily and seasonal) – which, with the increased role of renewable sources in the network, will be an important element stabilizing its operation – seems underestimated. The impulse for energy undertakings to invest in heat storage is to enable the establishment of their tariffs on the cost basis. It should also be possible to trace back heat generated from RES and introduced into the district heating network from the storage as a RES heat volume.
6. Reduction of the distribution tariff for electricity for the Power to Heat technologies	An important element in the structure of justified costs is the costs related to the purchase of electricity. It is therefore particularly important to introduce a system which, through dynamic distribution tariffs, will allow for an additional reduction of LCOH. The reduced tariffs would cover Power to Heat plants above 0.5 MW, and support would consist in lowering the electricity distribution tariff for the first few years of operation of the plant.
7. Ensuring a long-term stable level of cost from capital in the heat tariff for investments in Power to Heat plants	The cost of capital as a derivative of WRA is high in the initial lifetime of the investment, and decreases with accumulated depreciation. This has a negative impact on the price level for the end customer in the initial lifetime. It should be possible to negotiate with the ERO a long-term fixed amount of the cost of capital that would provide the same NPV of return as the traditional path (decreasing cost of capital due to increasing depreciation and decreasing WRA over time). This fixed path would be covered by the long-term guarantee of the ERO as to the method of its calculation.

8. Change in fees for water services for heat pumps	It is necessary to clarify the applicable regulations to indicate clearly that the discharge (into surface waters) of water used in heat pumps is not subject to a variable fee which depends on its temperature (exceeding the temperature of 26°C of the discharged wastewater). In cases where the temperature of the river water drawn is so high that, despite being routed through the heat pump, it will not be cooled down below 26°C, the company has to incur additional costs. In such cases, the "polluter pays" principle would be violated, as the heat pump operator would be obliged to pay an increased fee for tort unrelated to their business. In practice, this would mean turning off heat pumps in situations where they could actually support water cooling.
9. Making the variable fee for heat pumps dependent on the amount of energy drawn (not consumed) by water-based systems	It is necessary to consistently make the variable fee dependent on the amount of energy drawn (not: consumed, as under the currently applicable regulations) by systems using water drawn, used and then discharged to water or the same aquifer in the same amount and not deteriorated quality, except for the change of its temperature, and for non-returned process water drawn and not directly intended for heating or cooling. This proposal is in line with the Water Framework Directive – compensation for water services should be granted only for the environmental resources used. If this provision is made more specific, it will further promote the use of energy-efficient equipment.

Thanks to the implementation of the above-mentioned regulatory changes, favorable legal conditions would be created to accelerate the use of Power to Heat technologies in system district heating in Poland.

7.4. Method of calculating the volume of heat from RES

The provisions of sections 1a and 1b in Article 116 of the Act on renewable sources implemented regulations on the method of calculating the amount of aerothermal, geothermal, hydrothermal or ambient energy captured by heat pumps, which constitutes energy from renewable sources.

A detailed description of the methodology for calculating the amount of renewable energy is contained in the Commission Decision of 1 March 2013 establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council (as amended). The Commission Decision does not include default values for HHP and SCOP for heat pumps based on ambient energy.

Given the interpretation doubts about calculation of the amount of renewable energy, the recommended solution is to implement national regulations in the above-mentioned scope. This will also make it possible to correctly include it in the report on the district heating or cooling system submitted by March 31 each year to the President of Energy Regulatory Office and the Minister competent for energy.

7.5. A broader view of the decarbonization process

Despite the fact that the purpose of this analysis is only to analyze the potential and conditions of development of specific technologies allowing for heat generation from RES, a key condition for effective implementation of the process of decarbonization of system district heating in Poland is that all parties participating in the heat market should be involved in this process, as individual actions implemented depend on each other. The burden of transformation should not only be borne by heat producers, which could result from the basic requirement related to the need to change the energy mix in district heating systems, but also by district heating network operators (adaptation to the change of the heat-carrying medium parameters) or final consumers (activities involving thermal performance improvement of buildings and retrofit of consumer systems), which in total will impact the optimization of decarbonization costs, affecting, among others, the level of heat demand or whether they allow for the most efficient transmission and distribution of heat with reduced parameters. An important role in the process will also be played by decision-makers, who can largely support the decarbonization of the system district heating sector by implementing regulations improving the implementation of investment processes on such a large scale and adapting technical requirements to the applied technological solutions.

8. Case study in the form of reference scenarios for district heating systems with different capacities

The purpose of the following case study is to present the possibility of using Power to Heat in three existing district heating systems that differ in size, i.e. small, medium and large system. In each case, the transformation of the current systems was analyzed in the context of meeting the regulatory requirements, including in particular new criteria for efficient district heating systems, while maintaining continuity of heat supply and local conditions.

The possible investment scenarios presented below lead to the achievement of the status of an efficient district heating system, which in consequence reduces the risk of disconnecting customers from the district heating network to generate heat from their own sources. At the same time, they are beneficial from the point of view of the system heat consumers, as they allow to ensure optimization of heat prices. Moreover, the implementation of the investment project would have a positive impact on the natural environment due to the reduction of carbon dioxide emissions and other harmful substances generated during combustion of fossil fuels.

Case study results may be useful in the context of formulating investment plans for the transformation of district heating systems in terms of exploiting the potential of the Power to Heat technologies.

8.1. District heating system in Kraków – PGE Energia Ciepła S.A.

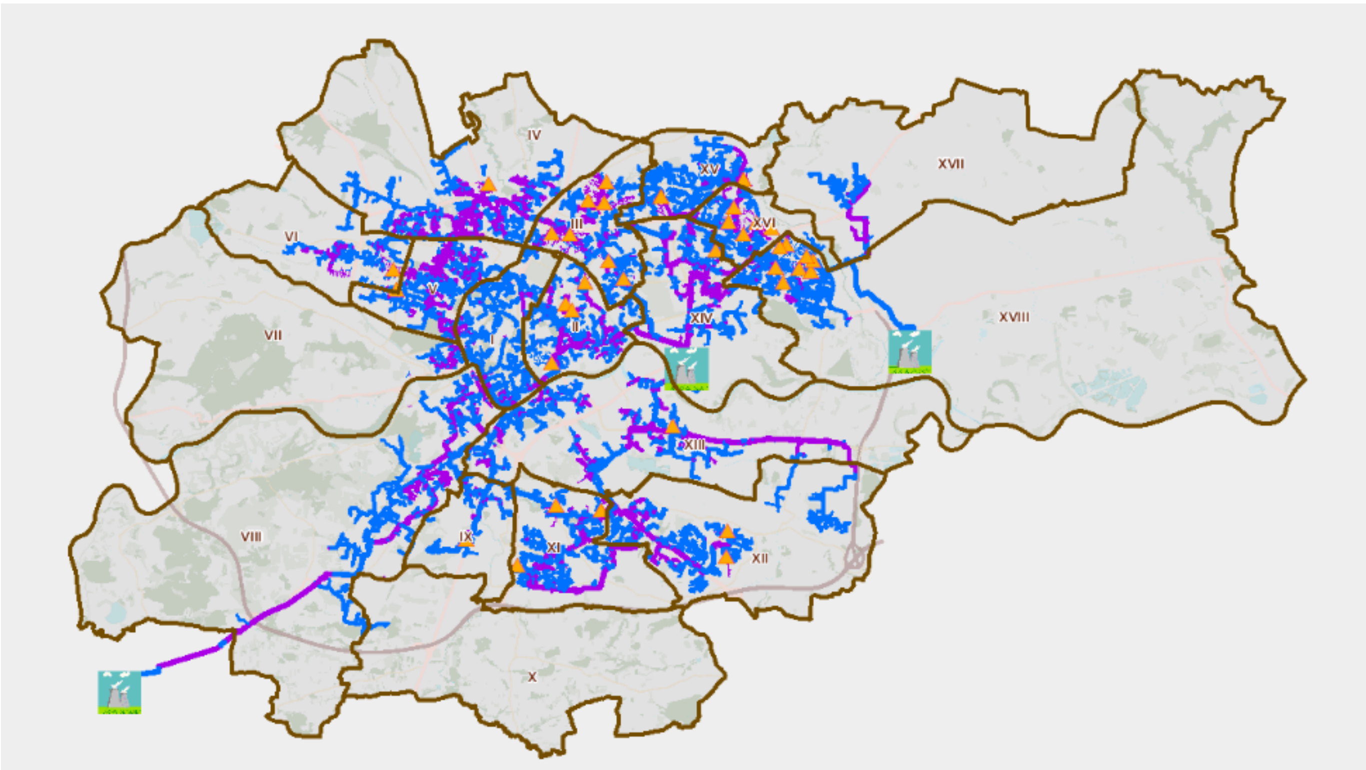
NOTE: the prepared case study should not be treated as the adopted asset transformation plan in Kraków and as the final and most optimal study from the point of view of selection of generation units. The purpose of this analysis is to indicate clearly the positive impact of increasing the share of P2H units on the set economic evaluation criterion, i.e. LCOH.

General description

The city of Kraków is located in the southern part of Poland, in the Małopolskie Voivodeship. Its latitudinal stretch is approx. 18 kilometers, while the longitudinal stretch is approx. 31 km. The area of the city is 327 km^2. The city's population is 706,065[33]. The heat demand of the city of Kraków is satisfied with district heat, local boiler houses and individual heat sources. The district heat distributor in Kraków is Miejskie Przedsiębiorstwo Energetyki Cieplnej S.A. (hereinafter referred to as: MPEC). The district heating system covers the area of the City of Kraków and Skawina and ensures heat supply to approx. 65% of the residents in the territory of Kraków.

The length of the district heating network is 929.3 km, of which more than 60% is made using pre-insulated pipes. The system contains approx. 6,000 district heating chambers, 3 facilities ensuring maintenance of medium pressure and 45 automated group heat exchanger stations. The contracted power in 2023 amounted to 1,742 MW.

Figure 30. Map of the district heating network in Kraków and locations of central heat sources and heat exchanger stations. Sections of the district heating network made in pre-insulated technology are marked in blue, and the sections of the district heating network made in pre-insulated technology are marked in violet color.



The heat suppliers to the municipal district heating system in Kraków are three companies (data for 2022):

- PGE Energia Ciepła S.A. (hereinafter referred to as PGE EC) – 68.8% share of energy supplied on the district heat market,
- CEZ Skawina S.A. – 22.7% share of energy supplied on the district heat market,
- Waste to Energy Plant (hereinafter referred to as: WTE Plant) – 8.5% share of energy supplied on the district heat market.

Heat is distributed through the municipal district heating network owned by MPEC, in which hot water is evacuated from the PGE EC source through the following district heating mains: eastern, western, northern and southern one by means of heating water mixing chamber. The areas of system supply from individual sources are determined by the distributor and due to the specificity of the WTE Plant operation (base operation) they are different during the heating season and outside of the heating season. Electricity is directed to the national power system. Figure 30 present an overview structure of the division of the areas of supply of the municipal district heating network from the installed generating units in the heating season and outside of the heating season.

The total sale of heat to final consumers in the area covering the municipal district heating network in Kraków is as follows:

MSC	Jedn.	2016	2017	2018	2019	2020	2021
Kraków	GJ	8 809 680	9 978 951	9 508 130	9 459 322	9 750 900	11 068 707

Currently, hard coal is the dominant fuel in the structure of heat generation to the municipal district heating network in Kraków (approx. 90% of the heat generation stream). 9% of the heat is generated from municipal waste, while 1% is generated by other energy sources, including renewable energy sources and fuel oil.

Currently, the Kraków branch of PGE EC is equipped with 4 power units with hard coal firing: two BC-90 extraction condensing steam power units No. 1 and No. 2 and two BC-100 extraction back-pressure power units No. 3 and No. 4, capable of generating thermal power to the network of 2 x 158 MW_t and 2 x 191 MW_t respectively. On the premises of the Plant, there is also a load back-up boiler house (hereinafter referred to as KRS), including water boilers fired with light oil operating during the peak heat demand period from the maximum power output up to 280 MW_t.

The source is additionally equipped with a heat accumulator with an operating capacity of 18,000 m^3, which cooperates with coal -fired power units. In the future, it is planned to ensure the possibility of cooperation of the existing heat accumulator with the planned generating units installation, including P2H units.

In order to fulfill the regulatory obligations and given local conditions, the transformation of the district heating system in Kraków may involve the use of the potential of P2H units for heat generation. Two wastewater treatment plants are located in Kraków, and due to qualitative and quantitative parameters, municipal wastewater may constitute a stable lower heat source. Moreover, it is possible to use the potential of energy accumulated in river water from the Vistula river outside of the period with a limited temperature parameter.

As there is no complete information on the intentions of all entities participating in the Kraków heat market, the analysis covered the source belonging to PGE EC together with the current power supply area of the municipal district heating

33 Source: https://www.bip.krakow.pl

34 Data for 2023.

network. For the sake of simplicity, the analysis assumes that market shares will not change in the following years.

Currently, as part of the project appointed at PGE EC, a phased transformation of the source of Kraków CHPP is under implementation. The first project stage assumes the construction of a gas cogeneration unit with a power of approx. 50 MW_t and a renewable energy source unit based on heat pumps with a lower heat source in river water from the Vistula river. Due to the need to ensure continuity of heat supplies, this process must start with the construction of new sources, temporary parallel operation with the current gradual phase-out of coal-fired units until they are completely replaced with new ones. Subsequent stages of the retrofit of generating assets in Kraków CHPP are still being analyzed in line with the changing regulatory and market environment. However, in each of the currently analyzed transformation options, the decommissioning of the current coal-fired units is planned in 2028 (BC1, BC2 and KW5) and 2030 (BC3 and BC4). As part of the next stages in 2028–2030, the construction of further sources is planned, including new peak load sources in the form of electrode water boilers as well as gas-fired boilers. The power distribution between technologies treated as peak heat generation sources will depend on the connection possibilities on the part of the Distribution Network Operator.

For the purpose of this report, it is assumed to present theoretical options, the implementation of which may contribute to increasing the power in Power to Heat units in the mix of technologies used in Kraków CHPP. Therefore, the options presented in the case study in question assume increasing the use of units using electricity for heat generation in order to examine their impact on the LCOH value for the leading heat source in one of the largest district heating systems in Poland. The presented options are compared to the scenario assuming restoration of generating power in Kraków CHPP by means of natural gas and partially biomass.

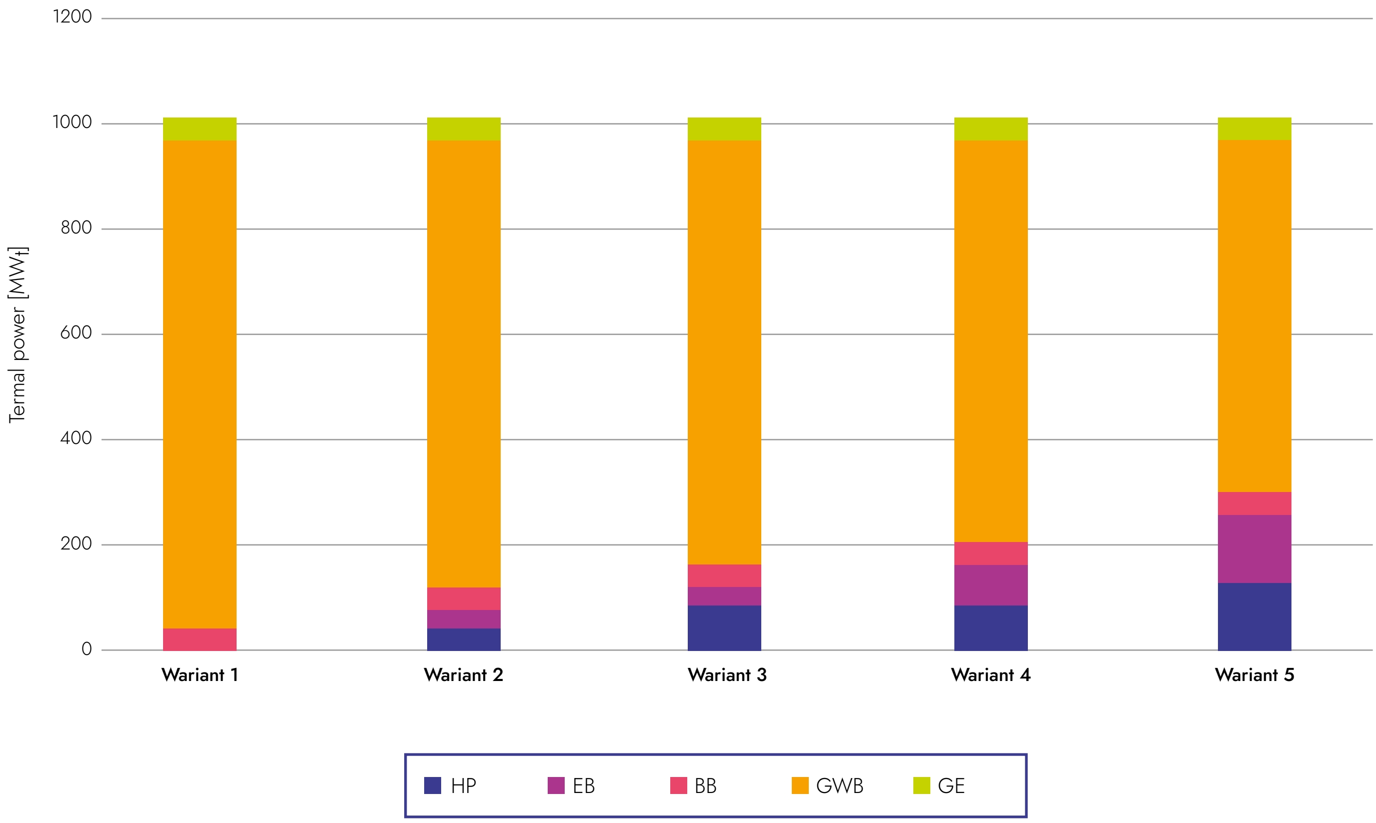
BASIC ASSUMPTIONS FOR THE ANALYSES

For the purpose of the analyses, the following assumptions were made:

- Decommissioning of all coal-fired units in Kraków CHPP by the end of 2026;
- The accumulator shall cooperate with new P2H units; it is not assumed to modify the process system, including in particular the accumulator power;
- In all scenarios, it is assumed that a 50 MW gas cogeneration source will be constructed and a 50 MW biomass-fired unit will be constructed;
- The gas cogeneration unit described above won the cogeneration auction in December 2023 and receives support for high-efficiency cogeneration;
- The contracted power (1,015 MW) will be filled to the forecast level using gas-fired water boilers;
- The obligations under the provisions of Article 26 of the EED (definition of an energy-efficient system) for the power supply area of Kraków CHPP may be met by changing gaseous fuel to green gas or by ensuring that all electricity supplying P2H units comes from RES energy;
- CAPEX/OPEX values for technologies described in the case study correspond to PTEZ (Polish Association of Utility CHPs) benchmarks prepared for the purpose of this study;
- River water from the Vistula river is the lower source for the units of the renewable energy source based on heat pumps;
- Electrode boilers and heat pumps are supplied from the electricity distribution network;
- Gas units supplied from the gas network owned by the Gas Network Operator GAZ-SYSTEM;
- In order to simplify the analyses for all new units, the first year of operation was set to 2027 (gas engines, biomass boilers, heat pumps, electrode boilers and gas-fired water boilers).

Given the above assumptions, five theoretical options of Power to Heat development in Kraków Combined Heat and Power Plant were developed:

Figure 31. Power to Heat development options in Kraków Combined Heat and Power Plant



Option 1

is the reference option and shows the arrangement of equipment operation without Power to Heat: Gas engines – 50 MW_t and 50 MW_e, biomass-fired boilers – 50 MW_t and gas-fired water boilers – 915 MW_t

Option 2

shows the current plans for the use of Power to Heat in Kraków CHPP: Gas engines – 50 MW_t and 50 MW_e, biomass-fired boilers – 50 MW_t, gas-fired water boilers – 830 MW_t, heat pumps – 50 MW_t and electrode boilers – 35 MW_t

Option 3

assumes an increase in power output in heat pumps: Gas engines – 50 MW_t and 50 MW_e, biomass-fired boilers – 50 MW_t, gas-fired water boilers – 730 MW_t, heat pumps – 100 MW_t and electrode boilers – 35 MW_t

Option 4

assumes power increase in heat pumps and electrode boilers: Gas engines – 50 MW_t and 50 MW_e, biomass-fired boilers – 50 MW_t, gas-fired water boilers – 715 MW_t, heat pumps – 100 MW_t and electrode boilers – 100 MW_t

Option 5

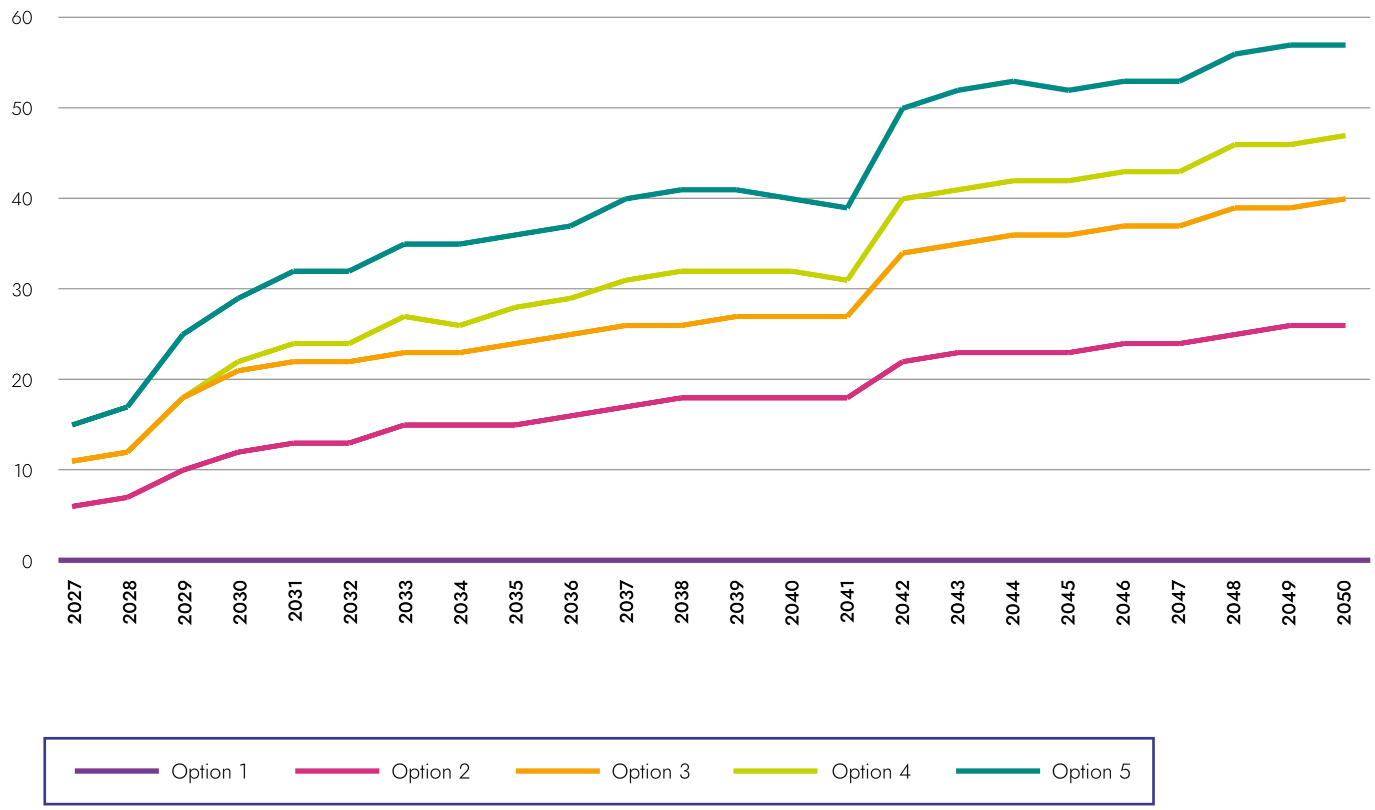
assumes the highest power increase in heat pumps and electrode boilers: Gas engines – 50 MW_t and 50 MW_e, biomass-fired boilers – 50 MW_t, gas-fired water boilers – 615 MW_t, heat pumps – 150 MW_t and electrode boilers – 150 MW_t.

The stacks of equipment prepared in such a manner for individual options were subjected to the technical and economic model, which determined with hourly resolution the most favorable generation scenario in terms of unit heat generation cost in a given hour.

The diagram below shows a gradual increase in the share of Power to Heat in heat sales of Kraków CHPP, which is caused by the following factors:

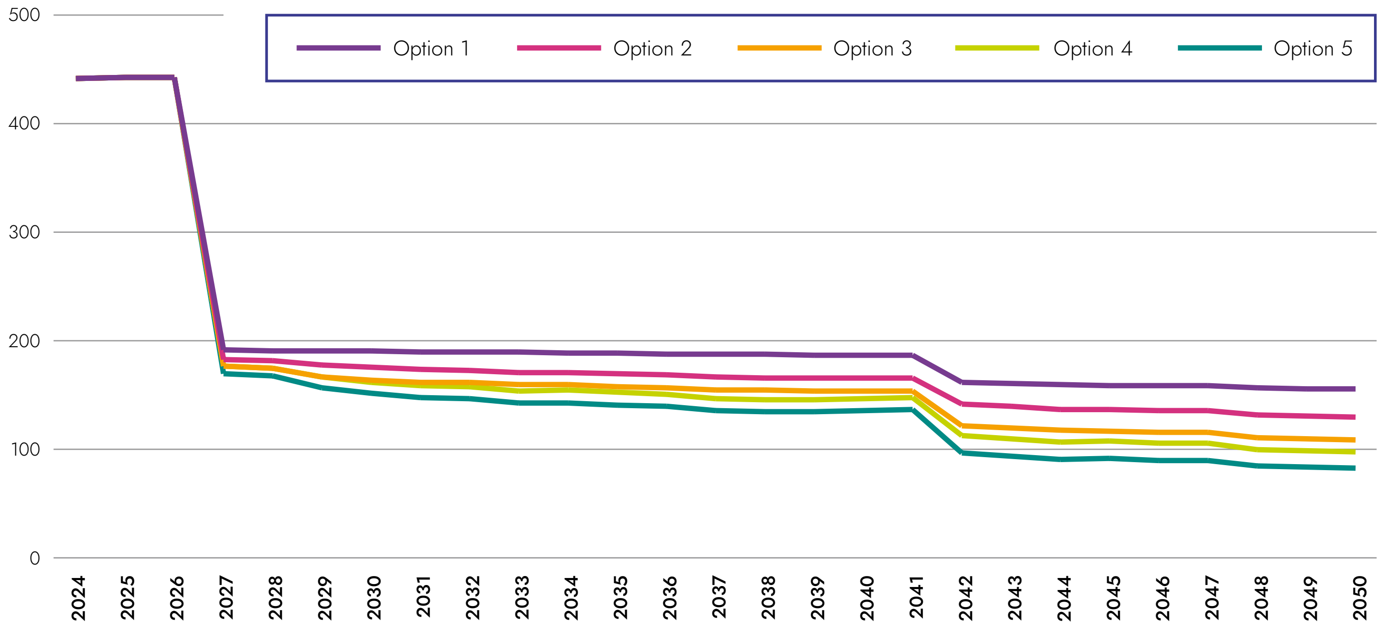
- Gradually decreasing cost of heat generation on heat pumps in relation to other technologies,
- Gradual increase in heat demand in the market base, caused by a forecast increase in domestic hot water demand,
- After the end of receiving support for high-efficiency cogeneration (2027–2041), the cost of heat generation on heat pumps becomes much more competitive than generation based on gas engines, which results in additional release of the heat market for this technology,
- After 2030, more and more hours appear on the electricity market with a price allowing to start-up electrode boilers at a low heat generation cost. These sources may additionally stabilize the operation of the power system during periods of increased electricity generation from RES sources.

Share of P2H in heat sales of Kraków [%]



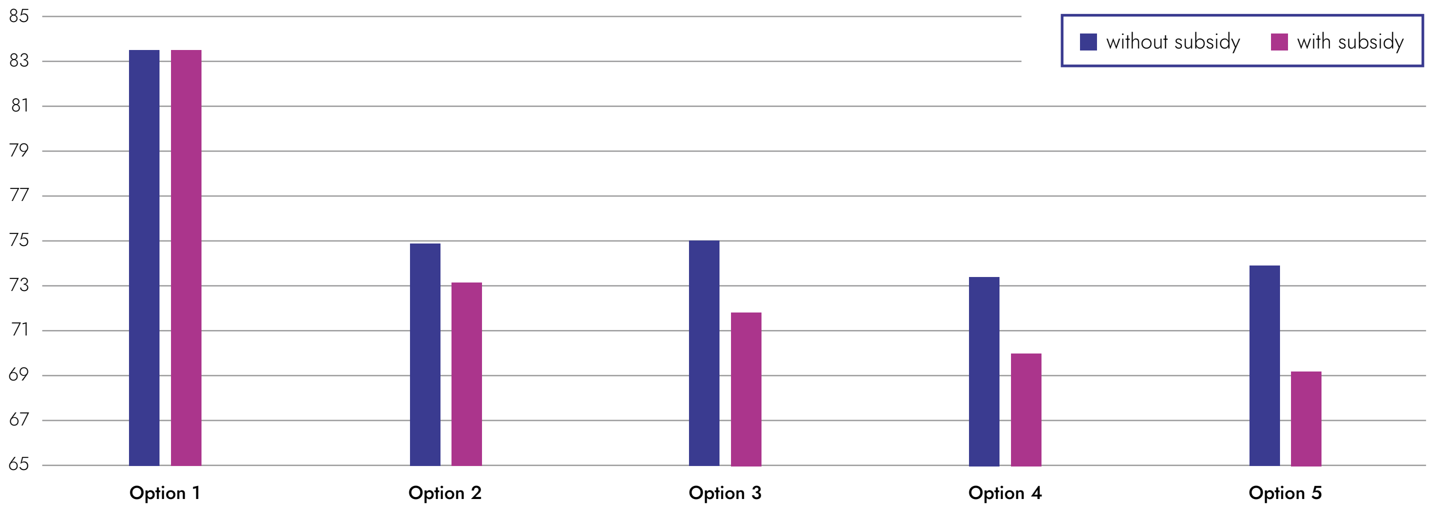
The effect of increasing generation from P2H sources will also lead to a greater reduction in the CO_2 emission rate value:

CO_2 emissions [kg/MWh]



Translating the above effects into the development of the LCOH value, which reflects both the operational and capital cost of heat generation, it can be concluded that the application of the P2H technology – despite higher capital expenditures – allows for a noticeable reduction of the heat price. This effect further increases the possibility of obtaining a subsidy for heat pumps (the analysis assumes a subsidy of 45% of CAPEX), which will not only allow to increase the investment possibilities of the heat generating plant and combined heat and power plant, but will also pave the way for lowering heat prices in the long term.

LCOH comparison [PLN'23/GJ]



8.2. Large district heating system – Łódź. Veolia Energia Łódź S.A.[35]

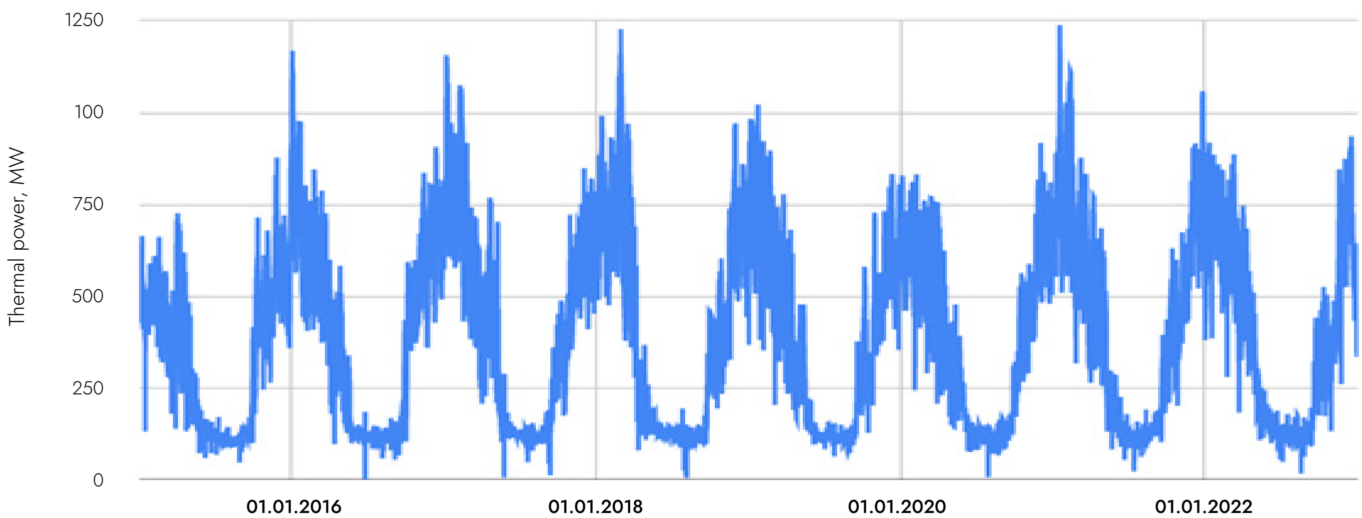
NOTE: This material shows one of the considered decarbonization scenarios for the Łódź district heating system.

General description

A subsidiary – Veolia Energia Łódź S.A. – owns and operates the district heating network and two combined heat and power plants supplying it in Łódź – EC3 and EC4. The network consists of over 860 km of pipework, heat mains, distribution and connection networks in Łódź and Konstantynów Łódzki. There are over 10,000 DH substations, 1,400 chambers and 3 pumping stations within the network. In EC3 there are 5 pulverized coal-fired steam boilers, one water boiler and a steam generator fired with light fuel oil. In EC4, there are 2 coal-fired steam boilers, 1 biomass-fired steam boiler, 1 light fuel oil-fired steam boiler (steam generator) and 3 coal-fired water boilers. Achievable thermal power EC3 (instantaneous) is 504 MW and achievable EC4 is 876 MW.

The diagram below shows the heat demand in the entire Łódź district heating network over the last few years.

Figure 32. Diagram of variability of thermal power demand in the district heating network in Łódź



Despite the projected decrease in heat demand, the trend is ±0 MW_t – new customers are connected, modernization is performed, some customers disconnect, but demand remains constant. Such an assumption was adopted for the purpose of this study.

BASIC ASSUMPTIONS FOR THE ANALYSES

Veolia Energia Polska's project on developing decarbonization and climate neutrality concepts developed over ten scenarios for retrofitting the district heating system of the city of Łódź. The following section presents one of them, using Power to

35 Based on a study prepared by Energopomiar Sp. z o.o. for Veolia

Heat technology – "Medium" scenario – SE.

The medium scenario (SE) included the following aspects:

- decommissioning of all coal-fired units in 2030 is a necessary condition (coal exit 2030);
- obtaining the status of an efficient district heating system is required;
- compliance with EU taxonomy regulations (Article 4.30 of the EU regulation on taxonomy of high-efficiency co-generation units).

In the SE scenario, due to the "coal exit 2030" requirement, it was assumed that the generating units will be operated with coal until the end of 2029 at the latest. From 2030, this fuel will be completely abandoned.

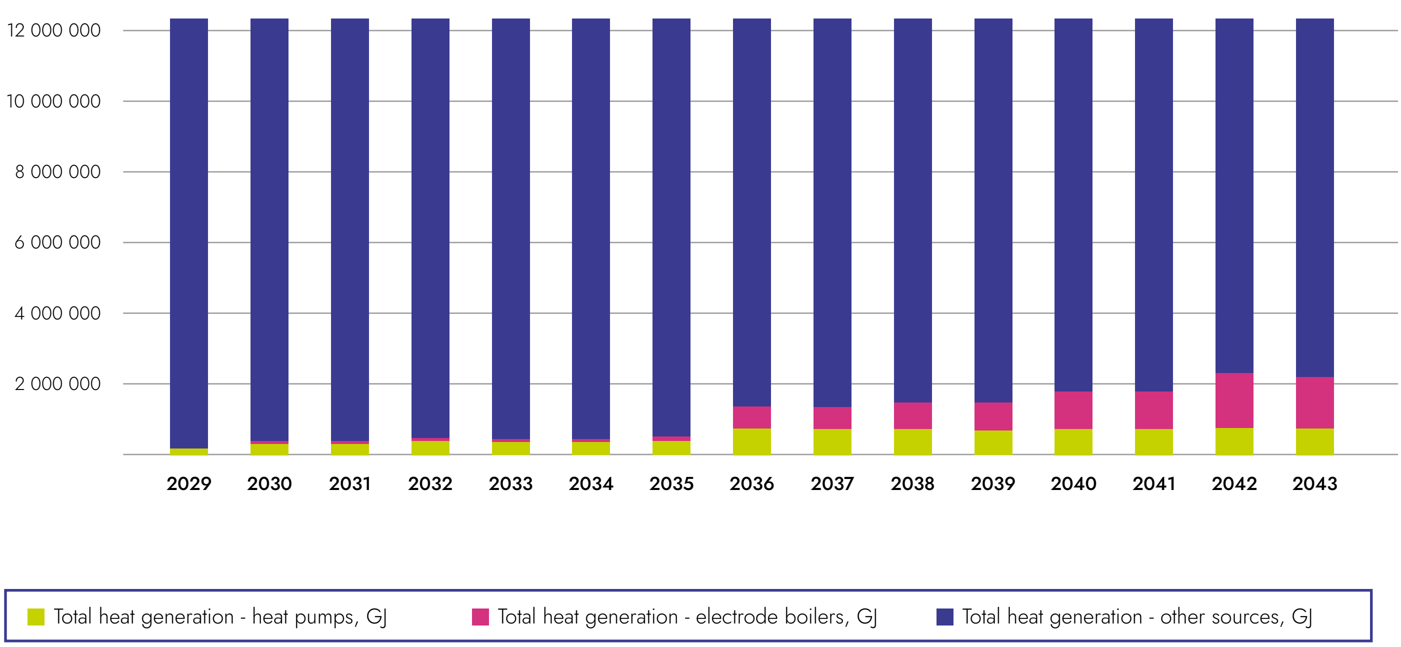
GENERAL ASSUMPTIONS FOR THE SE SCENARIO:

- Decommissioning of coal-fired power units at EC3
- Construction of 2 x EC3 electrode boilers, 35 MW_t each
- Construction of power units for CHP gas engines at EC4 with thermal power output of 170 MW_t
- Construction of the Energy Recovery Facility at EC4 with power output of 57 MW_t
- Conversion of the coal-fired boiler (EC4) into pellets
- Construction of 2 x EC4 electrode boilers, 35 MW_t each
- Biomethane combustion in gas units from 2036 (Taxonomy requirement).
- Heat recovery (wastewater, industry) – construction of heat pumps with a total power output of 35 MW_t.
- CAPEX/OPEX values for technologies described in the case study correspond to the benchmarks of the Polish Association of Utility CHPPs prepared for the purpose of this study.

The total planned installed power in Power to Heat technologies is ultimately 175 MW_t for this scenario.

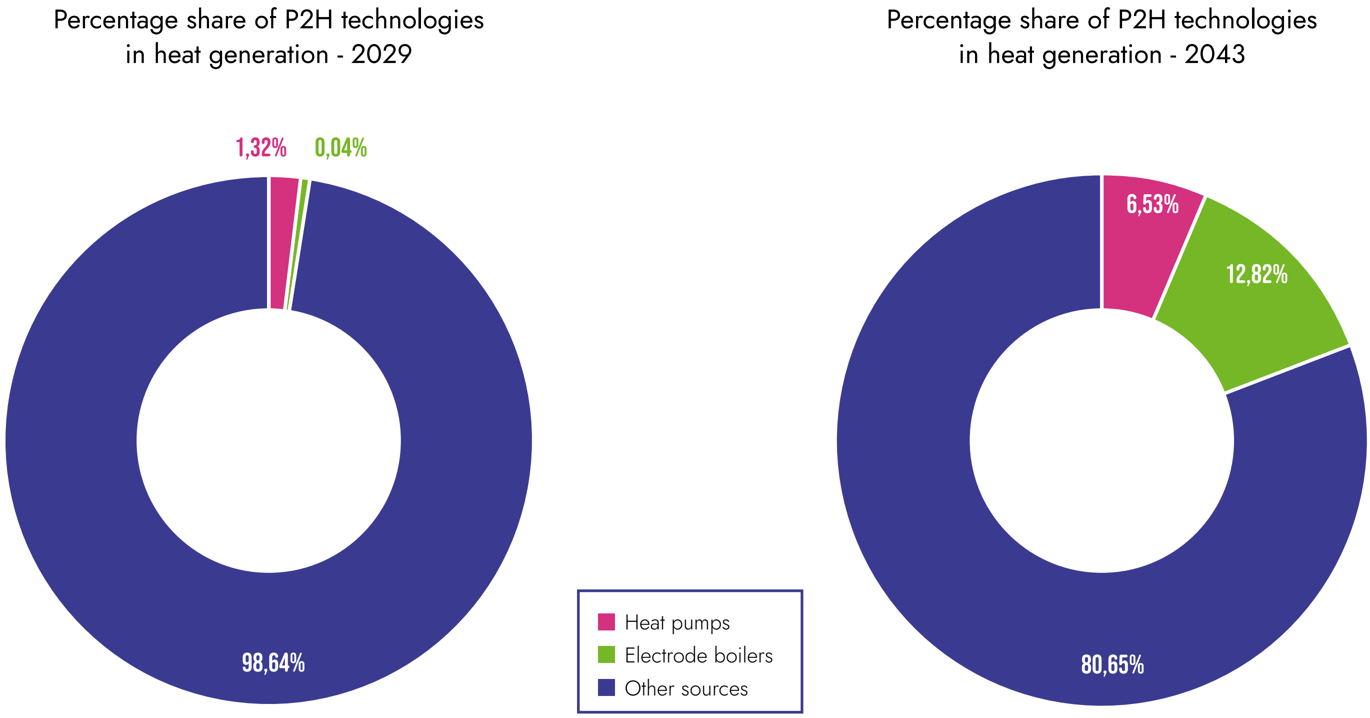
The table below presents the suggested configuration of operation of individual pieces of equipment in this scenario in each year of the analysis. [2] The share of the use of Power to Heat technologies in the forecast heat generation, in this scenario from the introduction of their use, i.e. from 2029 to 2043, amounts to:

Figure 33. Share of P2H technologies in heat generation from the moment of their introduction into the generation mix, for the SE scenario



The comparison below shows how the share of Power to Heat technologies increases in the discussed scenario in the first year of their introduction into the generation mix and the target year of the analysis, i.e. 2043.

Figure 34. Comparison of the percentage share of P2H technologies in heat generation between the first year of their introduction into the generation mix and the last target year of the analysis for the SE scenario



In the SE scenario, apart from the heat pump installed in the Water and Sewer Company (heat recovery from wastewater) and heat pumps recovering heat from industry (located in the southern part of the city 2 x 5 MW_t – one near Konstantynów Łódzki, the other in the southeastern part of the city), all generating units are located at the EC3 and EC4 plant.

8.3. District heating system in Siemianowice Śląskie – TAURON Ciepło sp. z o.o.

NOTE: The project presented in this material is at the stage of analyses and no decisions have been made, at the moment of preparation of this report, to commence its implementation in the assumed scope. Therefore, the described project should currently be treated only as a concept.

General description

The project, which is the subject of this study, refers to the local district heating plant supplying the "island" district heating system operated by TAURON Ciepło sp. z o.o. in the area of the city of Siemianowice Śląskie.

The Bańgów District Heating Plant is located in the northern part of the city of Siemianowice Śląskie, on an area of approx. 13,800 m^2, in the close vicinity of the "Bańgów" mine shaft owned by the Mine Restructuring Company, which is currently used to pump out the underground water.

The location of the above-mentioned facilities is shown in the photo below.

In the past, at the "Bańgów" District Heating Plant, there was a coal-fired boiler house in operation, which was fully replaced with gas-fired boilers (container-mounted) – currently, the district heating plant consists of three gas-fired boilers (with a total power output of 7 MW_t), constituting the exclusive power supply source for the local district heating system.

Based on the available data (applicable to 2022), it should be indicated that the length of the heating season in the case of the location in question was approx. 235 days (average ambient temperature during this period is 3.5°C). The annual heat generation reached the level of 34.4 TJ, with contracted power of 3.8 MW. The highest generation was recorded in January – 5099 GJ, while the lowest heat demand occurred in August, when 1089 GJ was generated. Thermal power of the boiler house outside the heating period (domestic hot water only) is approx. 450–550 kWt, while peak instantaneous power reaches 2.75 MW_t.

It should be noted that the Company identifies the potential for development of the local heat market, which is reflected in the forecast increase in contracted power.

Figure 35. Location of the facilities in the area of Siemianowice Śląskie[36]

36 TAURON Ciepło sp. z o.o.

BASIC ASSUMPTIONS FOR THE ANALYSIS

The assumed transformation process of the "Bańgów" District Heating Plant would consist in the construction of a heat generation plant using, on the one hand, solar radiation energy (PV farm) and, on the other hand, waste energy from the dewatering system of the inactive mine ("Bańgów" shaft). The construction of the above-mentioned source – cooperating with the existing gas-fired boiler house – would make it possible to meet, in the case of the above-mentioned location, the criteria for an energy-efficient district heating system. Therefore, it should be stressed that achieving the status of an efficient system by the district heating system in question is one of the main assumptions underlying the development of the project concept.

The planned process system would include:

- two heat pumps with a power output of 1.2 MW_t each;
- a photovoltaic farm with a power output of approx. 0.7 MWp, located on the ground surface of approx. 8,200 m^2;
- a two-line pipeline supplying the plant with mine water extracted from a nearby shaft of an inactive mine and returning water after use;
- necessary construction infrastructure;
- service lines, valving and systems ensuring cooperation with the existing gas-fired boiler house and district heating network, as well as the power network;
- control and automation systems with necessary software.

It is assumed that the primary source of power supply for heat pumps will be energy from the PV system, in the second place it will be electricity from the network, whereas the gas-fired boiler house will make up the entire system during periods of lack of power and/or temperature medium of the heat-carrying medium (lower heat source).

The key operational parameter of the new source would be to maximize generation of energy qualified as RES. It was assumed that the generation of heat from "green" energy is to achieve a share of more than 50% of the total energy directed to the local district heating system, thus achieving the status of an energy-efficient system.

As a result of the project implementation, power generation at the District Heating Plant would take place in three ways:

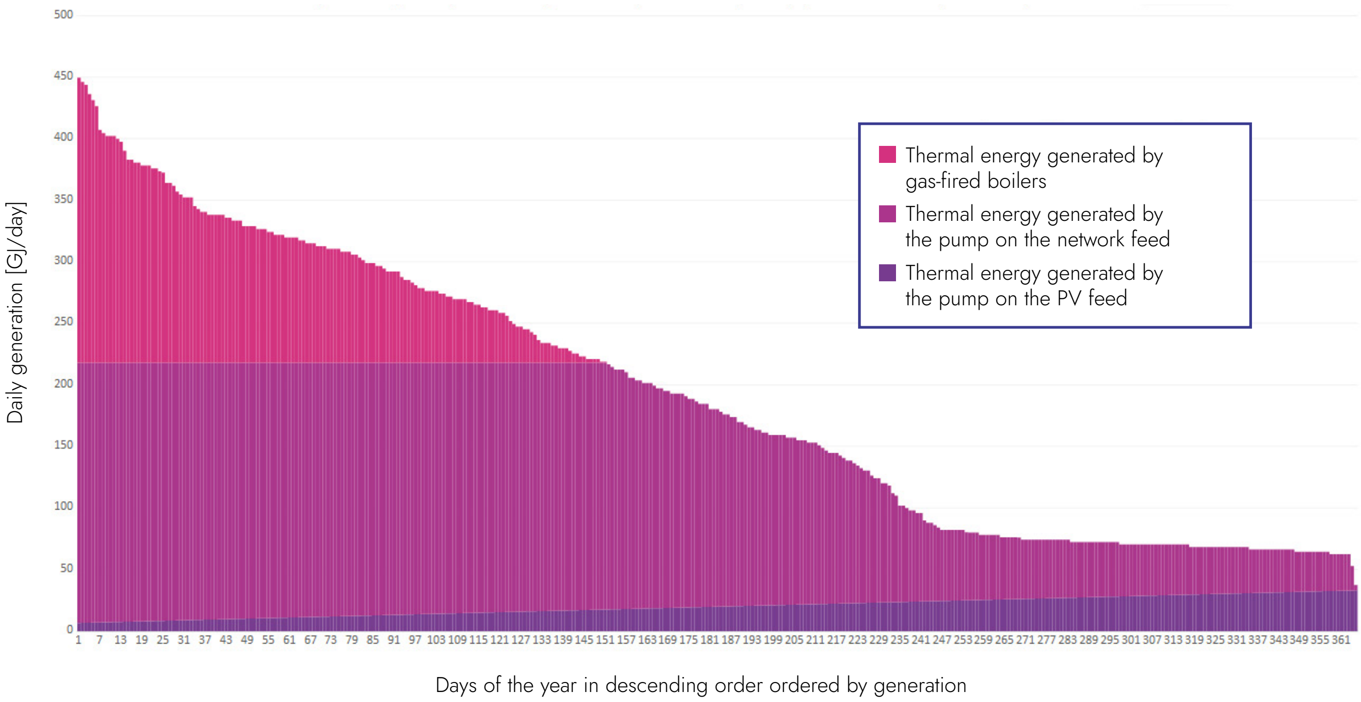
- generation by heat pumps on the PV farm feed;
- generation by heat pumps on the network feed;
- generation by gas-fired boilers.

In the scope of heat pump operation, on the PV farm feed, approx. 10–11% of thermal energy directed to the network will be generated on average annually. It was assumed that this energy would be 100% qualified as coming from RES (solar radiation). Therefore, such generation would have an absolute priority over the other forms of generation listed above. The PV farm power was selected so that in the summer period, during peak hours of solar energy supply, the generation of heat pumps on the PV feed would not exceed the network's heat demand for domestic hot water preparation.

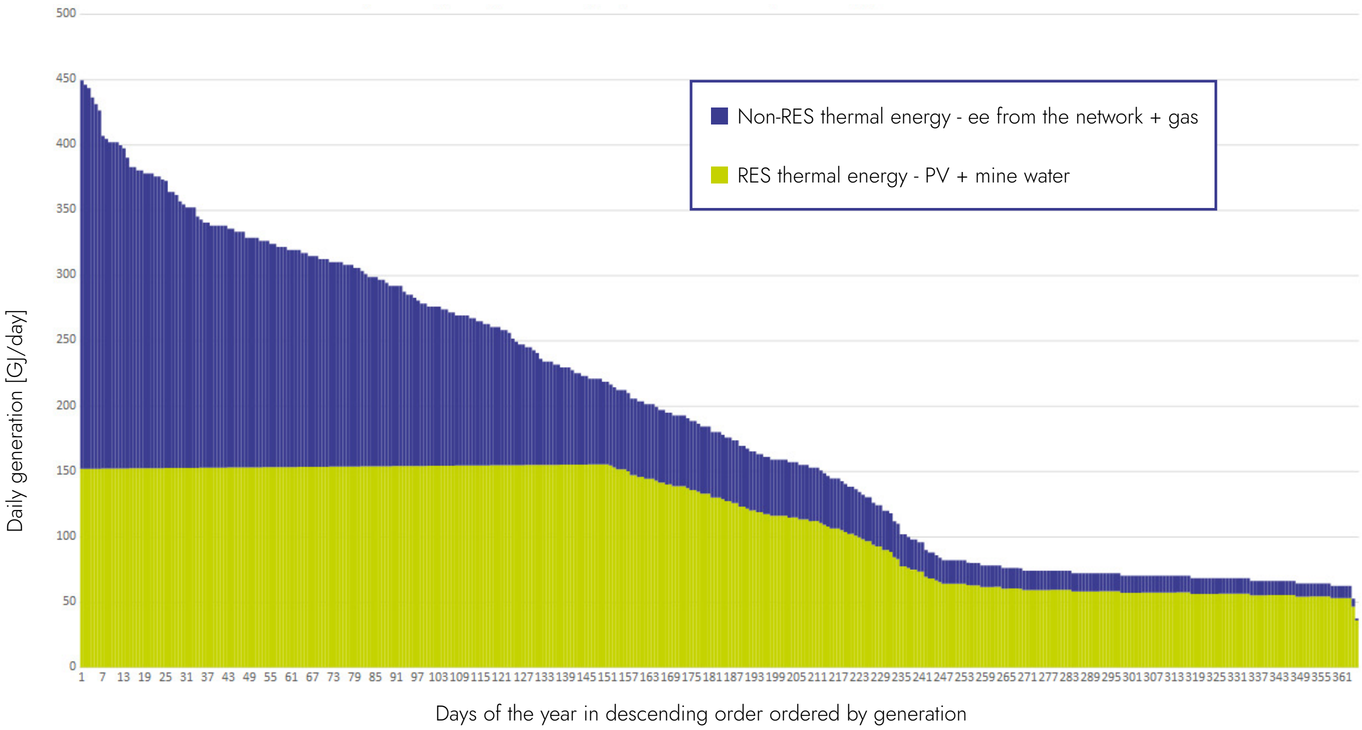
Regarding the operation of heat pumps on the network feed, heat generation of up to about 70% of the network's annual demand would be possible. However, it should be noted that such a type of operation would not provide heat entirely from the RES, because only in the part which in the energy balance of the pumps constitutes the lower source, we can speak of RES, and this – with the COP index of 3.21 – will constitute approx. 47% of heat introduced into the network. To sum up, the maximum level of heat supply to the network that could be ensured from generation qualified as RES may amount to 57% per year (the remaining part is electricity supplying heat pumps and a container gas-fired boiler house).

The duration curves below show daily energy demand, with an indication of the estimated share of the above types of generation and the share of "clean" RES.

Duration curve - annual distribution of generating unit operation



Duration curve organized by RES and non-RES generation



Conclusions of the analyses

As part of the preparation of the concept of transformation of the "Bańgów" District Heating Plant, four variants based on heat pumps were analyzed (in economic and technical terms) in order to select an optimal solution, the application of which would allow to obtain the RES share in the district heating system in question at the level of at least 50%.

1. HEAT PUMP WITH LOWER SOURCE IN THE FORM OF RIVER WATER + PV FARM
2. HEAT PUMP WITH LOWER SOURCE IN THE FORM OF RIVER WATER + SOLAR SYSTEM
3. HEAT PUMP WITH A LOWER SOURCE IN THE FORM OF MINE SHAFT WATER + PV FARM
4. HEAT PUMP WITH LOWER SOURCE IN THE FORM OF MINE SHAFT WATER + SOLAR SYSTEM

The conducted analysis showed that the implementation of the first two options would not allow the district heating system to achieve energy-efficient status, as the share of heat qualified as RES was below 50%. The other two options (i.e. 3 and 4), in turn, allow to meet the criteria set out in the definition of an efficient district heating system. It should be emphasized that the key issue when selecting the option was the economic aspect – as part of the conducted analysis, each option was compared in terms of its profitability. As a result of the profitability analysis, option No. 3 turned out to be the most advantageous one.
Additionally, it is worth noting that in the case of the option assuming the use of mine shaft water, a stable temperature can be expected, which would allow to obtain a higher COP index.
In the case of the lower source in the form of river water, the analyses should take into account temperature variability and temporary limitation of the possibility of using such water in the period of too low temperatures.

Estimated budget of the potential project

Based on assumptions made in the PTEZ Report regarding the unit CAPEX index for heat pumps, it was estimated that the total budget of the project in question would be at the level of approx. PLN 17.5 million, whereas the cost of heat pumps (including a complete system, required valving, service lines, control system and other elements necessary for operation) would amount to approx. PLN 13.2 million. In the context of the source of financing investment expenditures, it was initially assumed that such a project could be co-financed from the aid funds under the available support programs (e.g. FEnIKS or Priority Program "RES – heat source for district heating").

Main stages of potential project activities

The main investment process stages related to the implementation of the project are presented below, together with their approximate duration:

- development of a comprehensive feasibility study – 6 months;
- preparation of the procurement procedure for the development of design documentation – 3 months;
- development of design documentation by the contractor (together with obtaining all required consents and administrative permits) – 9 months;
- preparation and execution of the procurement procedure for civil works and delivery of equipment – 5 months;
- civil works including delivery and erection of equipment – 18 months;
- commissioning, tests and final acceptances – 3 months.

9. Appendices to the main part of the report

9.1. Appendix No. 1. Key programs and sources of investment support for projects in the field of heat generation from RES in Poland (extended version)[37]

EUROPEAN FUNDS FOR INFRASTRUCTURE, CLIMATE, ENVIRONMENT 2021–2027 (FENIKS) – PROJECTS IN THE FIELD OF GENERATING SOURCES

Key types of investment eligible for support	As part of FENX 02.01 Action District heating infrastructure co-financing may be used both for projects related to generation sources and projects related to investments in district heating networks. In the case of generating sources – support may be obtained for projects concerning high-efficiency cogeneration (in particular based on renewable sources) and energy storage facilities. Support for electricity and heat storage facilities will also be possible as stand-alone investments (to the extent permitted by state aid regulations), although preference will be given to combining the source and storage in a single project. FENX.02.02 Action RES development supports renewable energy sources for the generation of electricity or heat. Support also covers various types of heat pumps, including those cooperating with heat distribution units (systems of hybrid heat distribution units). For heat generation plants, the minimum plant power eligible for support shall be: ■ **biomass:** over 5 MW_t, ■ **solar radiation:** over 0.5 MWh, ■ **geothermal energy (including heat pumps):** over 0.5 MWh, ■ **biogas:** over 0.5 MWh[38]. An energy storage facility may be an element of the project.
Program/source of support budget	The planned allocation of funds for FENX 02.01 Action District heating infrastructure is EUR 1,183 million. The planned allocation under FENX 02.02 Action RES Development is EUR 538 million.
Existing/expected form of support	According to the information available, in the case of investments under FENX 02.01 Action: ■ **in the case of RES and high-efficiency cogeneration** – the support is to take the form of a mixed instrument in the form of a loan (from 51%) and a subsidy (up to 49% of the support amount). Under FENX 02.02 Action, the form of support may be mixed, comprising, in a single operation, a subsidy and a loan; it is assumed that: ■ **in the case of solar and wind energy –** a loan (85%) and subsidy element in the form of redemption (up to 15% of the amount of support granted); ■ **in the case of other RES, –** a loan (from 51%) and a subsidy (up to 49% of the aid granted).
Timeframe / key criteria/ conditions	The program is implemented within the framework of the EU's 2021–2027 financial perspective (MFF – multiannual financial framework). The period of expenditure eligibility is January 01, 2021 – December 31, 2029. In the case of competitions under the FEnIKS Program, the key ranking criterion will be the readiness to implement the project (understood as having a set of consents and permits).
Form and dates of recruitment	The recruitment shall be carried out mainly in the form of a competition (applications shall be submitted to NFOŚiGW). According to the recruitment schedule (of April 26, 2024), the specific date of the competitions, for the final beneficiaries of the support, for generation source projects under FENX 02.01 Action and for FENX.02.02 Action (except for the recruitment for biomethane projects) is not yet known.

37 Own study

38 Due to the demarcation introduced, as part of European funds programs for 2021–2027, RES with power below the above-mentioned thresholds are eligible for co-financing under regional level operational programs (regional operational programs), the implementation of which is the responsibility of local governments of individual voivodeships. Support shall also be provided through financial instruments.

NFOŚIGW PRIORITY PROGRAMS: "COGENERATION FOR DISTRICT HEATING" / "POVIAT CO-GENERATION" (FUNDS FROM THE MODERNIZATION FUND).

Key types of investment eligible for support	Support for part 1) of the "Cogeneration for District Heating" Program covers the construction and/or alteration of high-efficiency cogeneration units with total installed power not less than 10 MW, together with their connection to networks, in which energy generation uses, among other things: ■ energy from renewable sources, ■ waste heat, ■ gaseous fuels. For part 2) of the "Cogeneration for District Heating" Program, the minimum installed power of the plant eligible for support is 1 MW_t (RES-based sources, waste heat or gaseous fuels). In the case of the "Poviat Cogeneration" Program, investments concerning the construction and/or alteration of co-generation units with a total installed power of not less than 1 MW shall be supported (based on RES, waste heat or gaseous fuels). An element of the project scope may be a heat storage facility and a connection to the public district heating network owned by the project beneficiary.
Program/source of support budget	The budget of the "Cogeneration for District Heating" Program amounts to PLN 3,000,000 thousand, of which for ■ **non-repayable forms of co-financing** – up to PLN 1,500,000 thousand; ■ **for repayable forms of co-financing** – up to PLN 1,500,000 thousand. The budget of the "Poviat Cogeneration" Program amounts to PLN 100,000 thousand, of which PLN 500,000 is in the form of a subsidy and PLN 500,000 is in the form of loans.
Existing/expected form of support	Subsidies and/or loans are forms of co-financing (one or both forms of support may be applied for). Subsidies may amount to up to 50% of eligible costs; loan support may amount to up to 100% of eligible costs. The interest rate on the preferential loan is WIBOR 3M + 50 bp, not less than 1,5% per annum (no margin is applied for the "Poviat Cogeneration" Program); The loan may be granted for a period of up to 15 years calculated from the date of the scheduled disbursement of the first tranche of the loan to the date of the scheduled repayment of the last principal installment. The grace period may be maximum 12 months from the date of completion of the investment project. The loan shall not be redeemed.
Timeframe / key criteria/ conditions	The programs are implemented in the period 2022/2023–2030; the funds will be spent by December 31, 2030. The beneficiaries of the "Cogeneration for District Heating" Program may be enterprises conducting business activity in the field of energy generation, with installed thermal and/or electric power of energy sources of not less than 50 MW, implementing a project as part of the district heating system, with contracted thermal power, as of the date of application, not less than 50 MW (in the case of part 2) of the Program – the requirement for the power of generation sources for which economic activity is carried out does not apply). In the case of the "Poviat Cogeneration" Program, projects may be implemented in district heating systems with con-tracted power not exceeding 50 MW. Plants of which at least 70% of useful heat are eligible for co-financing generated in a RES unit in a calendar year shall be introduced to the public district heating network. Aid (in all forms) per project must not exceed the notification threshold (for high-efficiency cogeneration projects, this threshold is currently EUR 30 million).
Form and dates of recruitment	The recruitment is carried out continuously until the funds are exhausted, subject to the NFOŚiGW announcing sub-sequent editions (according to the information published by NFOŚiGW, the next recruitments under both programs are to be announced in June 2024 and will last until the end of November – for the "Poviat Cogeneration" Program / beginning of December 2024 – for the "Cogeneration for District Heating" Program).

NFOŚIGW PRIORITY PROGRAM "RES – HEAT SOURCE FOR DISTRICT HEATING" (FUNDS FROM THE MODERNIZATION FUND)

Key types of investment eligible for support	Support shall include investment projects concerning the construction and/or alteration of sources with a total installed power of at least 2 MW_t (the minimum power of the constructed/extended RES may not be lower than 2 MW_t), which use energy from the following sources to generate thermal energy: ■ heat pumps, ■ solar collectors, ■ geothermal energy. An element of the project scope may be a energy storage facility and a connection to the public district heating network owned by the project beneficiary.
Program/source of support budget	The budget for the purpose of the program is up to PLN 2,000,000 thousand, including: ■ **for non-repayable forms of co-financing** – up to PLN 1,430,000 thousand; ■ **for repayable forms of co-financing** – up to PLN 570,000 thousand.
Existing/expected form of support	Co-financing may be provided in the form of a subsidy and/or a loan. The total amount of investment project co-financing may not exceed 70% of eligible investment project costs. The co-financing in the form of a loan amounts to up to 70% of the eligible costs. The co-financing in the form of a subsidy amounts to up to 50% of the eligible costs. The conditions and financial parameters of the loan are generally the same as in the case of the "Cogeneration for District Heating" Program.
Timeframe / key criteria/ conditions	The program will be implemented in 2023–2030, whereas the funds will be spent by December 31, 2030. High-efficiency cogeneration projects, including ORC technology, are not eligible for co-financing under the Program. Plants of which at least 70% of useful heat are eligible for co-financing generated in a RES unit in a calendar year shall be introduced to the public district heating network.
Form and dates of recruitment	The recruitment is carried out on a continuous basis until the funds are exhausted, whereas the current edition of the recruitment takes place on April 16, 2024 – December 17, 2024.

NFOŚIGW PRIORITY PROGRAM "ENERGIA PLUS" (ENERGY PLUS)

Key types of investment eligible for support	In the scope of generating infrastructure, the support includes: projects concerning the construction or alteration of generating units with their connection to the distribution/transmission network, which use the following for energy generation: ■ energy from renewable sources, ■ waste heat, ■ heat from cogeneration excluding heat generated in the unit coal-fired cogeneration, ■ low-emission gaseous fuels, gas mixtures, synthetic gas or hydrogen.
Program/source of support budget	The budget for the implementation of the entire program (covering also other thematic parts/components) is up to PLN 4,000,000 thousand, including: ■ **for non-repayable forms of co-financing** – up to PLN 50,000 thousand ■ **for repayable forms of co-financing** – up to PLN 3,950,000 thousand.
Existing/expected form of support	Currently, the only form of support is a loan in the amount from PLN 0.5 million to PLN 500 million. The co-financing in the form of a loan may amount to up to 85% of the eligible costs. The interest rate on the preferential loan is: WIBOR 3M + 50 bp, not less than 1.5% per year. The loan may be granted for a period of up to 15 years calculated from the date of the scheduled disbursement of the first tranche of the loan to the date of the scheduled repayment of the last principal installment. The preferential loan may be partially redeemed in the amount of up to 10% of the disbursed loan amount, but not more than PLN 1 million.

Timeframe / key criteria/ conditions	The program will be implemented until 2030. The period of expenditure eligibility shall cover the period from January 01, 2015 to September 30, 2030.
Form and dates of recruitment	Currently, the fourth call for applications conducted by NFOŚiGW is in progress – the call deadline is December 13, 2024 (or until the allocation of funds is exhausted).

FUNDS FROM NATIONAL RECOVERY PLAN (KPO)

Key types of investment eligible for support	As part of the KPO, it is planned, among others, to support projects in the scope of construction of heat sources for the needs of district heating systems (B1.1.1 Investments in heat sources in district heating systems). Projects in the scope of RES plants, heat pumps and high-efficiency cogeneration are to be co-financed. As part of the KPO, it is also planned to launch an instrument – the Energy Support Fund (G3.1.4 Support for the national power system), under which it is assumed that financing may be obtained, among others, for projects in the field of RES development in district heating. KPO – loan for the Green Transformation of Cities (B3.4.1 "Investments for a comprehensive green transformation of cities")
Program/source of support budget	The assumed budget for the implementation of B1.1.1 investment project is EUR 300 million. The amount of funds under the Energy Support Fund is expected to be EUR 17,068,511,631. The budget of the instrument is EUR 8,879 million.
Existing/expected form of support	Support under item B1.1.1 Investments in heat sources in district heating systems are to be provided in the form of subsidies. The Energy Support Fund will provide long-term loans to finance investment projects in the scope of extension of energy or district heating networks, RES, RES-integrated storage facilities, energy efficiency, decarbonized gases and decarbonization of the energy sector. The entity responsible for the implementation and granting of the above-mentioned instrument will be BGK. The conditions for granting a loan shall be determined taking into account the limitations resulting from the General Block Exemption Regulation (GBER). Loans under the Green Transformation of Cities will be granted to finance investments contributing to the reduction of the negative impact of people on the natural environment and leading to climate neutrality. The loan amounts may range from PLN 2 million to PLN 500 million with a payback period of up to 20 years and in some cases at zero interest rates. The instrument also provides for the possibility of redemption of up to 5% of the capital amount of the loan.
Timeframe / key criteria/ conditions	Projects will be selected in an open competition, taking into account the following criteria: (i) readiness and degree of preparation of the project for implementation; (ii) degree of reduction in CO_2 or PM2.5 and PM10 dust emissions; (iii) use of renewable energy sources; (iv) location in areas with the highest annual PM2.5 and PM10 emissions. Conclusion of loan agreements under the Energy Support Fund by August 2026. Details of the operation of the Energy Support Fund are to be specified in the investment policy. One of the requirements for obtaining financing will be the borrower's creditworthiness Conclusion of loan agreements as part of the Green Transformation of Cities by June 2026, use of funds by December 2027, project completion by December 2030. Loans are provided by Bank Gospodarstwa Krajowego (BGK). BGK does not grant, under the above-mentioned instrument, loans where their granting would involve public or de minimis aid.
Form and dates of recruitment	The call for applications under B1.1.1 investment project is likely to be launched in 2024. Planned date of implementation of the KPO loans from the Energy Support Fund – second half of 2024. The loan instrument under the Green Urban Transformation was launched in April 2024. Enterprises will be able to apply for the loan from April 01, 2025.

ADDITIONAL INFORMATION (OTHER SELECTED POTENTIAL SUPPORT INSTRUMENTS) / STATE AID

- Co-financing for investments in the construction of RES plants in district heating systems may also come from the funds of **the voivodeship funds for environmental protection and water management**, which entities support a series of types of projects implemented in the field of environmental protection and energy.
- If the **Energy Transformation Fund** is established (the draft act was not adopted in the previous term of the Sejm), the support from the above-mentioned source could be allocated, among others, to investments in the scope of extension and retrofit of district heating systems. Co-financing (mainly in the form of loans and subsidies) would be provided primarily under priority programs run by NFOŚiGW.
- The co-financing referred to in the table above constitutes state aid. Under the current state aid rules set out in European Commission Regulation No 651/2014 (GBER)[39], **for large enterprises, the maximum aid intensity for RES projects, including heat pumps, may be 45% of the eligible costs, which are investment costs;** in addition, as an alternative to the above method, the aid intensity may be up to 100% of the eligible costs where the aid is granted through a competitive bidding procedure. For heat storage facilities, the aid intensity **may be 30% of the eligible costs provided that** the storage facility is connected to a RES within a single investment project or the storage facility is connected to an existing plant.

39 The GBER was thoroughly amended in 2023 by Commission Regulation (EU) 2023/1315 of June 23, 2023, which entered into force on July 01, 2023.

9.2. Appendix No. 3. Financing of district heating investment projects – analysis for the project of construction of a new generation mix in a system with a peak demand of approx. 200 MW_t, using Power to Heat technologies

Key principles of investment project financing by banks

Banks assess investment projects in different ways and their approach may vary depending on the type of investment project, the strength and credibility of the investor, the borrower's ability to repay the debt incurred for the investment project, the financing conditions and the type and value of the collateral. In addition, as the system heat generation activity is generally a regulated business and largely provides services to sensitive consumers, the assessment of the commercial conditions of the project takes into account the social aspect, including security and the eradication of energy poverty. These are a few selected steps that banks take when assessing investment projects:

- **Project assessment** – banks analyze the investment project thoroughly. They verify whether it is based on realistic assumptions regarding the budget and investment project schedule, operational (e.g. forecasting of heat demand and appropriate sizing of the source as to power and generation profile), macroeconomic, financial assumptions, as well as assumptions regarding prices affecting revenues and costs. The project must comply with the regulations and requirements (including environmental requirements), which at this moment have been defined as applicable during the expected lifetime of the investment project. In addition, it must be viable, capable of generating stable cash flows available for debt servicing. It is also important to assess the selected heat generation technology (commercially proven efficiency, reliability and ability to ensure the required environmental effects) of its suppliers and contractors (experience, reputation, financial credibility, terms and conditions of the contract). Moreover, the project must have the required permits and access to the infrastructure (including in particular the required agreements or at least the connection conditions) and a known contractual structure with confirmed costs.

- **Investor assessment** – regardless of whether the investment project is carried out on a project finance or corporate finance basis, banks always assess the creditworthiness, experience and reputation of the investor. In the case of project finance, although the loan is usually repaid solely from the cash flows of the project itself, the investor's difficult financial, asset, legal or organizational situation may exclude the financing of a project with good cash flows. In the bank's assessment, the investor must be able to make its own contribution, cover any overruns in the project budget, ensure stable management of both the investment project process itself and operational process.

- **Assessment of local market prospects.** In the case of the district heating sector, it is important to assess the risk of a decrease in heat demand in subsequent years as a result of 1) higher average temperatures and shorter district heating season, 2) increasing energy efficiency of buildings (Energy Performance of Buildings Directive (EPBD)), 3) demographic phenomena – a decrease in population in a large number of Polish cities.

- **Market assessment** – in the process of assessment from a regulatory point of view, the risk of changes in the prices of sales of heat and electricity assumed in the financial model and changes in the prices of media (biomass, electricity, gas) is important. A key factor in assessing creditworthiness is to demonstrate that the project generates adequate cash flows to service debt. However, as mentioned in the introduction, banks will always assess the impact of the investment project on the level of the tariff. Too high assumed dynamics of the tariff increase will raise concerns of banks in the context of the feasibility of acceptance by the ERO and the potential risk of reducing the demand of consumers for heat (risk of switching to individual heating). As regards the market assessment, the bank also assesses the risk of competition from other heat suppliers and the risk of loss of consumers.

- **Assessment of assets and collateral** – in this case, the investor's right to dispose of the assets required to carry out the investment project, the absence of legal defects in these assets, their market value and the possibility of establishing loan repayment collateral on these assets shall be assessed.

- **Financing structure assessment** – the bank adapts the detailed financing conditions to the specificity and risk factors of the project. Key conditions include: the length of the funding period, the grace period for repayment of the capital, the requirements concerning the amount and manner of the own contribution, the key project cut-off dates, the debt servicing schedule, the level of monitoring indicators, collateral, dividend payment rules and the key commitments or constraints to be complied with by the borrower or the investor.

Only the most important aspects of the assessment are listed above, but each project is approached individually by banks in an effort to understand its specificities and environment.
The bank perspective for a hypothetical project of construction of a new generation mix in a system with a peak demand of approx. 200 MW_t (i.e. for a city of approx. 100–150 thousand inhabitants). The selection of equipment is coherent with the conclusions of this Report.

Example

- The purpose of the conversion is to verify the possibility of financing a hypothetical investment project consisting in adjusting the generation mix to the requirements of an efficient system with debt.
- Common technical and price assumptions prepared for the purpose of the Report were adopted for calculations.
- The assumptions made for the project and financing are described in detail below.

Hypothetical project assumptions

- Maximum system demand at peak, approx. 200 MW_t
- Annual base – approx. 20 MW_t
- Equipment (see Chart 6):
  - Heat pumps – 20 MW_t (base operation)
  - Gas engines – 15 MW_t (base operation in the second place)
  - Biomass-fired boilers – 10 MW_t (sub-peak)
  - Gas-fired boilers and electrode boilers – 175 MW_t (sub-peak) – the share of individual peak boilers will be selected so as to meet the growing requirements of an efficient district heating system[40]
- The heat prices were selected as follows:
  - For district heating assets, a cost tariff with a regulated level of return in accordance with the guidelines of the ERO,
  - For cogeneration units – simplified tariff forecast – current ERO reference price indexed by changes in the gas and CO_2 price component,
  - The average heat tariff price in 2030 is approx. PLN 168/GJ and increases in subsequent years (see Chart 5),
  - For comparison, average reference prices of heat sales (source: Information of the President of the ERO No. 16/2024 and 17/2024) amount to:
    - PLN 173.96/GJ for units fired with gaseous fuels (for cogeneration units, the reference index is 0.78)
    - PLN 103.09/GJ for RES units
    - The above rates shall be applied in heat tariffs approved by the President of the ERO after March 31, 2024.
- Project: 2025–2029
- Operation and repayment of the loan: 2030–2045
- Decreasing heat demand, as a result of which the project results deteriorate over time (see Chart 4).

Financing assumptions

- Financing period: 4 years of construction + 15 years of repayment
- Project financing
- Financing currency: PLN
- Variable interest rate based on 3M WIBOR rate
- Margin, arrangement fee level and commitment fee level – typical values were used for this type of projects
- Fixed capital installments have been assumed in the payback period (see Chart 2)
- Capitalization of interest during construction
- Assumed debt financing of 70% of CAPEX (see Chart 1)
- Minimum debt service ratio (DSCR): 1.4x

Conclusions

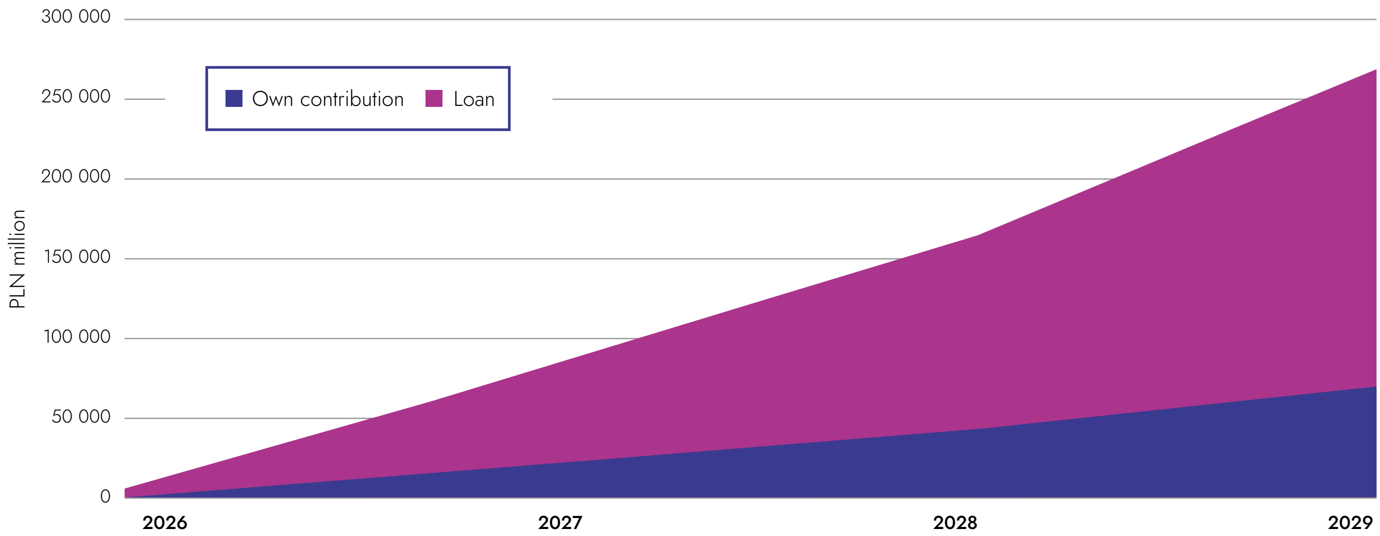
- With an assumed 30-percent own contribution, annual DSCR rates are above 1.40 over the entire financing payback period, which means that the project maintains its debt repayment capacity (see Chart 3).
- If heat prices in a given market as a result of implementation of the investment project program were to increase significantly, the banks would treat this as a significant regulatory risk and this may affect the financing decision.
- In the project financing model, any long-term agreements ensuring price predictability for deliveries of raw materials and sales of products will have a positive impact on the possibility of granting debt financing.
- Corporate financing would depend on the condition of the company carrying out the investment project program.

40 We assume that it will be possible to include green energy electrode boilers in the efficient system. Green heat can be generated by retrofitted hydrogen gas-fired boilers.

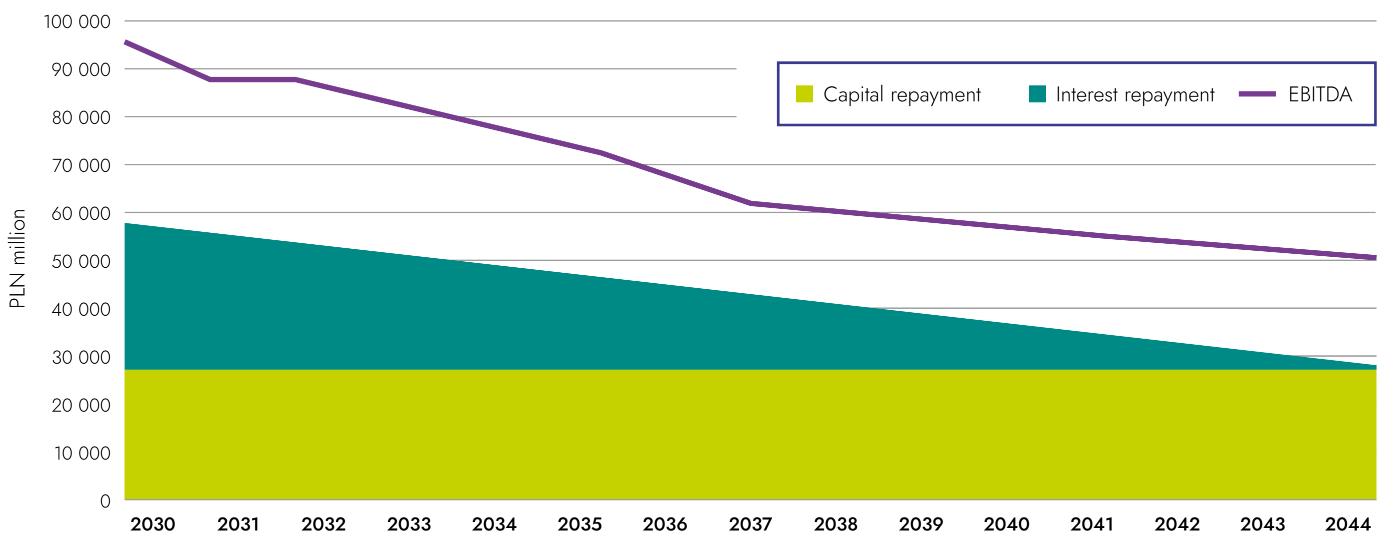
- The financing must take into account the decreasing volumes of heat sales over time. This may make it necessary to reduce the volume of debt.
- The possibility of financing will have to be verified by the banks on a case-by-case basis. Any deviations in the value of capital expenditures, heat price levels in a given market, shape of the heat curve in a given market, fuel and CO_2 price levels will affect the financing forecasts and financing parameters.

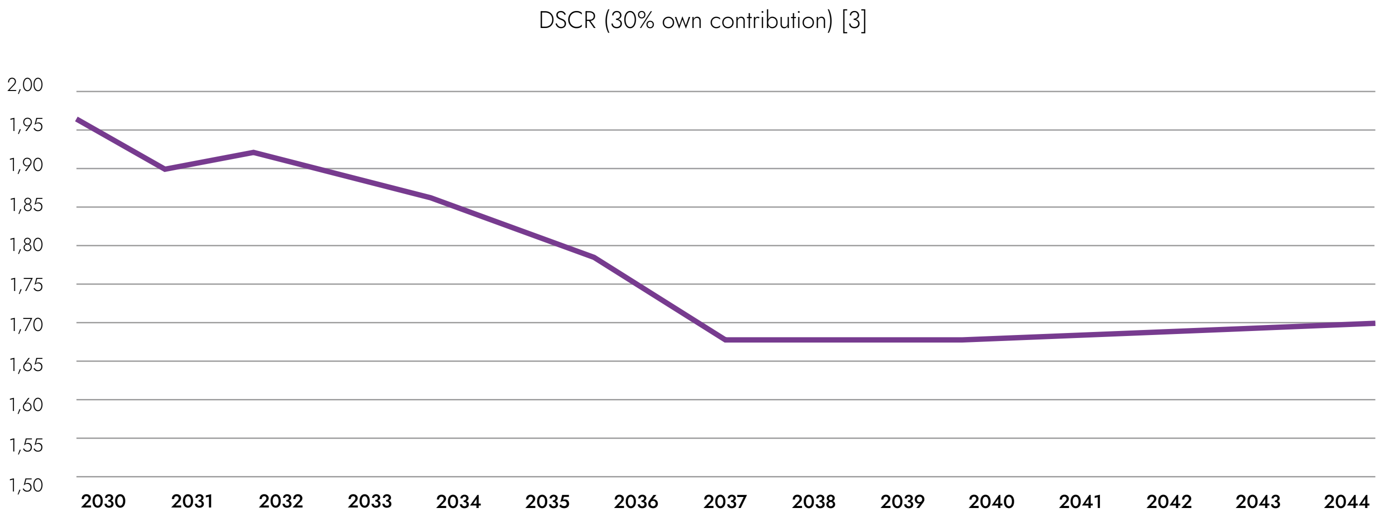
Charts

Financing capital expenditures [1]



EBITDA and loan servicing [2]




DSCR (30% own contribution) [3]
2,00
1,95
1,90
1,85
1,80
1,75
1,70
1,65
1,60
1,55
1,50
2030
2031
2032
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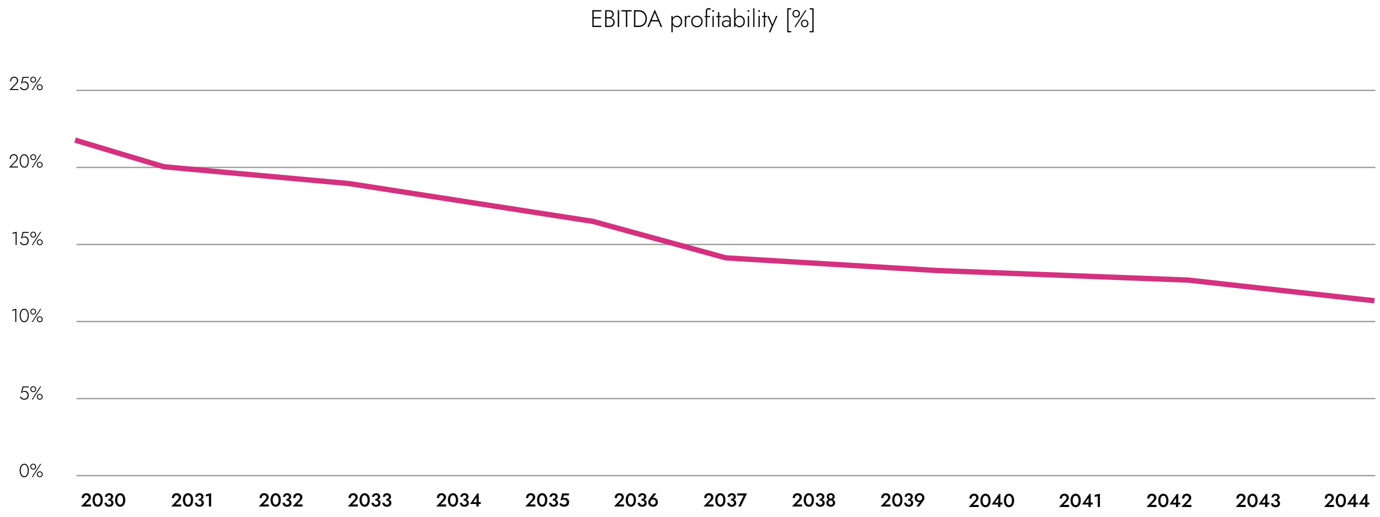
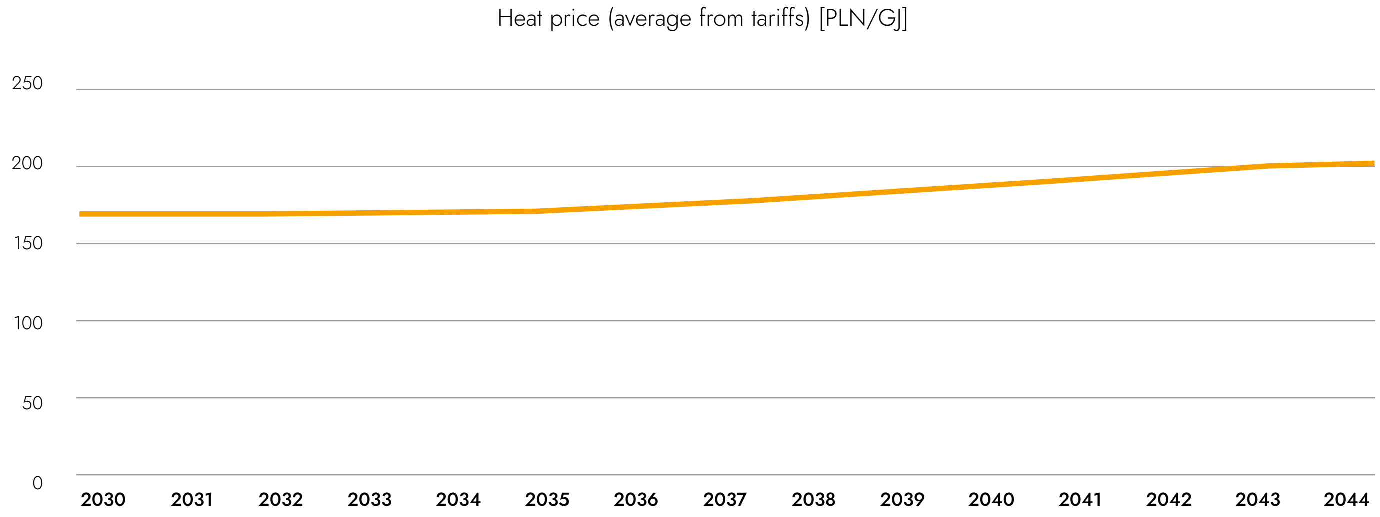
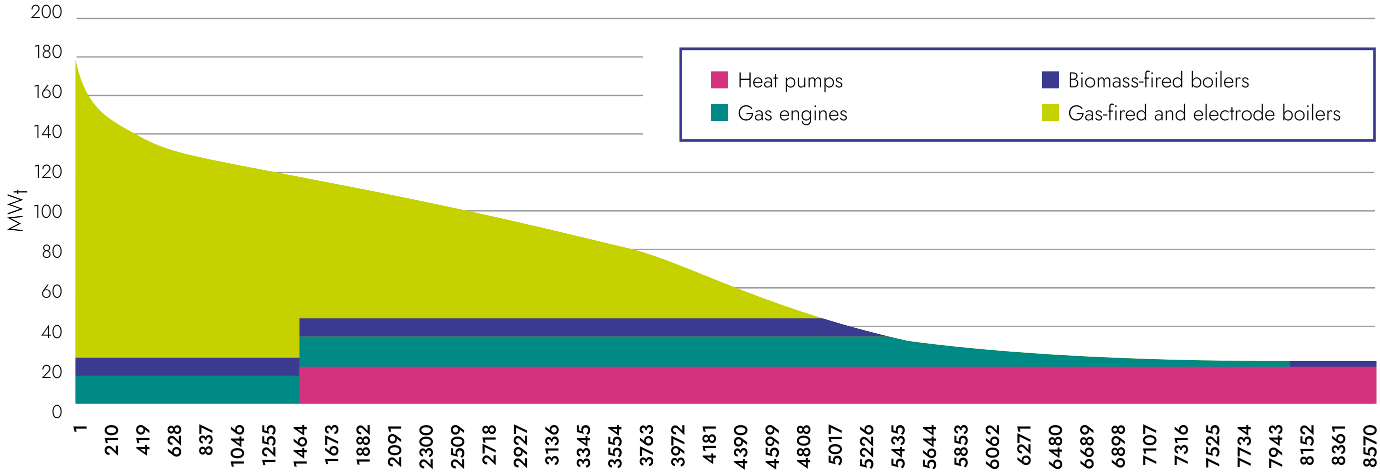

EBITDA profitability [%]
25%
20%
15%
10%
5%
0%
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044


Heat price (average from tariffs) [PLN/GJ]
250
200
150
100
50
0
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044

Ordered heat curve

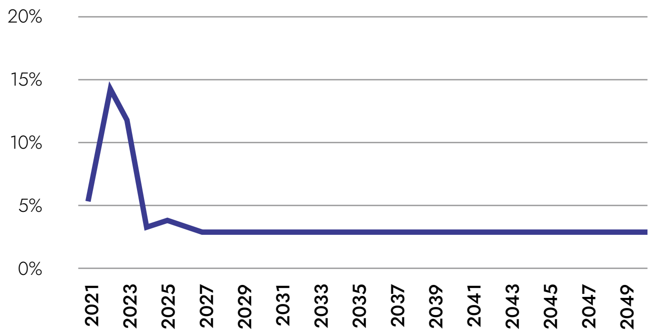


9.3. Appendix 3 Macroeconomic and market assumptions for the analysis in Chapter 6

Chart 1: EUR/PLN exchange rate

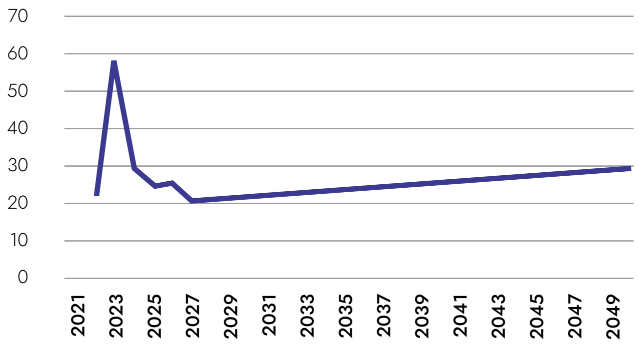
Źródło: opracowanie własne PTEZ w oparciu o Wytyczne Ministerstwa Finansów dotyczące stosowania jednolitych wskaźników makroekonomicznych, październik 2023 r.

Chart 2: CPI inflation forecast Poland



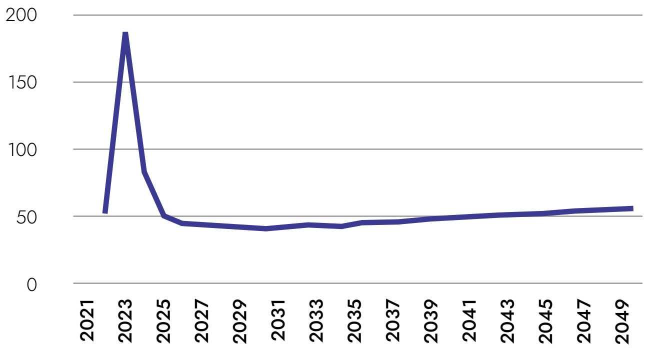
Źródło: opracowanie własne PTEZ na bazie danych Narodowego Banku Polskiego - Bieżąca projekcja inflacji i PKB (opublikowana 11 marca 2024 r.) oraz wytyczne Ministerstwa Finansów dotyczące stosowania jednolitych wskaźników makroekonomicznych, październik 2023 r

Chart 3: Hard coal price forecast [PLN'22/GJ]



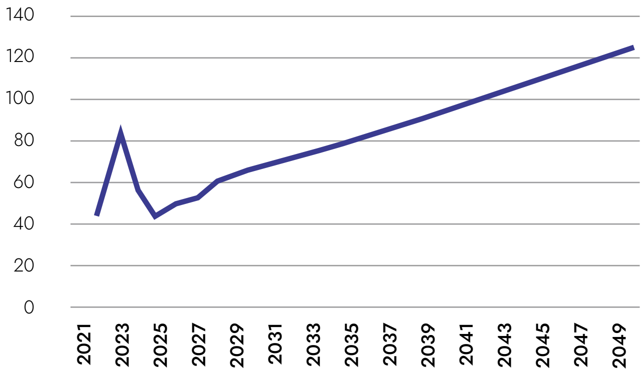
Źródło: opracowanie własne PTEZ na bazie bieżących notowań oraz raportu World Energy Outlook October 2023 - European Union; Stated Policies Scenario

Chart 4: Natural gas price forecast [PLN'22/GJ]



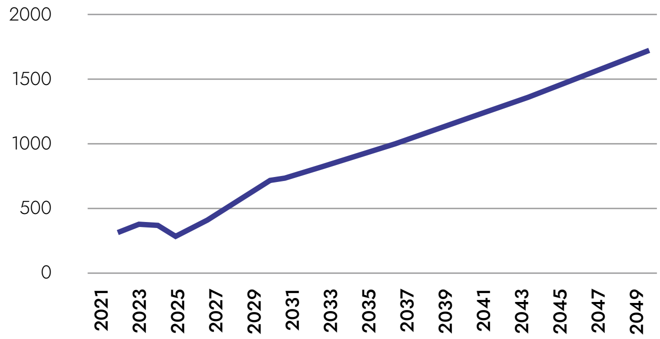
Źródło: opracowanie własne PTEZ na bazie bieżących notowań oraz raportu World Energy Outlook October 2023 - European Union; Stated Policies Scenario

Chart 5: Biomass price forecast [PLN'22/GJ]



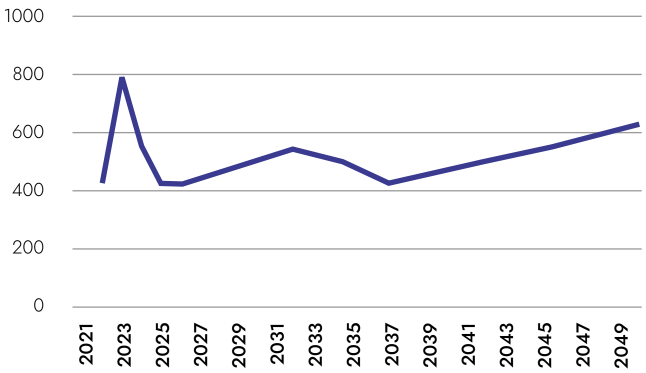
Źródło: opracowanie własne PTEZ w oparciu o dane dotyczące zawieranych kontraktów i prognozy cen biomasy Członków PTEZ

Chart 6: Price of greenhouse gas emission allowances [PLN'22/t]



Źródło: opracowanie własne PTEZ na bazie bieżących notowań oraz analiz World Energy Outlook October 2023 - European Union; Announced Pledges Scenario (APS) CO_2 prices for electricity, industry and energy production

Chart 7: Forecast of electricity prices on the wholesale market [PLN'22/MWh]



Źródło: opracowanie własne PTEZ na bazie przyjętych założeń kosztowych i założeniu marżowości rynku energii elektrycznej na poziomie 30 PLN'22/MW_h dla bardziej rentownej technologii spośród jednostek węglowych kondensacyjnych oraz nowych jednostek gazowych typu CCGT. Prognoza ceny energii elektrycznej w długim terminie uwzględnia przewidywane zmiany miksu paliwowego m.in. związane z rozwojem energetyki jądrowej oraz morskiej energetyki wiatrowej, a także stopniowym ograniczaniem pracy jednostek konwencjonalnych.

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