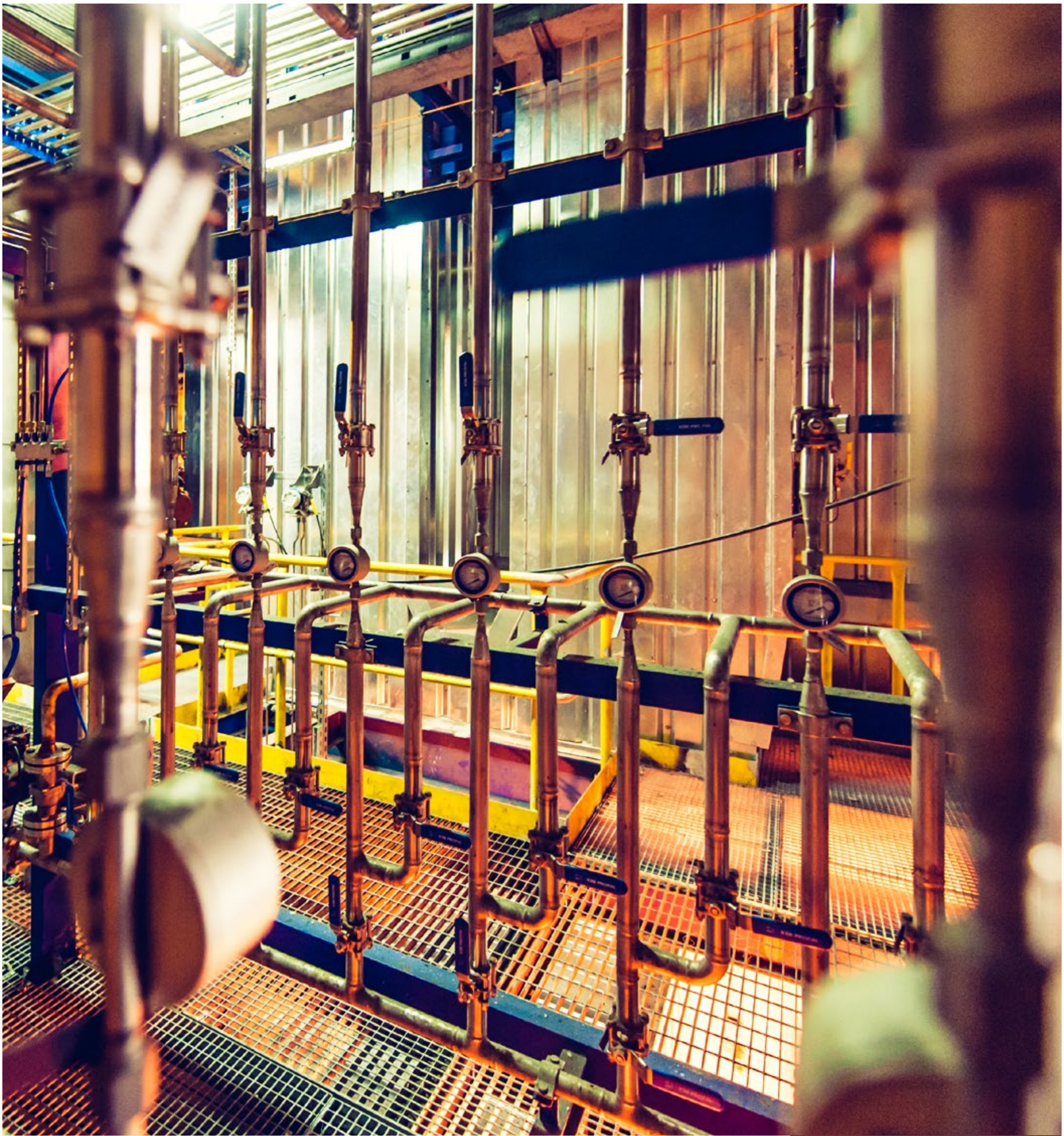

Integration of the district heating and electricity sectors, or how to use the transformation of district heating so as to ensure the security of heat supply and stabilize the operation of the power system

Polish Association of Heat Energy report

Integration of the district heating and electricity sectors, or how to use the transformation of district heating so as to ensure the security of heat supply and stabilize the operation of the power system

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Preface

Dear Sirs,

We have devoted this year's report of the Polish Association of Heat Energy entirely to the integration of the electricity sector with the district heating sector ("sector coupling"). This is an issue of great importance in the context of the power gap forecast by the Polish Power Grid Company (PSE) in the coming years, the temporary surplus of electricity production in the National Power System (NPS) and the direction of the transformation of district heating.

Meeting the requirements of the EU's "Fit for 55" package requires the district heating sector to take a new approach to doing business and to identify possible areas of cooperation with the electricity sector. The key factors include, among other things, cogeneration – that is, the simultaneous production of electricity and heat – and Power-to-Heat technologies, which allow surplus energy from RES in the NPS to be used to produce heat. Such solutions contribute to a deeper integration of sectors, thereby enhancing Poland's energy security, improving fuel utilization efficiency and primary energy conversion efficiency, while reducing greenhouse gas emissions. This is also a viable scenario for achieving climate neutrality by 2050.

The undoubted advantage of sector coupling is that the technologies such as gas cogeneration, heat pumps, electric boilers, heat storage and intelligent demand management systems are available already today. These technologies are the foundation for building a stable energy supply and affordable district heating prices in the coming decades. According to Polish Association of Heat Energy expert analyses presented in the report, the variable cost of heat generation with optimal operation of CHP units and electric heat sources is PLN 30/GJ. For the coal-based scenario, the value was 16% higher, while in the scenario without CHP it was as much as 143% higher. These results indicate the need to diversify generation sources and operate them in line with market signals.

However, in order to able to implement the sector integration scenario presented in this report, suitable regulatory

changes are needed. It should also be kept in mind that full integration of markets will only be possible with broad access to financial instruments and aid mechanisms to support decarbonization investments, the value of which – according to Polish Association of Heat Energy estimates – could amount to PLN 299–466 billion by 2050, depending on the adopted scenario.

Treating sector coupling as both an opportunity and a challenge for the district heating sector, I hope that the conclusions and recommendations contained in this report will become the basis for a lively discussion on the new energy market model.

I wish you an interesting reading!

Dariusz Marzec
President of the Management Board
Polish Association of Heat Energy

1. Executive summary

District heating sector – Basic data

- In Poland, district heating plays a key role in meeting the heating demand of 15 million Poles, and nearly 70% of urban residents rely on district heating.
- Although district heating is supplying more and more customers (as evidenced by the increasing length of the network), the volume of heat sold is decreasing as a result of milder winters and the ongoing thermal modernization of buildings. However, the district heating sector is diversifying its generation structure by consistently moving away from burning solid fossil fuels.
- The largest share in the structure of fuels used is coal (61.2%), although this share is decreasing year by year. However, the share of gaseous fuels is growing, reaching 13% in 2023, an increase of about 10% compared to 2022, placing natural gas as the third fuel, after RES (14.4%). The largest share of RES continues to be biomass – it accounted for 97% of total RES heat volume in 2023.
- A distinctive feature of Polish district heating is heat production in cogeneration, thanks to which district heating systems supply cities not only with heat, but also serve as important electricity providers. In the last year, CHP sources accounted for about 62% of total heat production in district heating systems. Utility and captive CHPs generated a total of about 27 TWh of electricity, accounting for about 16% of Poland's total electricity production.

Transformation of the National Power System

- Over the past decade, there has been a significant change in the structure of generation sources in the National Power System (NPS). The rapid growth of prosumer solar photovoltaics (PV) has caused the capacity of PV sources to increase from 1 GW to more than 21 GW in the past five years. As a result, the total installed capacity of all generation sources nearly doubled, reaching more than 72 GW in 2024, of which 33 GW (about 46.2%) was attributable to RES.
- However, the rapid growth of renewable capacity has not been coordinated with an increase in system flexibility, as reflected in the challenges of managing surplus energy and the safety of NPS operations.
- Since 2024, there has been an increasing oversupply of RES energy that the power system has not been able to accommodate. The non-market redispatch of RES units in 2024 was more than 680 GWh, and in 2025 (since April) it was 390 GWh. In hours with reductions, the percentage of RES in the balance of the NPS was 40–60%.

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- The change in electricity demand profile has created new challenges for balancing the power system. As a result, the wholesale electricity market saw negative prices during peak RES generation and high prices during peak consumption hours. For the entire 2024, the number of hours with negative prices in Poland was 186, and from January to April 2025 it was already 129 hours.
- This situation is a challenge for the NPS, but at the same time a source of new opportunities – including flexible consumption management, the development of energy storage and the integration of the electricity and district heating sectors.

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Sector coupling – or how to use district heating transformation to ensure power system security and flexibility

- Sector coupling means the integration of the electricity sector with other sectors of the economy, in this case district heating, in order to increase the flexibility of the power system and make better use of RES.
- Over the years, cooperation between the heat and power sector has been based mainly on combined heat and power production. Both sectors face challenges in meeting the demands of energy and climate policies, including the "Fit for 55" package, which laid out a path for decarbonizing district heating systems. Integration of the sectors requires defining potential new synergies for further cooperation between the heat and power sectors.
- The district heating sector is taking steps to move away from burning coal by using natural gas, but to ensure a smooth decarbonization process, it will also be necessary to increase the share of heat from RES.
- One of the main challenges of integrating renewable energy sources into the power system is their weather dependency, which determines the hourly electricity price profile.
- The answer to the challenges of daily balancing of the NPS is district heating supplied with heat generation technologies such as cogeneration sources or Power-to-Heat technologies (technologies that use electricity to produce heat) supported by heat storage.

Analysis results – cooperation of the district heating system with the power system using cogeneration and Power-to-Heat technologies

- The report presents an analysis of the cooperation of a district heating system based on cogeneration and electric heat sources (Power-to-Heat) with the power system. It was examined how the proposed technological mix of equipment would perform in the market conditions that exist today.
- For the first time, a full optimization of the system's hourly operation was applied, it covered a whole year and was based on actual electricity prices on the Polish Power Exchange and actual power generation in the National Power System. The results apply to data for the period from January 2024 to April 2025, when there were significant price fluctuations, rapid changes in demand, negative prices and surplus RES in the NPS.
- The analysis was conducted for a large district heating system with a thermal capacity of 725 MW for the following options of hybrid arrangements of equipment in the system:
  - **OPTION 1:** A system showing the current state, i.e. coal-fired cogeneration and coal-fired boilers;
  - **OPTION 2:** A system after transformation, showing the situation of model operation of CHP and Power-to-Heat technologies together with heat storage in the district heating system, assuming the operation of these units in the current situation on the electricity and heat market;
  - **OPTION 2B:** A system identical to Option 2 with an increased share of Power-to-Heat technology caused by forced operation of electrode boilers when the RES share in the NPS exceeds 40%;
  - **OPTION 2C:** A system identical to Option 2, assuming no support mechanism for CHP;
  - **OPTION 3:** A system after transformation without the use of cogeneration, which is a district heating system that produces only heat using gas boilers, heat pumps and electrode boilers.
- Each option assumes the operation of a heat storage facility, and Options 2–3 also provide for the operation of biomass boilers.
- **The simultaneous use of Power-to-Heat and cogeneration technologies makes it possible to achieve the lowest variable costs of heat generation. The variable cost of heat generation with optimal operation of CHP units and electric heat sources was PLN 30/GJ; for the coal-based system, the value was 16% higher; and for the option without CHP, it was 143% more.** Revenues from electricity generation improve the economics of district heating companies.
- Increasing the share of electrode boilers in heat generation, associated with operation at times of high generation from RES (over 40%), but not necessarily the lowest electricity prices can – by increasing the share of renewable heat – effectively help meet the requirements for an efficient district heating system. **In Option 2B, which featured the largest share of electricity in heat production, the variable costs of heat generation were 26% higher than those for Option 2.** Currently, this heat generation method is not covered by a support mechanism, but with the need to decarbonize the heating sector, it may become necessary.
- **The use of hybrid Power-to-Heat systems and high-efficiency gas cogeneration promotes lower CO_2 emissions and reduced fossil fuel consumption. The hybrid system achieved 40% lower CO_2 emissions than a coal-based cogeneration system,** and the carbon footprint of the entire hybrid system (combined for electricity and heat) was approx. 200 t of CO_2/MWh (compared to 370 t of CO_2/MWh for a coal-based system).

The complementary nature of the operation of CHP and Power-to-Heat cogeneration

- The analysis results show that district heating can use gas cogeneration and Power-to-Heat technologies depending on the situation in the power system. The activation of Power-to-Heat technology is justified in a situation of low electricity prices, while CHP is able to flexibly adapt production to heat and electricity demand.

The role of heat storage facilities

- Heat storage facilities work both with cogeneration units, storing heat during periods of increased electricity production, and with electrode boilers, storing heat generated from surplus electricity from RES. In each of the analyzed options, a storage facility improves the daily operation of district heating equipment, supporting its flexibility and reducing unit shutdowns and thus reducing the number of repeated start-ups.

- Through the use of heat storage facilities, the flexibility of generation equipment in a district heating system can be increased, making it possible to respond appropriately to the NPS needs.

Transformation of the heating sector

- The analysis showed that the use of Power-to-Heat technology in combination with gas-fired CHP units could already help meet the requirements that are being set for district heating systems in terms of future reduction of carbon footprint and achieving efficient district heating status.

- **Electrification can significantly support district heating and reduce the cost of heat generation, but it is necessary to properly optimize the use of such units at times of low prices and low demand for electricity**. According to Polish Association of Heat Energy analysis, if a significant portion of heat generation is electrified by building electrode boilers at the base load, an increase in annual demand of 500 MW in the NPS (in each hour of 2024) would raise the average annual BASE price of electricity in 2024 by 5%, and an increase of 1,000 MW of demand in the NPS would mean a 10% higher price.

Benefits for the National Power System

- The analysis showed that the district heating sector using an optimal combination of cogeneration and Power-to-Heat equipment can successfully achieve synergies with the electricity sector, while providing an optimal solution to energy transition challenges, such as balancing the operation of the NPS, managing surplus electricity and operational security of the national power grid.

- At the same time, the district heating sector can support the NPS during high electricity demand or sudden drops in RES generation. The construction of gas-fired cogeneration units can effectively replace the phase-out power in coal-fired cogeneration units.

Veolia Group in Poland

Fortum

Recommendations

- The development of sector coupling requires a number of regulatory changes that will contribute to greater cooperation between the electricity and district heating sectors, the most important of which include:
  - **Power-to-Heat technologies:**
    - classifying the whole stream of heat generated in heat pumps and electrode boilers as heat from RES (for the purposes of compliance with the definition of an efficient district heating system);
    - operational support for heat pumps and electrode boilers in the district heating sector;
    - reduction of fees for contracted capacity for district heating systems that use electricity and can perform a balancing role for the NPS;
    - preferential terms for connecting heat pumps and electrode boilers to the electricity grid;
    - changes to the heat tariff policy, including by means of a dedicated distribution tariff for heat pumps and electrode boilers;
    - changes to the heat tariff model to compensate for the efforts of heating companies to decarbonize and stimulate the development of renewable energy sources, e.g. a bonus for heat generation from RES, a change in the way investment outlays are accounted for in the investment bonus.
  - **Cogeneration units:**
    - changes to the operational support mechanism for cogeneration through amendments to the Act on promotion of electricity from high-efficiency cogeneration in three areas: extending the deadline for obtaining a construction permit from 12 to 24 months; extending the deadline for generating electricity from high-efficiency cogeneration for the first time in a new cogeneration unit or a substantially upgraded cogeneration unit from the date of settlement of an auction/call for applications from 48/60 months to 60/72 months, respectively; easing the provision that prevents a generator from participating in the CHP support system for a period of three years if the deadlines for construction and generation of electricity are exceeded;
    - increasing in the pool of funds allocated for auctions for cogeneration bonuses by transferring unused funds due to pending calls for applications for an individual cogeneration bonus;
    - maintaining the simplified method tariffing model and ensuring uniformity in revenue formation for all cogeneration units;
    - extending the role of high-efficiency cogeneration in meeting the definition of an efficient district heating system beyond 2040.
  - **Heat storage facilities:**
    - enabling the tariffing of storage facilities.
  - **Financing decarbonization**
    - providing investment aid for the construction of heat storage facilities as stand-alone projects and the construction of electrode boilers that generate heat for district heating systems, and to continue investment support programs for high-efficiency cogeneration;
    - increasing in the intensity of public aid to 60% of eligible project costs;
    - increasing the notification threshold for state aid to €100 million per project;
    - extending the Modernization Fund beyond 2030.
  - **Investment process:**
    - deregulation of the investment process and simplification of administrative procedures, aimed at developing heat pump and electrode boiler technologies.

2. State of the district heating and power sector

2.1. Characteristics of district heating in Poland

District heating plays a key role in Poland in meeting the heating needs, covering more than half (52.2%) of households[1]. District heating systems in Poland are located in most cities, so that nearly 70% of city residents use district heating. In this report, we focus mainly on licensed district heating (i.e. activities that require a license, which covers sources with a total installed thermal capacity of more than 5 MW), which is subject to the pricing regulations of the Energy Regulatory Office (hereinafter: ERO).

Detailed data showing the characteristics of licensed district heating in Poland over the past two decades are given in Table 1.

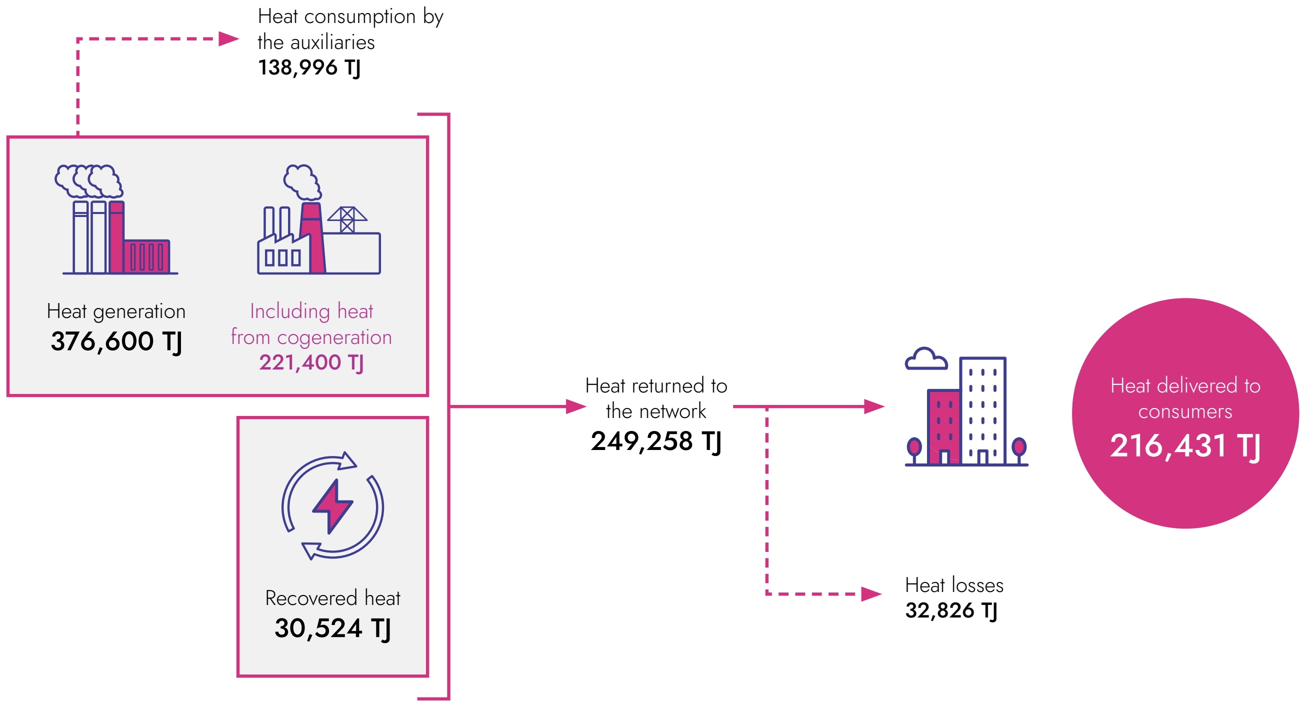
Table 1. Characteristics of licensed district heating in 2002–2023[2]

Item	2023	2022	2012	2002
Number of licensed district heating companies	398	392	466	894
Installed capacity in MW	52681.5	53188.4	58147.9	70952.8
Contracted capacity in MW	34667.4	34923.7	34142.5	38937.0
Length of networks in km	22837.8	22578.4	19794.1	17312.5
Employment in jobs	27943.0	27772.0	36084.0	60239.0
Total heat sales in TJ	335430.3	357702.6	389364.5	469355.5
Heat returned to the network in TJ	249258.3	265658.5	283920.9	336043.0
Heat supplied to network-connected consumers in TJ	216431.5	233134.4	248040.1	298938.1

1. Statistics Poland, Energy carrier consumption in households in 2021
2. Own study based on "Heat power engineering in numbers – 2023", Energy Regulatory Office, Warsaw, January 2025 and "Heat power engineering in numbers – 2022 and 2012

In 2023, the total installed thermal capacity of district heating companies was 52,681.5 MW. In recent years there has been a systematic decline in installed capacity, but at the same time there has been a small but steady increase in the length of district heating networks – their length in 2023 was 22,837.8 kilometers. It is also worth noting the continuing downward trend in contracted capacity and the amount of heat sold, i.e. put into the district heating network and delivered to consumers. In 2023, the total heat generation by licensed enterprises, taking into account heat recovered from technological processes, amounted to 376.6 thousand TJ. This represents a decrease by 7% compared to 2022, when 404,700 TJ of heat was produced (by comparison, 425,100 TJ of heat were produced in 2021). The observed downward trend in heat demand is due to weather changes (warmer winter periods) and changes in the energy performance of buildings through increased rates of thermal modernization and tighter technical requirements for new construction.

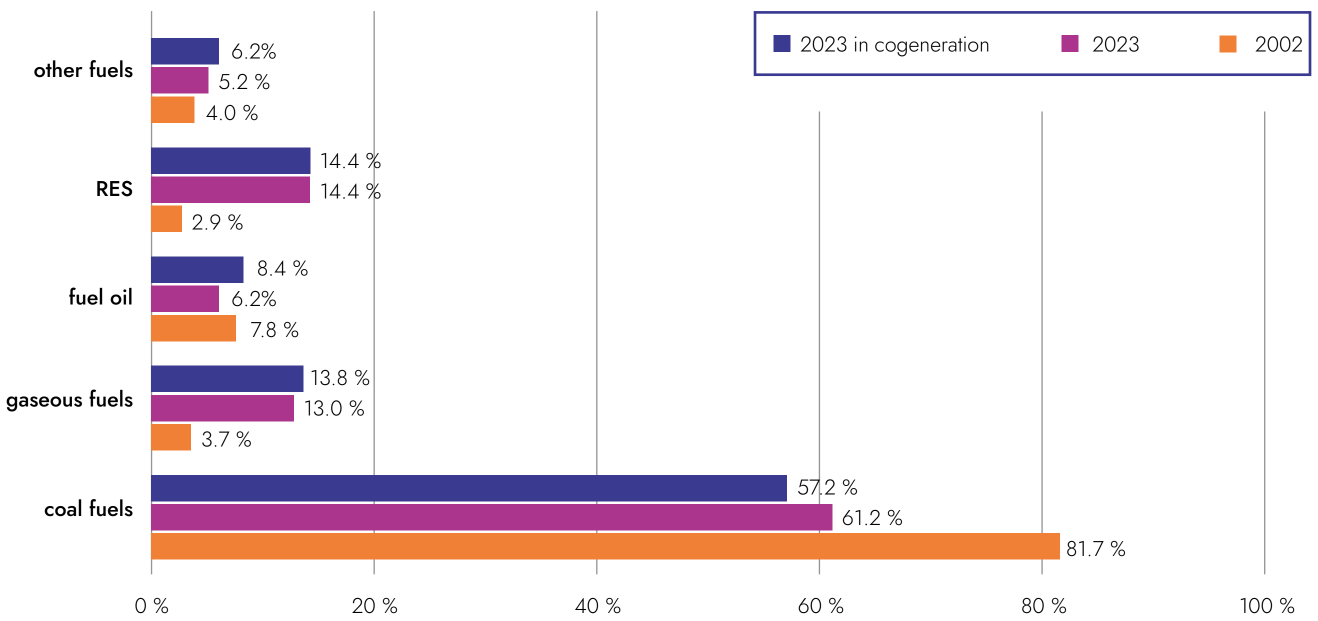
Fig. 1. Heat generation in Poland in 2023[3]



3. Own study based on "Heat power engineering in numbers – 2023", Warsaw, January 2025

When analyzing the structure of fuels used for heat production, it is important to note the systematic diversification of energy sources. Nevertheless, due to historical conditions, coal fuels still prevail – in 2023, their share was 61.2% of all fuels used in heat sources. However, it is noticeable that the downward trend in the share of these fuels in heat generation has continued in recent years (66% in 2022, 69% in 2021, 71% in 2019 and 74.0% in 2017). Since 2002, the share of coal fuels has decreased by 20.5 percentage points (pp), with a significant increase in the share of renewable sources (by 11.5 pp) and gaseous fuels (by 9.3 pp). Equally important, in 2023, heat production using cogeneration accounted for 64% of total heat production (an increase of almost 2 pp compared to 2022). These figures show the scale of the measures taken by the entire district heating sector and the commitment to the transformation and decarbonization of district heating in Poland. The structure of fuels in 2002 and 2023 is shown in Fig. 2.

Fig. 2. Structure of fuels according to energy content, consumed for district heat generation in 2002 and in 2023, and for heat production in cogeneration in 2023[4].



The share of heat from renewable energy sources (RES) was 14.4%, consisting of the use of: biomass (14.0%), biogas (0.08%) and other renewable sources (0.32%). This means that in 2023 biomass accounted for 97% of the total RES heat volume.

In terms of the financial condition of district heating companies, the 2023 data shows continued negative gross profitability from 2019. Nonetheless, the ratio improved in 2023, reaching -9.51% against -22% in 2022. The lower profitability continues to be achieved by cogeneration sources (-17.49%) compared to non-cogeneration sources (2.6%).

4. Ibid.

Table 2. Average heat prices from cogeneration sources in 2012-2023[5].

Year	total [PLN/GJ].	cogeneration sources [PLN/GJ]	sources other than cogeneration [PLN/GJ]	change when compared to the previous year – total [%]
2023	104.65	93.14	125.52	63.4 %
2022	64.03	55.15	76.39	34.4 %
2021	47.65	45.27	53.31	7.5 %
2020	44.33	41.32	51.87	8.2 %
2019	40.97	37.87	48.48	5.8 %
2018	38.72	36.54	43.80	2.3 %
2012	33.12	no data	no data	5.7 %

The average price of heat sold from all licensed heat-generating sources was PLN 104.65/GJ (an increase of 63% as compared to 2022), with the average price of heat generated from cogeneration sources at PLN 93/GJ, which is still lower than the average price of heat from sources other than cogeneration, which was PLN 125/GJ. An increase in heat prices progressing from 2022 onward was due to a spike in energy commodity prices (through the heat tariff system shifted and spread over time) and an increase in the price of CO_2 emission allowances.

5. Ibid.

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Another significant area as mentioned above – due to its significant share of total heat production – is the production of energy and heat in cogeneration. In 2023, there was an increase in the number of cogeneration companies – from 131 entities to 140. This means that cogeneration heat generation was shown in 36.7% of the 381 reports from district heating companies. The development of cogeneration units is possible thanks to the support scheme, which was implemented based on the Act of December 14, 2018 on the promotion of electricity from high-efficiency cogeneration (Journal of Laws 2025, item 602).

The scheme provides for the promotion of electricity from high-efficiency cogeneration of existing, modernized and new units. The report focuses on a summary of the support scheme for new units, for which the following units are eligible:

- new and significantly modernized cogeneration units (with an installed electrical capacity of not less than 1 MW and less than 50 MW) under the cogeneration bonus, where units make bids in a cogeneration bonus auction;
- new and significantly modernized cogeneration units (with an installed electrical capacity of not less than 50 MW) under the individual cogeneration bonus, where units submit proposals in a call for applications for individual cogeneration bonus.

New and significantly modernized units are subject to a prequalification procedure before entering an auction or call for applications. If a unit becomes subject to the bonus, the obligation of first electricity generation is imposed on the unit, with the use of the support scheme starting with the first generation, injection into the grid and sale of a given volume of electricity. The maximum period of operational support, in the form of a bonus, is 15 years from the date of the first – after the date of winning the auction or call for applications – generation and sale of electricity to the power grid (but no longer than December 31, 2048).

An analysis of past calls for applications shows that the individual cogeneration bonus has been awarded twice in calls for applications that were settled in 2020. Since then, not a single proposal has been submitted in any of the eight calls for applications. It is worth noting that over PLN 13.8 billion were available for distribution in the last call for applications (March 2025).

The situation is different with regard to the cogeneration bonus awarded in auctions, which has seen visible interest since 2023. According to the announcements of the ERO President, the auctions resulted in cogeneration units with a total capacity of 210 MW in 2023 and 161 MW in 2024 receiving a cogeneration bonus, making a total of 371 MW of new cogeneration capacity. In addition, another auction was held in March 2025, with 6 cogeneration units receiving support. A noticeable problem, however, is decreasing auction budgets, therefore it is reasonable to consider reallocating unused funds from individual calls for applications to the auction budget for 2026 and beyond. Given the results of the described cogeneration support mechanism, it is likely that new cogeneration units will be built and continue to be present in the district heating system, also supplying electricity to the power system.

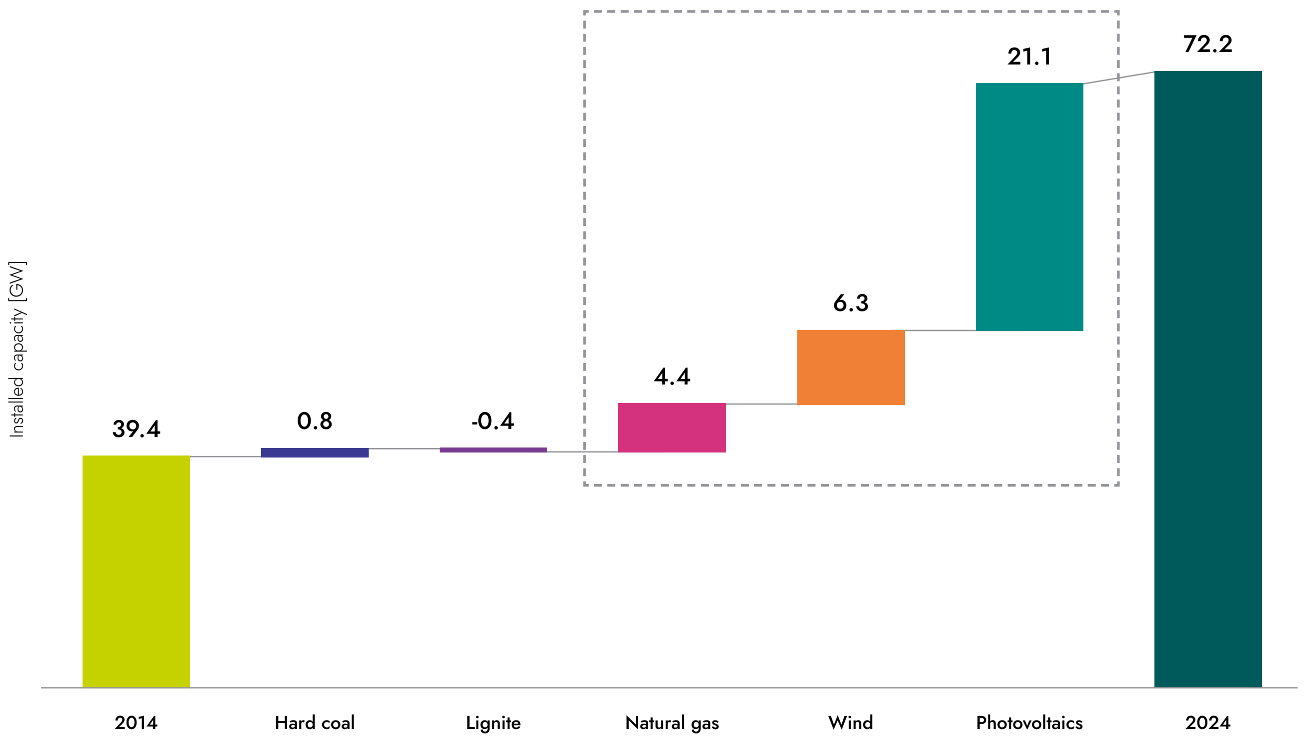
In light of the presented information, it should be pointed out that the key issue determining the direction of the sector's transformation is represented by the EU criteria for efficient district heating systems (resulting from the Energy Efficiency Directive 2023/1791), according to which from 2050 on, they will be supplied exclusively by heat from renewable energy and/or waste heat. A detailed analysis of EU regulations for the district heating sector was presented in last year's Polish Association of Heat Energy report entitled: ***"The impact of EU regulations on the transformation of the system district heating sector in Poland, assessment of effects and recommendations for national regulations"***. The report indicates the need for capital outlays of PLN 299-466 billion by 2050 to meet EU requirements. In addition, carrying out the transformation of the district heating sector has been significantly complicated by the energy crisis in the fuel markets, triggered by Russia's aggression against Ukraine, but also by the earlier price turmoil caused by the COVID-19 pandemic. At the same time, the sector faces declining demand for heat and a lack of sufficient funding, which is reflected in problems with the profitability of cogeneration sources.

2.2. Challenges for the National Power System related to the energy transition

Transformation of the National Power System

Over the past decade, the National Power System (NPS) has undergone a significant transformation. The installed capacity of generation sources has almost doubled, mainly due to the rapid development of renewable energy sources. In 2014, conventional sources accounted for 85% of installed capacity, while onshore wind farms prevailed among renewable sources, with a total capacity of nearly 3.9 GW. In total, renewable sources accounted for nearly 20% of the share of generation sources. 2019 was a breakthrough year, when the rapid development of prosumer photovoltaics (PV) began. In five years, the capacity of PV sources increased from 1 GW to more than 21 GW. As a result, the total installed capacity of all electricity sources in Poland in 2024 reached more than 72 GW, of which 33 GW (about 46.2%) was attributable to renewable technologies. Figure 3 shows the changes in installed capacity from 2014 to 2024.

Fig. 3. Increase in installed capacity of renewable sources and flexible, controllable sources in Poland from 2014 to 2024



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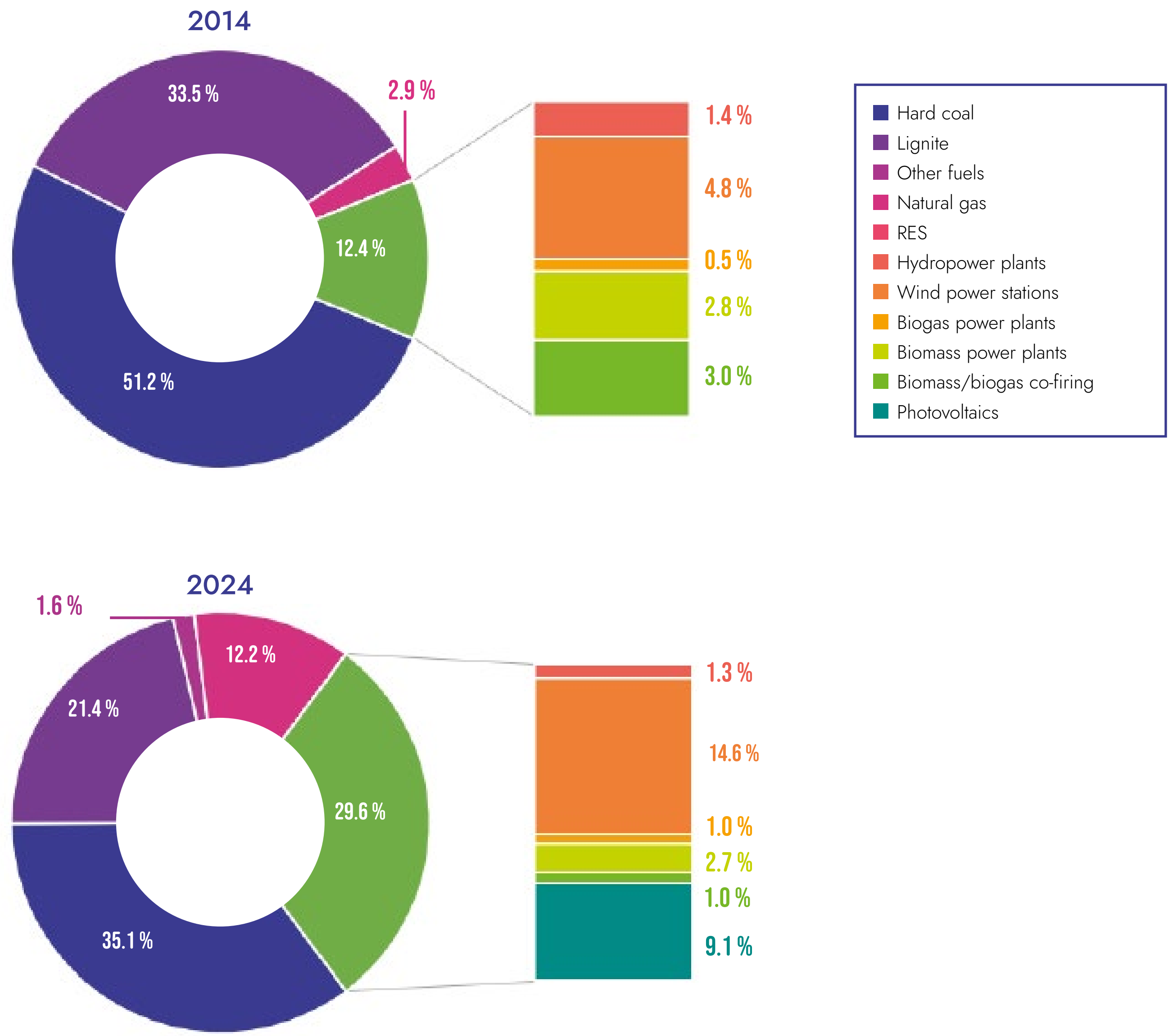
However, the rapid growth of renewable capacity has not been coordinated with an increase in system flexibility, which was reflected in the difficulties of managing surplus energy and the safety of NPS operations.

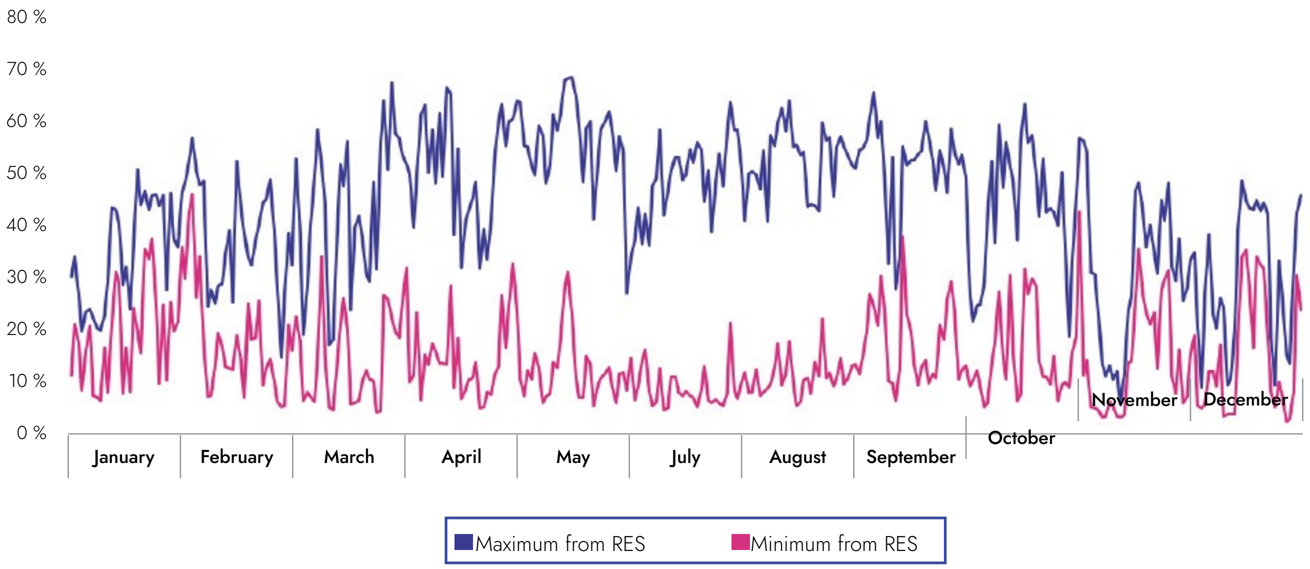
As installed capacity increased, the share of RES in electricity generation increased. Despite this growth, the NPS still relies mainly on conventional sources, although their share is steadily declining. In 2024, coal and lignite-fired units accounted for over 55% of the country's electricity production. The mix was supplemented by gas units with a share of about 12%, while the share of RES reached 29% in 2024 (in 2014 it was only 12%).

Fig. 4. Structure of electricity production in 2014 and 2024
Source: Own study based on data from Energy Market Agency, PSE



On a daily and hourly basis, the share of RES in electricity generation depended on weather conditions and the level of demand. At certain hours, the RES share reached values of more than 50%, and at times of highest production (when RES reductions occurred)it reached almost 70%. The highest RES generation values were observed in spring and summer with the highest sunshine. However, it is worth noting that there were high shares of RES energy in the NPS also in fall and winter. This means that significant volumes of energy from RES come at times when they can be used by the district heating sector.

Fig. 5. Maximum and minimum shares of RES in daily electricity generation in 2024
Source: Own study based on ENTSOe

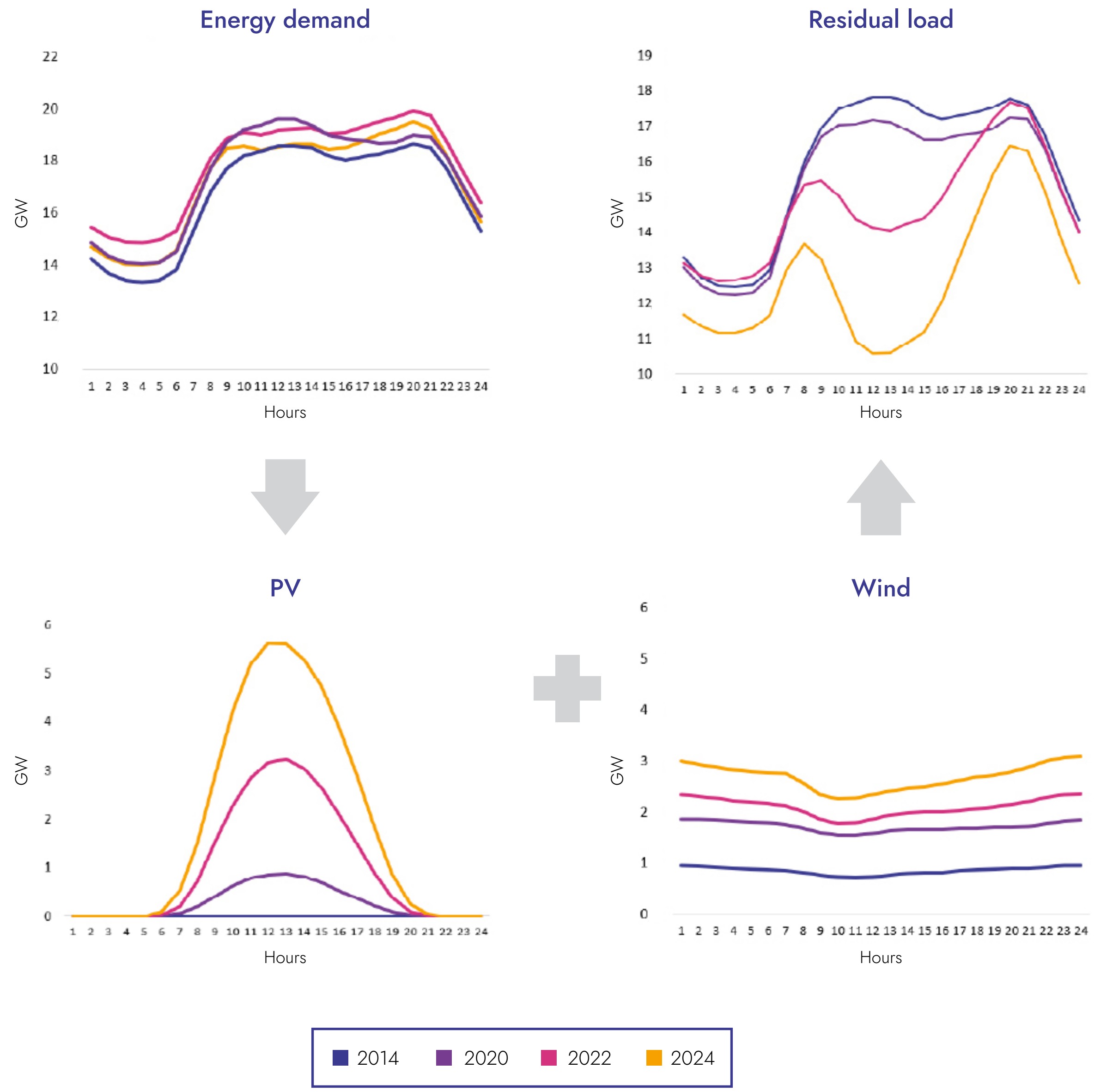


Change in energy demand profile

With the development of renewable energy sources, the profile of electricity demand is changing. In systems where conventional units were the main source of energy, demand was stable and predictable (as illustrated in Figure 6 – see 2014). However, the amount of energy that conventional units provide is reduced by the electricity generated by variable renewable sources – mainly wind and photovoltaic farms. This results in what is known as residual demand (residual load), or net demand for electricity from conventional sources.

Until 2020, the lowest residual demand in the NPS was recorded during nighttime hours. Consumption gradually increased in the morning, reaching a first peak associated with the start of operation of industrial plants and offices, and a second peak in the evening. After 2020, this historical profile has been altered by the rise of solar PV – especially prosumer PV. Noon PV power production became high enough to significantly reduce the demand for power from the grid. As a result, low levels of demand appear on sunny days, and the consumption profile has taken on a "U" or "duck curve" shape, with a deep valley between the morning and evening peaks.

Fig. 6. Change in electricity demand profile under affected by RES development *Source: Own study based on PSE data.*

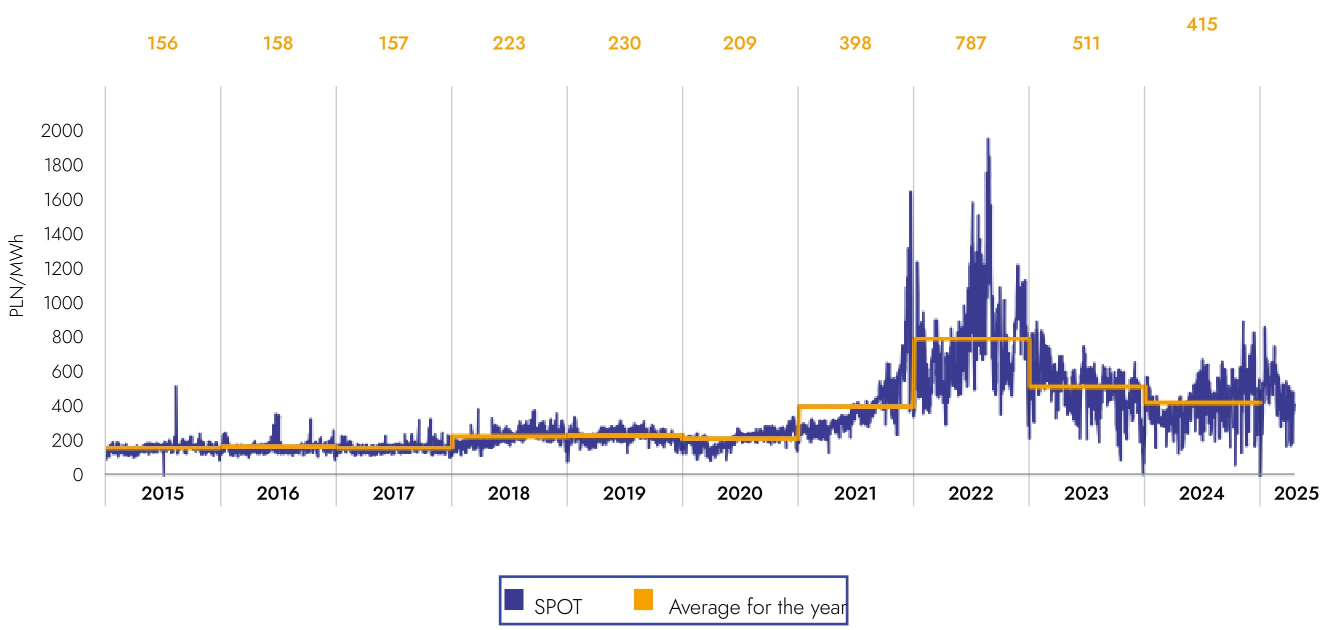


The change in demand profile has created new challenges for balancing the power system. There is an increasing oversupply of energy during midday hours, forcing conventional power units to reduce their operation to technical minimums or temporarily shut down. Then there are spikes in demand during evening hours, which must be met by flexible conventional sources, imports or energy storage facilities. As a result, the wholesale electricity market saw negative prices during peak RES generation and high prices during peak consumption hours. This situation is a challenge for the NPS, but at the same time a source of new opportunities – including flexible consumption management, the development of energy storage and the integration of the electricity and district heating sectors.

Volatility of energy prices on the day-ahead market

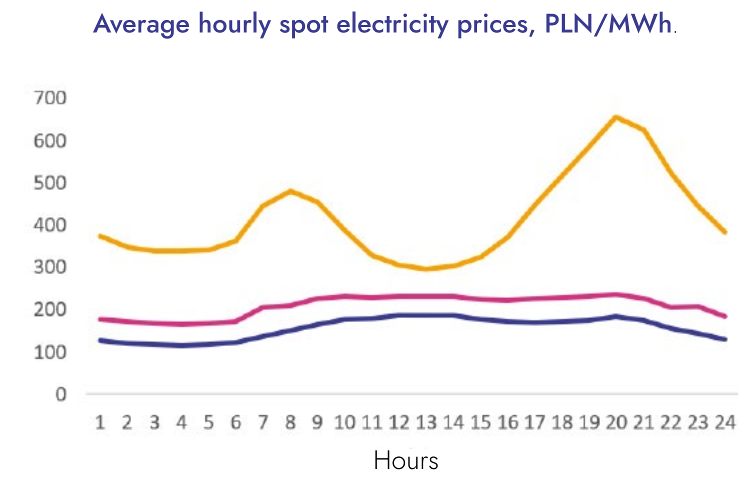
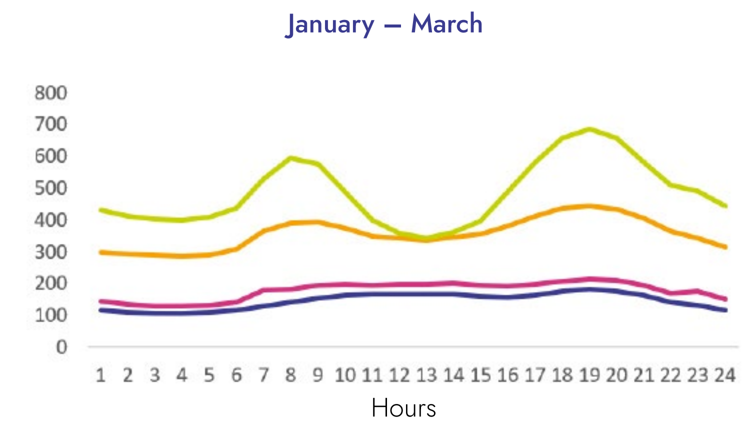
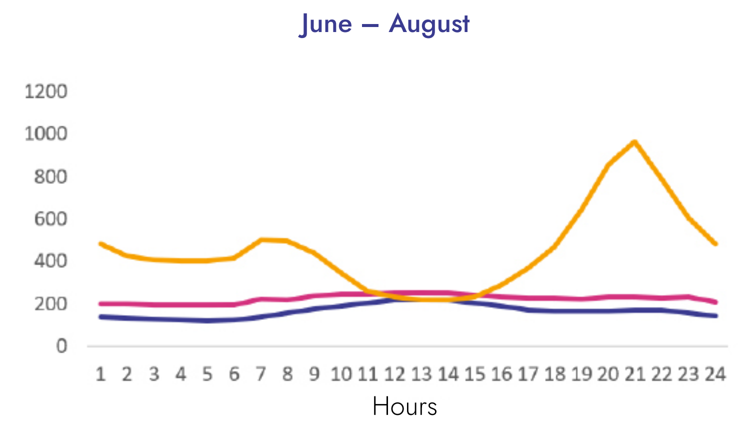
An increase in the installed capacity of RES, the growing production of wind and solar power and changes in the demand profile are factors that have significantly affected electricity prices on the wholesale market. By 2021, energy prices were relatively stable and predictable, and daily differences were moderate – lower prices at night, higher during peak demand.

Fig. 7. Electricity prices on the spot market in Poland in 2015–2024
Source: Internal analysis based on the TGE data

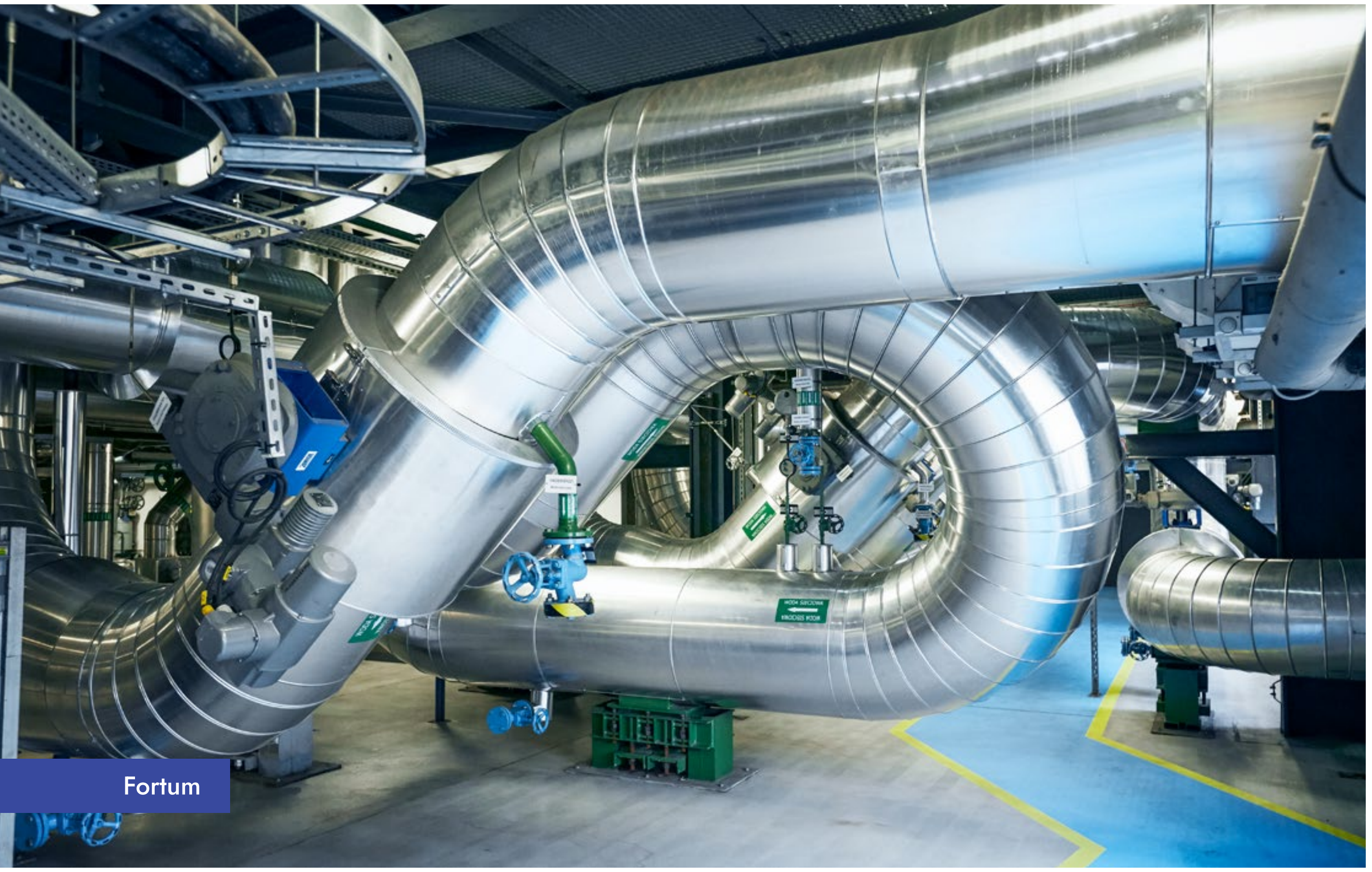


From 2021 onward, there was a steady increase in prices, which peaked between June and August 2022. Then, as a result of the normalization of the situation on fuel markets (natural gas and coal), prices began to fall steadily – until June 2024. In June 2024, balancing market reform was implemented, which contributed to greater price volatility on the spot market. Daily price fluctuations have become more pronounced – from negative values at midday to several thousand zlotys in the evening. Energy prices were strongly linked to RES production – cheap energy at times of oversupply of RES and more expensive energy when RES stopped producing energy and high demand had to be supplemented by conventional units.

Fig. 8. Changes in the daily price profile on the wholesale electricity market in Poland in 2015–2025
Source: Internal analysis based on the TGE data

Comparison of price profiles	Comments
	In 2024, electricity prices in Poland varied significantly on a daily basis. The lowest price of electricity was – PLN 320/MWh (August 14) and the highest was PLN 2,750/MWh (November 6 + a system stress event)
	The average price of electricity on the day-ahead market in January-March was PLN 144/MWh in 2015, PLN 355/MWh in 2024. During the winter season, there are higher prices due to higher demand, but even then there is sufficient variability throughout the day to take advantage of the potential of electric sources. High electricity demand and prices in the evening are an opportunity to use cogeneration units.
	Between 2015 and 2020, average summer day-ahead market prices looked very similar to winter prices. In the 2024 summer period, the difference in average day-ahead market prices between midday and evening hours was about PLN 800.

2015 2020 2024 2025



Fortum

Increasing price volatility is characteristic of power systems in transition. A rapid increase in the output of weather-dependent sources (wind, solar) is not balanced by the development of flexible controllable sources, which leads to ever-increasing price fluctuations throughout the day. Data from the spot market in Poland confirms this trend – the first months of 2025 (the peak heating season) saw significant price fluctuations, including an increasing occurrence of very low and even negative electricity prices. In line with national decarbonization plans, investment in RES will still be carried out, while conventional units will operate in the system to ensure the stability of the NPS, which requires maintaining a suitable level of spinning reserve. Simultaneous expansion of renewable sources with the need to maintain capacity in conventional sources with a certain dynamic of technical parameters will exacerbate the issue of increasing price volatility on wholesale markets.

In the context of sector cooperation, the following theses can be formulated:

- The volatility of electricity prices encourages the development of flexible sources in other sectors.
- Power to Heat plants can take advantage of low electricity prices, while gas cogeneration can operate at times of high prices and support the NPS when demand increases rapidly.
- The development of cogeneration provides power available to the NPS when periods of "Dunkelflaute" occur.
- The development of weather-dependent capacity in the NPS offers the potential to use electricity to power electrode boilers and heat pumps.

3. Sector coupling – the transformation of the system district heating sector and the security and flexibility of the power system

3.1. The concept of sector coupling

Sector coupling means the integration of the power sector with other sectors such as transportation, industry and district heating in order to increase the flexibility of the power system and make better use of RES. In this report, we will focus on the district heating sector.

Over the years, cooperation between the district heating and power sector has been based mainly on combined heat and power production. Cogeneration units in Poland, although based primarily on coal-based fuels, make it possible to achieve relatively high overall efficiency (above 85%), while extraction condensing systems provide a wide range of production configurations depending on the needs of the district heating system and the profitability of electricity generation. System district heating remains a significant producer of electricity for the National Power System (NPS). In the last year, cogeneration sources accounted for about 62% of total heat production in district heating systems. At the same time, utility and captive CHPs generated a total of about 27 TWh of electricity, accounting for about 16% of Poland's total electricity production.

However, the situation is changing dynamically and requires interface points and potential new synergies to be defined for further cooperation between the district heating and power sectors. Both sectors face challenges in meeting the requirements of the "Fit for 55" package, yet companies feel a sense of social responsibility in caring for the climate and the state of the environment.

The most significant changes affecting both sectors include:

- derogations and exemptions – which are to end in the coming years – from the obligation to meet emission standards for coal-fuel-based generation sources;
- a decline in the profitability of coal-based production due to the rising cost of CO_2 emission allowances, forcing a shift away from coal;
- requirements for maintaining the status of an efficient district heating system under the regulations of the revised Energy Efficiency Directive (EED);
- dynamic development of RES production with all its natural limitations;
- changing future distribution of generation assets due to the development of offshore wind farms and nuclear power in the north of the country;
- emerging new technologies and technical solutions.

There is a noticeable trend of a gradual shift away from coal combustion towards the use of natural gas and renewable sources, while the potential for deploying sources that use electricity to produce heat – Power to Heat – is growing. On the other hand, one of the main challenges of integrating renewable energy sources into the power system is their weather dependence, i.e. the variability of electricity production depending on weather conditions. In Poland, surpluses of green energy can be observed with increasing frequency, and with the projected further increase in the share of RES, it will intensify.

Thus, there is an emerging need to increase the flexibility of the power system. On a daily basis, the amplitude of electricity demand that conventional units must cover exceeds 10 GW. Coal-fired power plants characterized by moderate flexibility – among other things, due to long start-up times, low power ramp-up rates and high technical minima for unit operation (for coal-fired thermal units it is about 40–60% of rated capacity) – are unable to respond effectively to changing demand in the NPS. Table 3 shows favorable and unfavorable actions from the point of view of the further development of the NPS at times of NPS imbalance.

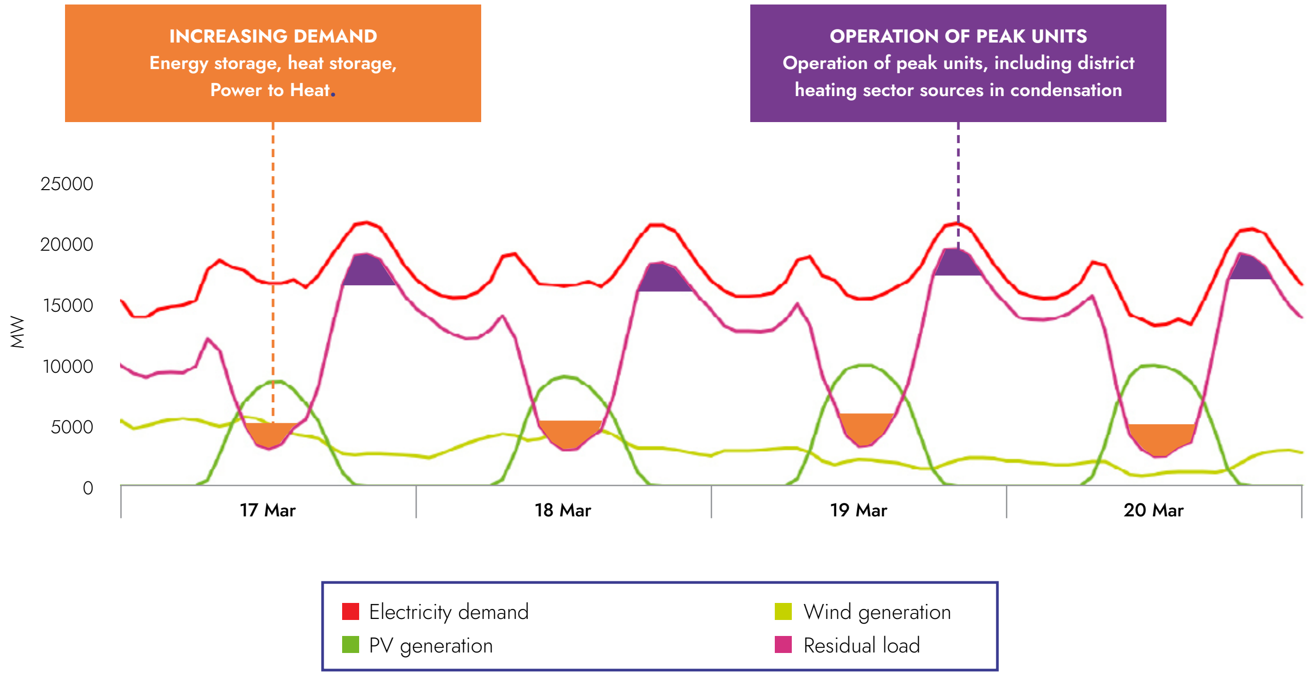
Table 3. Summary of actions from the point of view of further development of NPS

At times of high renewable generation and low energy demand	At times of high energy demand and low generation of renewable sources
NEEDED: ■ Units that flexibly reduce production. ■ Increase in energy consumption by entities operating on the market. UNFAVORABLE: ■ Increased, inflexible production of electricity going into the NPS.	NEEDED: ■ Units that flexibly increase their production. ■ Reduction of energy consumption by entities operating on the market. UNFAVORABLE: ■ Inflexible demand, lack of demand response to price signals.

Fortum

The answer to the challenges of daily balancing of the NPS is system district heating equipped with heat generation technologies, such as cogeneration sources or electric heat sources (technologies that use electricity to produce heat – Power to Heat). In addition, it will be important to increase the installed capacity of peaking units with very flexible technical parameters in terms of load shifting, start-ups and shutdowns (referred to as "pickers"). Figure 9, using three days of NPS operation as an example, shows at what times energy consuming and producing units can cooperate and balance the power system.

Fig. 9. Conceptual presentation of the cooperation of NPS and system district heating



Depending on demand, district heating companies can put Power to Heat plants – especially electrode boilers – into operation quickly enough. The implementation of Power to Heat technology partially solves the problem of balancing electricity supply and demand. These technologies, especially when combined with heat storage, have significant potential to stabilize the NPS by taking away excess RES energy when production exceeds demand. Such a model will also reduce the need to redispatch renewable sources (costly for both electricity generators and consumers).
During times of electricity shortages in the system (e.g., during the autumn-winter season, with a limited supply of PV energy), cogeneration units can be put into operation as NPS support, as they simultaneously supply electricity and heat to district heating systems.
In addition, heat storage facilities make it possible to efficiently use the heat generated in Power to Heat or cogeneration units. It is worth noting that due to the significantly lower cost of construction compared to battery storage, heat storage facilities can be tailored to a specific area of the NPS – they can be large-capacity systems located at combined heat and power plants, as well as smaller solutions located in different areas of the district heating network.

However, it must be kept in mind that while sector coupling is an indispensable support for the power system, the electrification of district heating alone cannot be equated with and treated as the only way to transform district heating. Especially given the data on final energy consumption in Poland, which shows that 53% of final energy is consumed for district heating and only 20% for electricity (Table 4).

Sector coupling is the future of modern district heating – it makes it possible to integrate it with the power system, increase the share of RES, reduce costs and emissions and strengthen the resilience of both systems. However, sector coupling should be understood as the integration of the power system with the district heating system, not the transition of all district heating to electrification.

Table 4. Final energy consumption in Poland
Source: Own study based on: Heat storage market roadmap – EC BREC Renewable Energy Institute | Photovoltaics

Final energy consumption	TWh	Share [%]
Heat consumption	447	53
Electricity consumption	170	20
Fuel consumption in transport	228	27
Gross final energy consumption	846	100

3.2. Technologies to support sector connectivity

This report section will focus on the technologies that will be used in sector coupling – these are primarily cogeneration and Power to Heat technologies, further supported by heat storage.

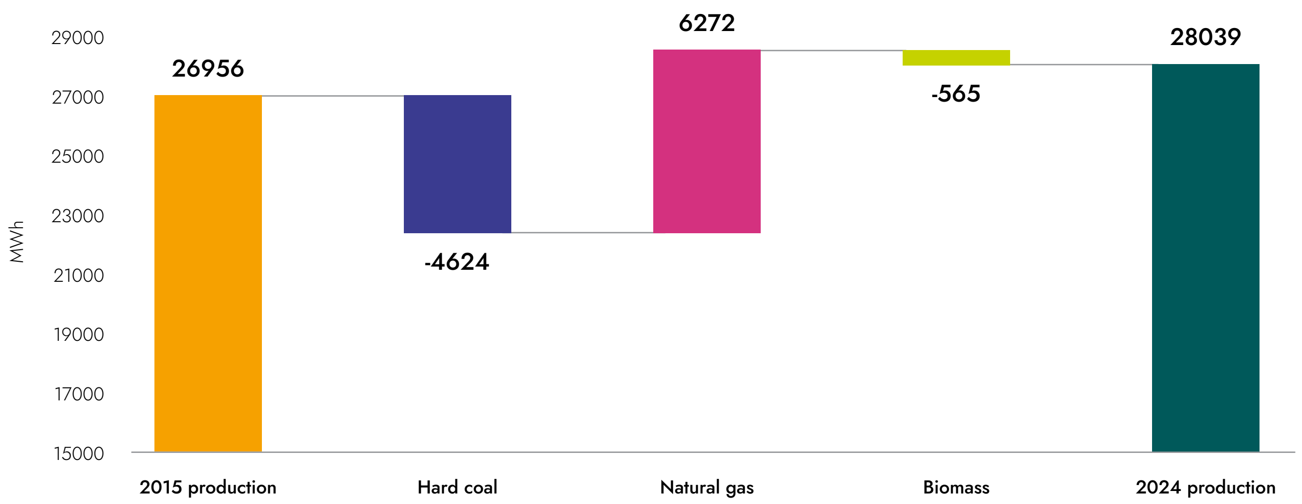
3.2.1. Gas cogeneration

Cogeneration, or combined heat and power production, is a key technology used in Polish system district heating. Compared to a classic power plant, the main advantage of cogeneration is that the heat is not released to the environment, but it is used for district heating purposes. As a result, cogeneration heat and electricity are generated with much higher efficiency, at 80–95%. In addition, reductions in fuel consumption and air emissions are achieved.

Cogeneration plays an important role in both the heat supply structure and domestic electricity production. Much of this energy is generated by coal-fired cogeneration, but in recent years there has been a noticeable increase in the use of natural gas as a fuel in cogeneration units. Production based on this fuel increased from 6.5 TWh to nearly 13 TWh in 10 years. This corresponds to the decarbonization process, but is also associated with greater efficiency, flexibility and much better ability to operate in variable mode for these units, making it possible for them to adapt more quickly to changing demand and prices. It is the gas-fired cogeneration units that have the greatest potential for combining sectors.

Commercially available cogeneration technologies include SCGT (Simple Cycle Gas Turbine) with HRHWB (Heat Recovery Hot Water Boiler), CCGT (Combined Cycle Gas Turbine) and gas engines. The selection of suitable equipment is adjusted to the needs of a given district heating system.

Fig. 10. Change in electricity generation from utility and captive CHPPs
Source: Internal analysis based on the ARE data



- **SCGT + HRHWB gas systems** consist of a gas turbine driving an electricity generator and a water-based heat recovery steam generator (HRSG). Hot flue gases from a gas turbine are used in a water boiler to produce district heat. Although electrical efficiency is lower, SCGT + HRHWB have faster start-up times and lower investment costs, relative to CCGT + HRSG systems. SCGT + HRHWB systems are used in systems where high flexibility of operation and responsiveness are required.

- **Combined Cycle Gas Turbine (CCGT)** systems use a combined cycle in which hot exhaust gases from a gas turbine are used to produce steam in a Heat Recovery Steam Generator (HRSG). This steam then drives a steam turbine for additional electricity production. Heat for mains water heating is recovered from steam turbine extractions and/or additional heat exchangers in the HRSG. As a result, electrical efficiency is higher than for SCGT + HRHWB systems. CCGTs admittedly have a higher coupling rate than SCGTs but usually do not achieve such high overall efficiencies. Due to the use of a steam member, the start-up time is considerably longer, which affects the speed of response and at the same time reduces the flexibility of their operation. CCGT systems fit better into large district heating systems where they can operate over a smaller range of load changes and with no need for cyclic operation or frequent start-up/shutdown on demand.

- **Cogeneration power generators (gas engines)** convert the chemical energy of fuel (natural gas) directly into mechanical energy that drives an electric generator. Waste heat from the engine is recovered and used to produce heat. The electrical efficiencies achieved are higher than for SCGT + HRHWB systems and lower than for CCGT systems. They feature high flexibility achieved, among other things, through the use of small, individual modules.

Table 5. Summary of the parameters of cogeneration technologies

	POWER RANGE OF A TYPICAL UNIT	TYPICAL EFFICIENCIES
SCGT+HRHWB	several hundred kWe to several hundred MW_e (on the average 60–70 MW_e for a single unit)	total 82–90%; electrical efficiency up to 41%
CCGT	from a few to a few hundred MW_e (for district heating applications, a typical unit with an extraction back-pressure turbine from 50 to 200 MW_e, with a condensing turbine the power can even exceed 200 MWe)	total 82–90%; electrical efficiency 50–60%
Co-generation power generators (Gas engines)	from a few kWt to 20 MW_t for a single generator (typically between 1–10 MW_t for a single engine	total 82–90%; electrical efficiency 42–46%

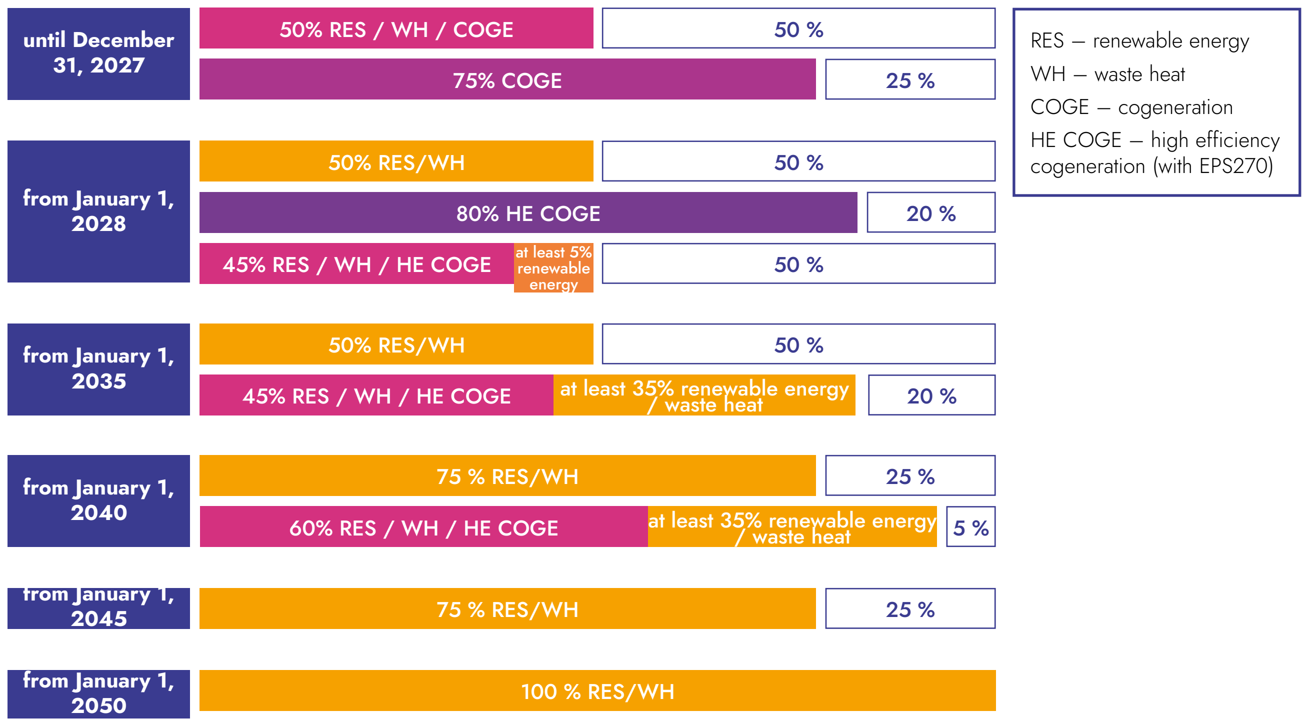
Regulatory considerations

The use of cogeneration in the transformation of system district heating has been reflected in EU regulations by identifying the technology as contributing to meeting the criteria for efficient district heating systems set forth in Article 26 of Energy Efficiency Directive 2023/1791 (hereinafter the EED)[7]. According to these criteria (they are indicated in Figure 11), achieving efficient district heating status is possible based on the predominant share of high-efficiency cogeneration by 2035, and in subsequent years by the end of 2045, while increasing the share of heat from renewable energy or waste heat. It should also be noted that if CHP units are refired with renewable gases, the decarbonized heat generated in this way will acquire the status of renewable heat and will be able to contribute to the achievement of district heating system neutrality by 2050. Nevertheless, the question of the commercial availability of these corresponding quantities of gases is not yet determined.

At the same time, for high-efficiency cogeneration (based on fossil fuels), the EED introduces a limit for direct carbon dioxide emissions (the EPS270 – Emissions Performance Standard), which, for fossil-fuel-based units, is 270 g CO_2/kWh (EPS270) of energy produced. EPS270 applies to new and upgraded units (i.e., built or upgraded after the transposition of the aforementioned Directive into national legislation), and in the context of meeting the criteria for efficient district heating systems, will apply from 2028. It should be noted that for cogeneration units operating before the entry into force of the amended Directive, the provisions of Annex III provide for the possibility of derogation from the application of the emission criterion until January 1, 2034, provided that such units have an emission reduction plan to achieve the threshold of 270 g CO_2/kWh by January 1, 2034. In practice, this means the termination of operation of coal-fired CHP units at the beginning of 2034. In view of this, meeting EPS270 is possible only by gas units operating most of the time in full cogeneration, so that the annual average overall efficiency of a cogeneration unit is not lower than 76%, which will ensure that the CO_2 emission standard is met at the required level. Thus, meeting the requirements of the EPS270 forces CHP units to operate in combined mode and limits the flexibility of electricity production. Given this limitation, in the context of sector coupling, it should be read as a barrier that can be mitigated through the use of heat storage – in a situation of increased demand for electricity, CHP can continue to operate in combined mode, and the heat generated will be directed to storage.

7. Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (OJ L of 2023, No. 231).

Fig. 11. New criteria for efficient district heating systems



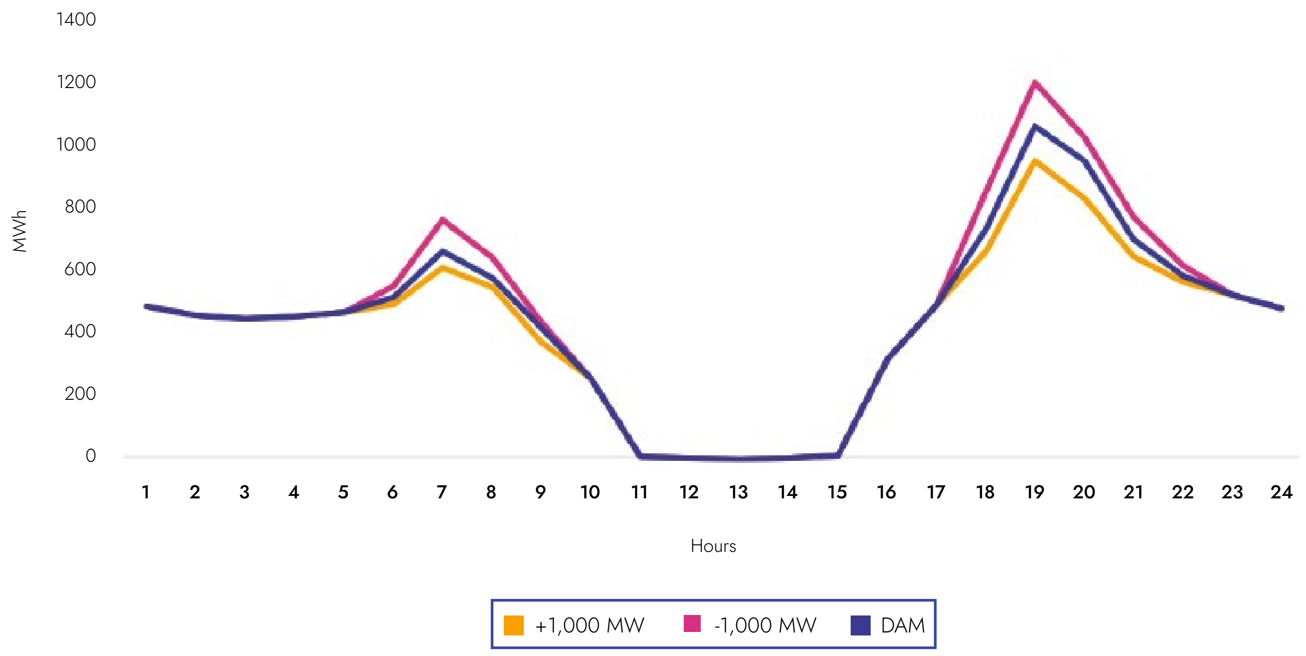
District heating operation features and flexibility

Cogeneration units are featured by high operating dynamics. CHP units can be started up and shut down at short notice (excluding CCGT units), which is key to ensuring the flexibility of the power system. For example, when hot, gas engines can reach full power in a few minutes, while gas turbines need about 10 minutes to do so. The start-up limits for CHP units further depend on the specific manufacturer and model, and are also affected by warranty provisions and service conditions, but, nevertheless, engines or gas turbines can usually be started at least 200 times a year. Thus, the use of cogeneration provides opportunities to quickly adapt energy production to changing market conditions and demand.

Sector coupling potential

CHP sources are an important component in providing peak NPS power demand. At the same time, they can operate in condensing mode, which makes them suitable for rapid load variations due to the variability of renewable production. During NPS peak demand, cogeneration units can provide additional energy. Figure 12 shows an example of the change in electricity prices on the DAM (Day-Ahead Market) due to a reduction or an increase in available capacity during peak demand hours, which could be provided by CHP sources. Using a selected March day as an example, the potential impact of a change in the capacity of generating sources on electricity prices is illustrated. On March 20, 2025, there were zero energy prices during the midday hours (11:00 a.m. to 3:00 p.m.), which could be used by electrified heat sources. Between 6:00 p.m. and 9:00 p.m., prices were rising dynamically and were naturally featured by the greatest sensitivity to changes in available capacity. An additional 1,000 MW of capacity available for cogeneration – generating electricity with a relatively low variable cost – could reduce prices by more than PLN 100/MWh on that day. In contrast, a loss of 1,000 MW of available capacity or a 1,000 MW increase in demand would increase energy prices by more than PLN 150/MWh.

Fig. 12. The impact of the change in available capacity on electricity prices on the example date: 20 March 2025



The above price situation is observed in the system with increasing frequency. Further development of cogeneration could reduce costs during morning and evening peak demand, and the development of heat electrification would make it possible to take advantage of low electricity prices during midday to produce heat at low variable costs. As a result, the power system would get a better capability for flexible balancing.

Interaction of cogeneration units in condensing mode with the NPS

Some generating units, especially in larger district heating systems, have the ability to operate in condensing or "pseudo-condensing" mode, i.e., to generate more electricity independently of the heat produced. This applies to extraction condensing turbine generator units with district heating extraction or backpressure turbine units with a system of dedicated cooling towers. Such units basically operate in district heating mode, and at lower heat demand, with favorable electricity prices, they can operate in condensing mode. A similar mode of operation is also available for gas engines equipped with the so-called hot stack or a system of dedicated cooling towers. These capabilities are extremely beneficial for ensuring the safe operation of the National Electricity System Some of these units are so-called Centrally Dispatched Generating Units (CUs). Thus, they provide control services for the Transmission System Operator (TSO). Part of the available capacity band is utilized for the needs of the district heating system, and the surplus is at the disposal of the Operator and is used in condensing mode. Outside the heating season, the unit can be entirely at the TSO's disposal. Typically, these are high-capacity combined cycle gas turbine units with great operating flexibility, high gradient of power intake and reduction, and relatively short start-up time. These properties make these units essential for stable operation and balancing of the NPS.

Other units that the Operator cannot directly control, the so-called nJWCDs (non-centrally dispatched generating unit), which have the ability to operate in condensing mode, can provide various services ordered by the TSO, such as the Reliability Must Run (RMR) service. This service consists of increasing or decreasing the level of electricity generation at the TSO's order.

In recent years, due to the significant growth of RES units and the emerging surplus of electricity, the role of units that can operate with capacitive reactive power for the NPS to compensate the system has been increasing. This service can be provided by commissioning a condensing unit whose operation is not required for district heating reasons, as well as by making appropriate use of generators from decommissioned coal-fired units. Despite the oversupply of active power, the TSO often decides to maintain such units in operation due to their controllability to achieve voltage stability in a given part of the System.

Improving grid performance

In addition, cogeneration units can significantly improve power distribution in electricity grids and reduce transmission and distribution losses. Since CHP plants are often built in cities, all electricity is consumed on site, which eliminates the need to transfer it using transmission networks. An example is Warsaw's combined heat and power plants, which cover almost 50% of the capital's electricity demand, significantly improving the functioning of Warsaw's power unit. In addition, CHP units stabilize grid frequency. CHP units provided with turbines and generators, with large rotating masses (a power reserve that is maintained to respond quickly to sudden changes in electricity demand or system disturbances) and thus high inertia, delay momentary changes in system frequency at times of significant power fluctuations. In addition, the cogeneration systems described, especially those based on SCGTs and engines, are an excellent generating source for providing self-start service and blackout protection.


Veolia Group in Poland

3.2.2. Power to Heat technologies

Power to Heat (P2H) consists in the use of equipment converting electricity into heat. 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 (the so-called upper heat source).
- **Electrode boilers** – use electricity directly to heat water in the district heating network to a set temperature.

Heat pumps

Heat pump is a device that transports heat from a lower temperature medium, from the so-called lower heat source, to a higher temperature medium, the so-called upper heat source, which may be, for example, a district heating network or a heating system of a building. This uses a cycle of thermodynamic processes to which the working medium is subjected. At the beginning of the cycle, it receives heat from the lower source and it vaporizes; then, its temperature increases using energy supplied to the device. Temperature 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). The working medium then enters the condenser, where it gives up heat and takes liquid form. In the last transformation, it is directed to the expansion valve where its pressure is reduced.

Heat pumps are commonly used to extract heat from low-temperature sources. 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 processes. In system-based district heating, typically large-scale pumps are used, reaching a capacity range of 0.5 MW_t to 25 MW_t. The advantage of heat pumps is their high efficiency, allowing them to obtain an average of about 2.5–4 MWh of heat from one MWh of electricity (for compressor pumps).

Electrode boilers

The operation of an electrode boiler is based on heat generation that accompanies the flow of electricity through properly prepared circulating water with a specific electrical conductivity. The main component of the boiler is a high-pressure vessel filled with water and electrodes to which voltage is applied. 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 can reach high temperatures, up to 160°C. Electrode boilers can reach capacities from 1 MW_t to 60 MW_t. The advantages of electrode boilers include compact size, scalability, and low investment cost. As an alternative to electrode boilers, resistance boilers can also be used, where water is warmed up by heat released in resistance elements (heaters) due to the flow of electricity.

For more details on the Power to Heat technology, refer to Polish Association of Heat Energy 2024 report titled ***Potential for the use of Power to Heat technologies in the transformation of the system district heating sector in Poland.***

Regulatory conditions

Under the current legal status, national regulations do not provide the possibility to fully support energy companies in meeting the criteria for declaring the district heating system effective using the Power to Heat technology. It is possible to treat heat extracted from the environment as renewable heat only in the case of heat pumps.

On the grounds of the recent amendment to the Renewable Energy Directive (hereinafter: the REDIII Directive), the possibility was introduced to count renewable electricity used for heating and cooling towards the average annual increase in renewable energy in the heating sector (Article 23) – as flexibility (up to 0.4 pp), and in district heating systems (Article 24) – where the target explicitly includes renewable electricity. Furthermore, for the heating sector, requirements have been set that in practice are met only by heat pumps. With regard to district heating systems, no specific requirement has been specified for the type of eligible heat and cooling generating units, so, as a rule of thumb, renewable electricity, used by heat pumps or electric boilers of any kind, can contribute to pursuing the goal. Although the above regulations are quite restrictive regarding the qualification of heat generated from electricity as renewable heat, they provide a formal basis for using Power to Heat technology to produce heat from renewable electricity.

A separate mechanism for qualifying individual heat shares is used to meet the definition of an efficient district heating system under the EED Directive. According to the Commission's Recommendations, with regard to the interpretation of Article 26 of the EED Directive[8], the share of a given type of heat, including renewable heat, should be understood as the amount of heat supplied to the district heating network. The Commission's Recommendations also points out that heat coming entirely from a heat pump should be accounted for, pursuant to the EED Directive, as energy from renewable sources, provided that the heat pump in question meets the minimum efficiency conditions of Annex VII to the Directive (EU) 2018/2001 at the time of installation. At the same time, the Commission's Recommendation also confirms that electricity from renewable sources and converted to heat in electrode boilers can be qualified as renewable heat.

In view of the above, to increase the use of electricity from renewable energy sources for the production of renewable heat, it is necessary to introduce solutions allowing to include as renewable energy also heat or cold generated from RES electricity 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.

8. COMMISSION RECOMMENDATION (EU) 2024/2395 of 2 September 2024 setting out guidelines for the interpretation of Article 26 of Directive (EU) 2023/1791 of the European Parliament and of the Council as regards the heating and cooling supply.

District heating operation features

Due to their relatively low operating costs but high investment, heat pumps appear to be good devices for heating. In contrast, electrode boilers have high operating costs that depend on instantaneous electricity prices and low CAPEX. Electrode boilers can be used as backup and peak sources, but this will be associated with operation at times of high energy prices. Much greater benefits can come from optimizing the operation of electrode boilers for the NPS situation and low electricity prices. A factor that significantly reduces the cost-effectiveness of Power to Heat equipment is the connection capacity fee, which in terms of electricity will be noticeably higher compared to similar fees for other utilities (gas, system heat). There is also certainly a lack of legislative solutions that would promote this technology as emission-free and supporting the development of RES in district heating.

Utilization in sector coupling

With proper optimization of operation, Power to Heat technologies in district heating will be able to be used to produce heat at times of low electricity prices, that is, at times of low demand or excess generation from renewable sources. A technology that can reconcile the needs of district heating and the NPS are electrode boilers that allow:

a. Taking advantage of low electricity prices in the market, which translates into lower heat generation costs. Beginning in 2024, the number of days with negative electricity prices increased significantly in the wholesale market across Europe, including Poland (this was one of the most significant energy market phenomena observed in 2024). A comparison of the number of days with negative energy prices is provided in Table 6. This structural variability in the market has created favorable conditions for the development of sector coupling.

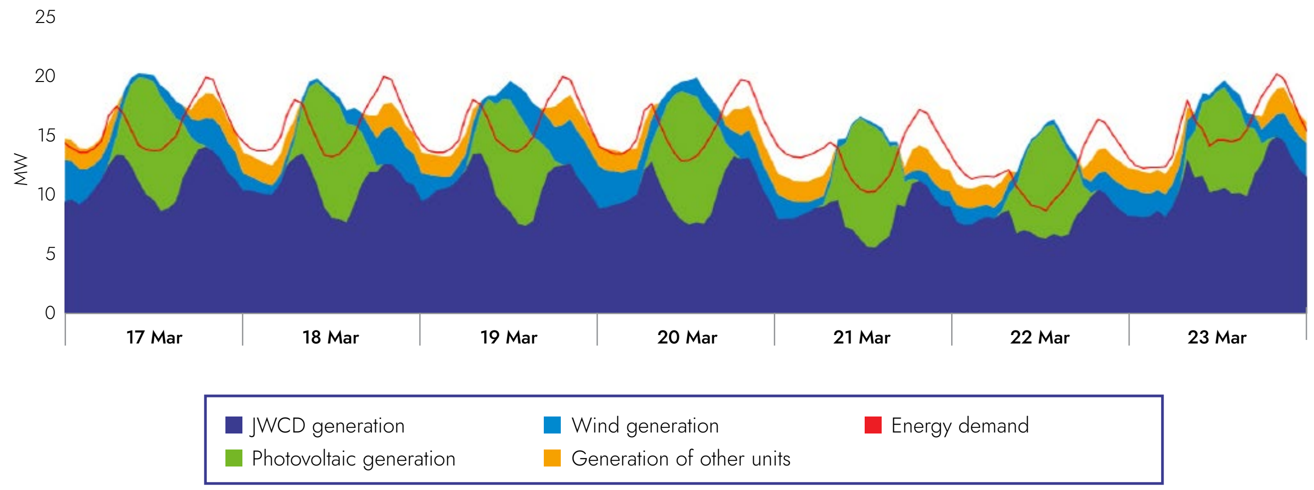
The Power to Heat units operate at their best performance at low electricity prices. In the case of heat pumps, due to their high efficiency, electricity consumption will be lower compared to the heat generated. This is much more important in the case of electrode boilers, where the amount of electricity consumed is almost equal to the amount of heat produced.

Table 6. Comparison of the number of days with negative electricity prices

	2024	January – April 2025	Heating and transitional season (January 2024 – April 2025)
Number of hours with negative electricity prices	186	129	219
Number of days with negative hours greater than 6 in a row	13	9	13
Maximum number of hours with negative prices in a row	8	8	17
Minimum price, PLN/MWh	-360	-500	-500

b. More heat from RES and less reduction of renewable sources in the NPS – it means operation at high production from renewables and increasing demand for energy in the NPS at times of "excess" production, thus avoiding non-market reduction of RES. The heat produced at this point comes from electricity, which is mainly sourced from renewable energy. In the long term, this can help ensure the required shares of RES heat and meet the requirements of an energy-efficient district heating system. RES shares appear not only in the summer, at times of highest generation from photovoltaic sources, when there is, in general, lower demand for system heat. In both 2024 and 2025, significant RES shares also occurred in the transition months; usually, increased shares came from wind generation.

Fig. 13. Example spring days with oversupply of RES electricity and RES shares at given times



The variability of renewable generation and demand led to significant challenges with balancing of the NPS in 2024 and in January to April 2025. On many days, in summer with high photovoltaic production, in winter with strong winds, on weekends or holidays, there was an oversupply of energy that the system was unable accommodate. PSE benefited from non-market redispatching of RES units, i.e., the curtailment of wind and photovoltaic farms. In 2024, the volume of RES reduction exceeded 680 GWh, and in 2025 (until April) it was 390 GWh. In hours with reductions, the percentage share of RES in the balance of the NPS was at 40–60%.

JANUARY 2024 – APRIL 2025

RES reductions
1070 GWh

RES share
40–60%

9. Data based on PSE reports – Non-market redispatching of RES sources

3.2.3. Heat storage facility – cooperation with cogeneration and Power to Heat technologies

Since surplus electricity from RES is not always correlated with heat demand, the use of heat storage facilities is envisaged. This allows for making heat production (and therefore power consumption of Power to Heat equipment) independent of demand from the district heating system, and for reducing the cost of heat generation thanks to the variability of electricity prices.

Short-term storage facilities that enable flexible operation of heat sources are those most commonly used in district heating systems. A proven and mature technology involves water accumulators which are hot water tanks that use the phenomenon of heat stratification. Layers of hot water with a temperature of approx. 98°C (for non-pressurized tanks) or higher (for tanks with increased or high pressure) are located in the upper area, and layers of cooler water, with the temperature of return water from the municipal district heating network, are located in the lower area of the tank. 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 Power to Heat sources and cogeneration units. The accumulator is capable of storing heat generated during periods of surplus electricity from RES occurring in the National Power System or more generally during periods when electricity prices are low. The operation of the accumulator contributes to obtaining electricity from the spot or balancing market at a favorable price regardless of heat demand, thus reducing the cost of heat generation.

In addition, by storing heat, investments in power networks can be significantly reduced by optimizing electricity generation and adjusting it to demand in local markets. Combined heat and power plants are mostly located near cities, where the electricity and heat produced meet local needs, which has a positive effect on energy flows in the power network. A combined heat and power plant equipped with a heat storage facility is exceptionally advantageous for optimizing electricity and heat production with respect to the two shifted curves of hourly electricity demand in the power system and hourly heat demand, as shown in the figure below. This shift results in better optimization of electricity production relative to local market needs and the accumulation of surplus heat in the heat accumulator, and in the case of increased heat demand, which occurs at night when the electricity demand is reduced, the heat accumulator returns the stored energy to the district heating network, allowing the reduction in production in cogeneration units.

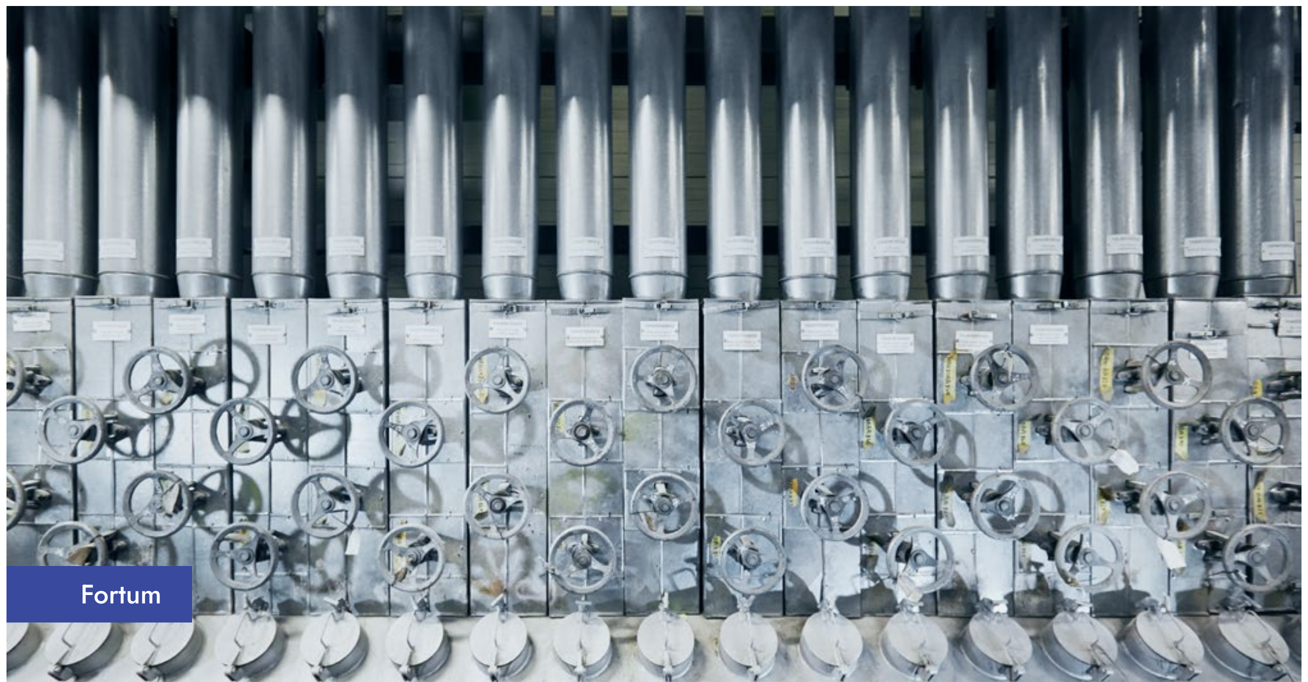
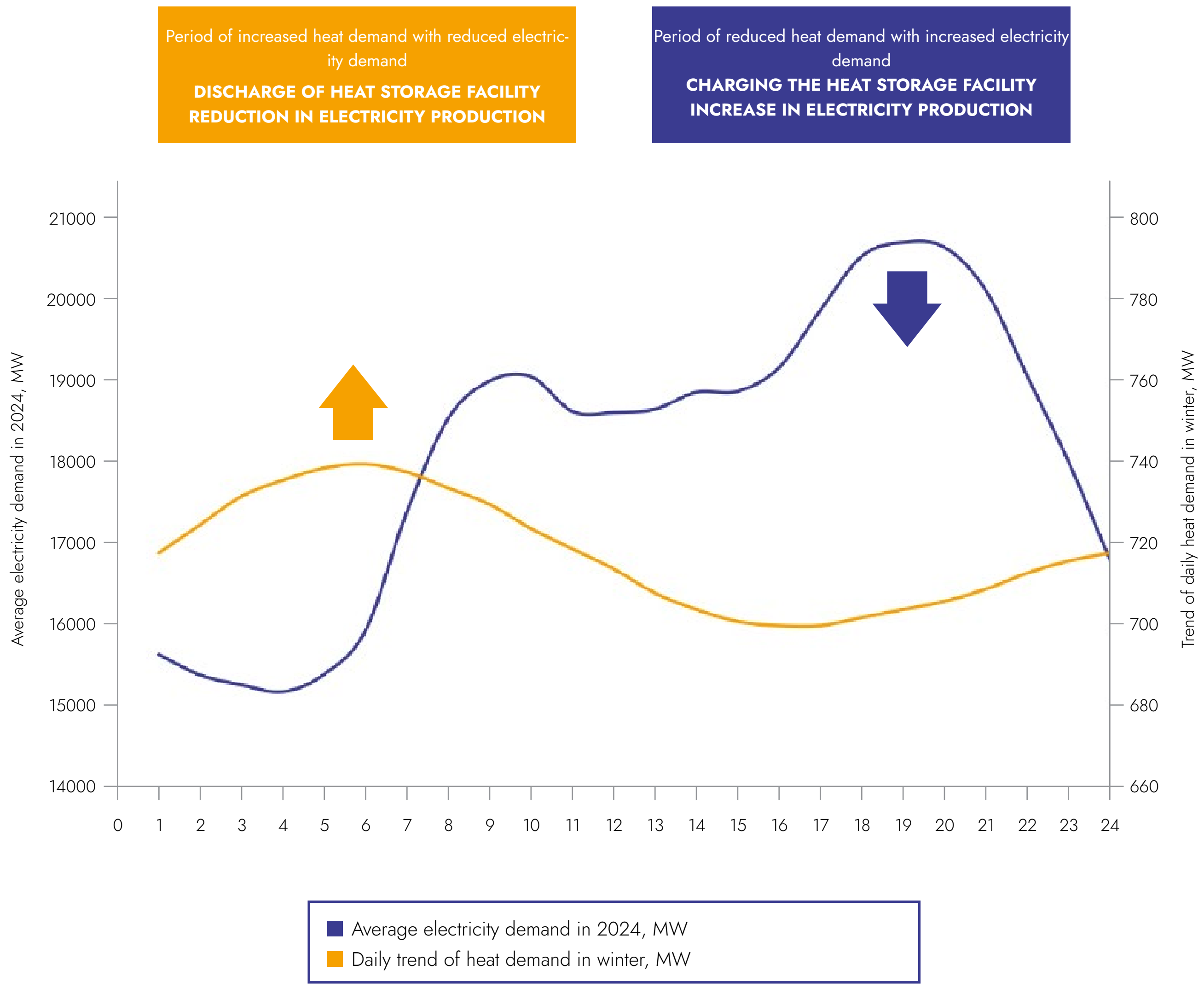


Fig. 14. Heat and electricity demand curves for a sample day in winter



At the same time, seasonal heat storage facility technologies are being developed, that allow for longer heat retention than accumulators. Their purpose 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 panels, photovoltaic farms connected to Power to Heat equipment, and directly from electrode boilers or heat pumps, due to relatively cheap electricity 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. Seasonal heat storage facilities can also cooperate with cogeneration units to avoid excessive electricity production in the condensing mode.

3.3. District heating assets

3.3.1. Transformation of district heating assets

District heating assets can be divided into heat generation and heat distribution assets. The former include district heating plants and combined heat and power plants, as well as smaller distributed units (e.g., local boiler houses), including generation sources integrated with heat units (heat interface units). Distribution assets include district heating networks with the accompanying infrastructure, including heat units. Most of Poland's district heating assets are currently undergoing a transformation, driven by the significant exhaustion of the infrastructure and the need to adapt the assets to changing regulatory and environmental requirements.

From the point of view of meeting the criterion of an efficient system by district heating systems in future time frames, it will be necessary to gradually abandon combustion of fossil fuels. As a first step, it will be necessary to resign from the operation of coal-fired sources, as they have higher specific CO_2emissions. The intermediate fuel in achieving individual milestones within the definition of an efficient district heating system will comprise natural gas, but from a regulatory perspective, its use fits into the definition of an efficient district heating system until the end of 2039[10], and in the case of high-efficiency cogeneration until the end of 2044. After this period, as long as a sufficient volume of decarbonized gases is available, it is possible to use some of these assets as RES plants. Technologies based on combustion of renewable fuels such as biogas or biohydrogen are not currently available on a large scale. In addition, it should be noted that after 2040, under the current parameters of the EU ETS, the CO_2 allowances available in the primary market will run out.

The use of weather-dependent RES (e.g., solar panels) in district heating systems requires their reservation and a heat accumulation. In addition, the direction of change in district heating also includes the use of technologies based on electricity, such as heat pumps and electrode boilers (Power to Heat). Polish Association of Heat Energy 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.

Current projections indicate that as a result of the transformation of district heating assets, the existing structure of heat and electricity generation in cogeneration will also change. In 2023, electricity produced by utility combined heat and power plants amounted to approx. 16% of total production in the NPS. Under current regulatory conditions and available support systems, the share of cogeneration in system district heating in Poland will gradually decrease starting from 2035. Such a change will result in the reduction in installed power output in the power system by the power installed in cogeneration sources. Particularly noteworthy here is the fact that these sources are usually located in close proximity to the areas of the distribution network, where the largest energy consumption occurs, i.e. in small, medium and large cities.

As it can be seen, in connection with the above directions of transformation of system district heating, the interface points between the district heating and power sectors will change – on the one hand district heating will become an increasing recipient of electricity, and on the other hand the challenge will be to replace the depleted coal-fired cogeneration units, which are currently a significant producer of electricity for the National Power System.

The National Power System today faces a problem of imbalance in electricity supply and demand. For the system district heating, in the context of transformation of its assets, this means two major problems – the problem of availability of connection capacity for Power to Heat equipment and the problem of obtaining conditions for connection to the network for cogeneration units. However, within the framework of sector coupling, it is possible to develop solutions advantageous for all the parties, as the district heating industry has the opportunity to adjust production periods and electricity consumption to the requirements of the NPS.

10. Polish Association of Heat Energy Report *"The impact of EU regulations on the transformation of the system district heating sector in Poland, assessment of effects and recommendations for national regulations"* p. 77.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3.3.2. Conditions on the part of district heating networks

In order to identify opportunities for cooperation between the NPS and the district heating sector, a less obvious aspect to be taken into account comprises the considerations relating to district heating networks.

The majority of district heating networks in Poland are high-temperature networks, which have been designed with the assumption that the supply temperature will be approx. 150°C (under design conditions). It should be pointed out that the introduction of pre-insulated pipe technology (which is now a commonly used solution for the construction/replacement of sections of district heating networks) resulted in the possibility of lowering the supply temperature of the heating medium to 120–135°C[11].

Heat is supplied to consumers in accordance with certain quality requirements – the district heating company must provide the required thermal power and meet the requirements for the relevant parameters of the heat carrier, in particular its supply temperature, flow rate and available pressure.

Most district heating networks in Poland have been designed to transport water heated to at least 120°C. However, this is becoming a limitation for the implementation of low-temperature RES sources, among others: heat pumps, that is, sources that draw electricity. In practice, the implementation of low-temperature technologies in networks operating in the high-temperature regime allows the heat demand to be met mainly in summer, while in winter additional water heating using other equipment is necessary. Cogeneration and electrode boiler technologies, on the other hand, are fully capable of delivering heat to a set temperature. At the same time, in high-temperature networks, with the right range of equipment, the potential of both low- and high-temperature units can be exploited.

11. Polish Association of Heat Energy, The impact of EU regulations on the transformation of the system district heating sector in Poland, assessment of effects and recommendations for national regulations, Warsaw, October 2024.

3.3.3. Barriers to the introduction of low-temperature networks

The development of low-temperature district heating networks is an integral part of the process of transforming district heating (due to the lack of a uniform definition, for the purposes of this document, it was assumed that low-temperature networks are infrastructures where the maximum supply temperature is below 70°C). The main benefits of low-temperature networks can be primarily:

- the possibility of using "low-temperature" generation sources (RES, including heat pumps) for the district heating system;
- the possibility of ensuring closer cooperation between the NPS and district heating systems;
- saving on capital expenditures due to the possibility of using, mainly in the case of heat pumps, units with a lower thermal power (compared to a situation where there is a need to supply a high-temperature system);
- operational cost savings (i.a. due to lower network losses).

The development of low-temperature networks in Poland will be particularly challenging, due to a number of barriers of different nature. These barriers can be divided in particular into: **technical, financial, formal and organizational,** which are shown in table 7.

Table 7. Barriers and challenges to the introduction of low-temperature networks

Barriers and challenges to the introduction of low-temperature networks	
Of technical nature	■ The specificity of district heating systems, the need to meet high technical parameters. ■ The need to adjust internal systems in buildings to operate in a low temperature regime[12], changing the adjustment of heat substations.
Of financial nature	■ The scale of expenditures on the retrofit of internal systems in buildings (according to Polish Association of Heat Energy estimates) could range from PLN 115 billion to PLN 149 billion[13]. ■ Undertaking investments by district heating companies in the retrofit/alteration of system heat transmission and distribution infrastructure, networks, substations, pumping stations. According to Polish Association of Heat Energy, the estimated expenditures for network replacement/retrofit could amount to at least PLN 82 billion[14]. ■ The above means that without a significant public support, the process of retrofitting internal systems and network infrastructure will not be able to be carried out on a scale adequate to the needs.
Of formal and organizational nature	■ Low, out-of-date design temperatures determining the heating load of buildings (PN-EN 12831:2006 standard) in the range of -24°C to -16°C cause oversizing and suboptimal selection of systems. ■ The need to update climate zones in terms of the applied design temperatures.

12. Polish Association of Heat Energy, The potential for the use of Power to Heat technologies in the transformation of the system district heating sector in Poland, Warsaw, June 2024.
13. Polish Association of Heat Energy, The impact of EU regulations on the transformation of the system district heating sector in Poland, assessment of effects and recommendations for national regulations, October 2024.
14. Ibid.

3.4. Benefits of sector coupling

The integration of the district heating and power sectors represents an opportunity not only to reduce greenhouse gas emissions and contribute to the EU's climate commitments, but at the same time to improve energy security. In view of the growing share of unstable renewable energy sources and the recent fuel market crises, the concept of closer sector coupling is gaining importance as a part of a modern energy policy that includes technical, economic and environmental aspects.

Table 8. Benefits of sector coupling of the system district heating and power sector

Benefits of sector coupling of the system district heating and power sector	
Of technical nature	■ Improvement of stability and decrease in the load of the power network. Distributed district heating systems located throughout the country can locally consume surplus RES energy. ■ Reduction in the need to transmit electricity over long distances – large district heating systems provided with cogeneration sources are located in major cities. ■ Ability to support the NPS through the production of electricity in high-efficiency cogeneration, which increases fuel use efficiency and promotes the efficient conversion of primary energy. ■ Use of publicly available electricity.
Of financial nature	■ Optimization of operation of electricity generating units (taking advantage of high electricity prices) and units that consume electricity for heat production (taking advantage of low electricity prices), which can contribute to lower heat production costs. ■ Reduction in the costs associated with RES redispatch. ■ Possibility of new functions for district heating: development of balancing services. ■ Reduction in dependence on fossil fuels when using electricity produced from RES.
Of formal and organizational nature	■ Decarbonization of district heating and diversification of fuels through the use of electricity. ■ Possibility of supplying Power to Heat equipment with zero-emission fuel. When the share of RES energy is high in the production of electricity in the NPS, district heating supplied with this energy can produce heat with a high share of RES. ■ Reduction in CO_2 and particulate emissions.

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4. Cooperation of the district heating system with the power system using cogeneration and Power to Heat technologies

The previous chapters presented general information on sector coupling, including the description of technologies that support sector coupling and its benefits. This section will present an analysis showing how system district heating can cooperate with the NPS. The cost of heat generation for different technology options was compared on the basis of the actual electricity generation in the National Power System and the price situation on the Polish Power Exchange as observed in 2024 and 2025 (the period between January 2024 and March 2025).

Annual hourly heat demand data for a large district heating system with a thermal power of approx. 725 MW_t was used as the basis for the modeling. At the same time, a hybrid process system using diverse energy sources was assumed. Detailed information on the above-mentioned options is presented in table No. 9.

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Table No. 9. Analyzed technology options

Option	Description	Equipment	Installed capacity, MW_t/MW_e
Option 1	**Layout showing the current state.** The main equipment includes coal-fired power units and boilers. They are complemented by a heat storage facility.	Coal-fired cogeneration	400/188
		Coal-fired boilers	200
		Coal-fired boilers	75
		Oil-fired boilers	50
		Heat storage	19,000 m^3
Option 2	**System after transformation, showing a situation in which cogeneration and Power to Heat technologies would already be operating in the district heating system in a model way today.** The option assumes that cogeneration units benefit from a support system. A biomass-fired boiler complements the generation mix. The operation of a heat storage facility was assumed.	Gas-fired boilers	375
		Gas engines	150/150
		Electrode boilers	150
		Biomass-fired boilers	50
		Heat pumps	50
		Heat storage	19,000 m^3
Option 2B	Option 2 with forced operation of electrode boilers as balancing units of the NPS with surplus RES energy.		
2C **variant**	Option 2 without a support mechanism for high-efficiency cogeneration.		
Option 3	**After-transformation system,** showing a situation in which cogeneration does not receive support, and generation would only include heat generation. Checking how variable costs of heat generation are affected by revenues from the sale of electricity.	Gas-fired boilers	375
		Electrode boilers	200
		Biomass-fired boilers	150
		Heat pumps	50
		Heat storage	19,000 m^3

It should be noted that capital expenditures and fixed costs – employee remunerations, costs of overhauls, insurance and taxes – were not included in the presented cost calculations for the various options. However, variable costs (fuel costs, CO_2 allowance costs, distribution fee costs) and some fixed costs affecting technology selection and performance analysis (costs of fees for contracted capacity in gas and electricity) were included. In addition, generation costs are reduced by revenues generated from the sale of electricity to the network and support for high-efficiency cogeneration.

To sum up – the analysis aims to show how the order of operation of the assets is shaped, assuming the production of heat at the lowest cost (mainly variable) of heat generation in a given year, with the indicated technology stack.

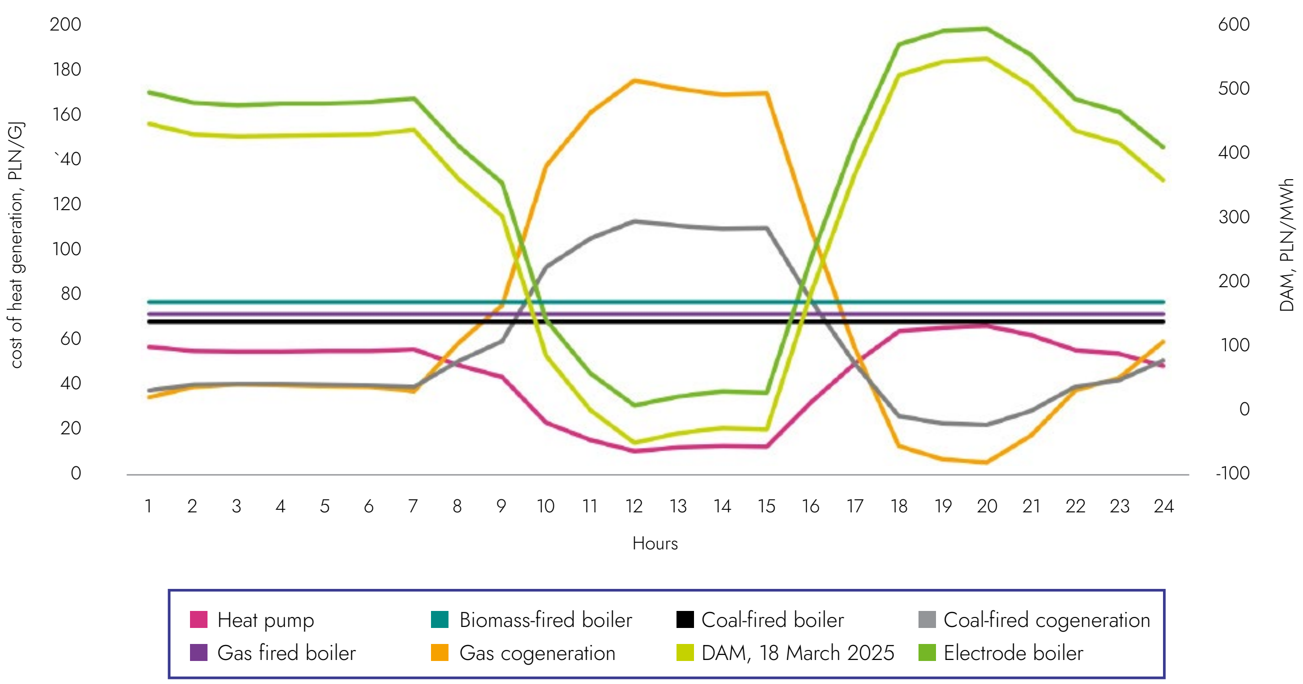
Key assumptions:

- electricity prices, CO_2emission allowance prices, natural gas prices, hard coal prices and electricity production volumes – in accordance with the values observed in 2024[15],
- support for high-efficiency cogeneration equal to PLN 200/MWh,
- electricity distribution costs were assumed at PLN 55/MWh,
- fees for contracted capacity for gas and electricity were assumed at the level of averaged values from 2024 tariffs.

Methodology

A model that optimizes the operation of combined heat and power plant equipment based on hourly electricity prices was used for the calculations. Bringing the calculations down to the level of hourly prices is important when presenting the relationship between the district heating and power sector and in the context of use of cogeneration, as well as electric heat sources, whose operation depends on electricity prices in the market. Using the average annual price of energy does not allow for capturing moments when the use of Power to Heat technology is more cost-effective than cogeneration units or gas-fired boilers.
The variable costs of heat production depending on the price of electricity for an example date of March 18, 2025 are presented below.

Fig. 15. Variable costs of heat production based on hourly electricity prices for an example day: 18 March 2025



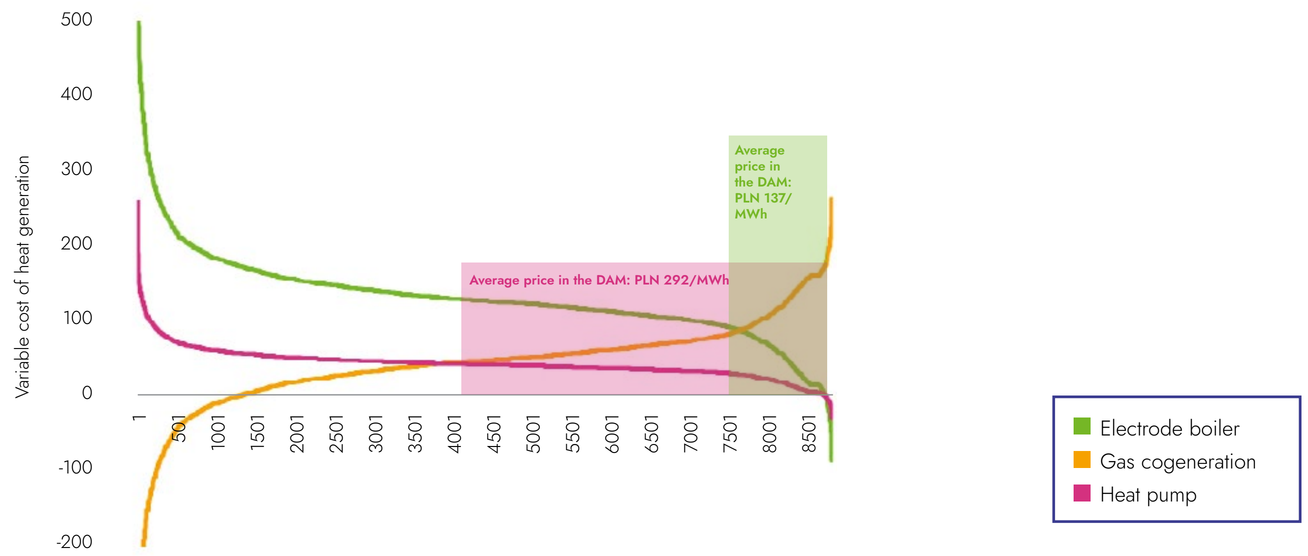
15. Electricity and natural gas prices based on DAM data from the Polish Power Exchange; CO_2 allowance prices based on Intercontinental Exchange data; hard coal prices based on Industrial Development Agency data; electricity production volumes based on Polish Power Grid Company data.

The variability of hourly prices in the energy market influences dynamic changes in the order in which units in the generation stack start up. During certain hours (see Figure 15, 1:00 a.m. to 7:00 a.m. and 6:00 p.m. to 12:00 a.m.), with appropriate pricing conditions, CHP units can generate energy at a lower cost, which allows them to operate at the base of the system. Electrode boilers, on the other hand, are shifted to the role of peak load units due to their highest variable costs. The opposite situation occurs at times of low or negative energy prices (see Figure 15, 10:00 a.m. to 4:00 p.m.) – electrode boilers and heat pumps can then act as base units and replace cogeneration.
Based on data for the entire year 2024, an assumed distribution rate of PLN 55/MWh, and without taking into account the support for high-efficiency cogeneration, the number of hours when the use of electrode boilers and heat pumps was more cost-effective than CHP amounted to:

- **for electrode boilers** – 1,100 hours – with the average price of electricity on the wholesale market of PLN 137/MWh, and the maximum price of electricity reaching PLN 256/MWh;
- **for heat pumps** – 4,200 hours – with the price of electricity on the wholesale market of PLN 292/MWh, and the maximum price of electricity reaching PLN 411/MWh.

The results presented in the following section concern the optimization of the operation of the entire system consisting of multiple units of equipment. Therefore, the number of operating hours and the price of electricity purchase by Power to Heat sources will also depend on other units of equipment.

Fig. 16. Comparison of heat generation costs for CHP and Power to Heat sources



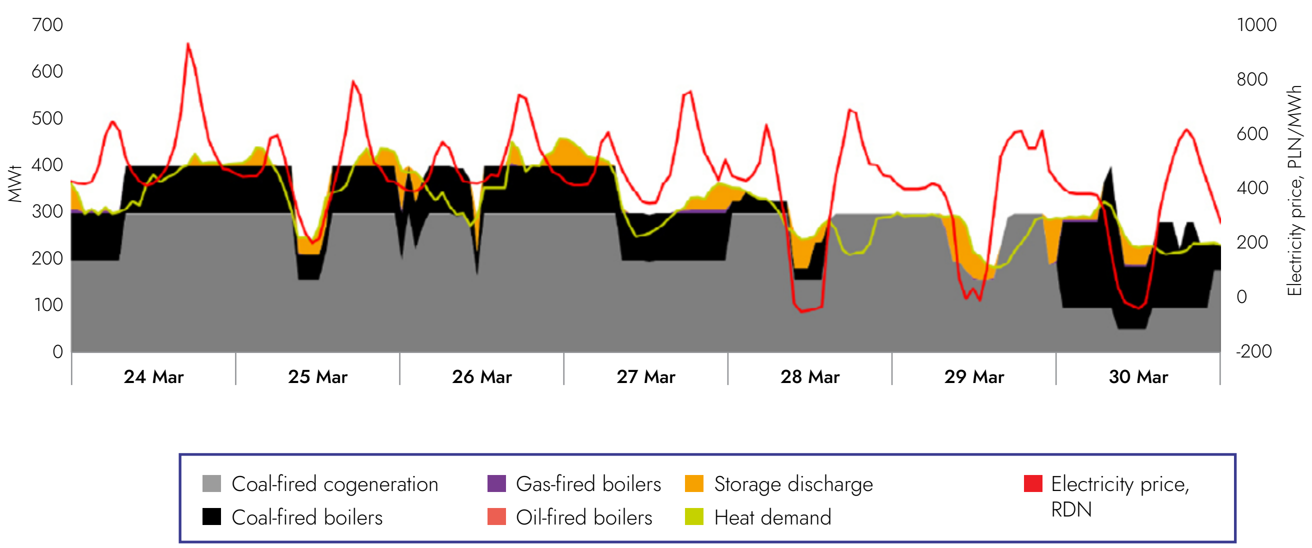
4.1. Weekly operation of equipment in individual options

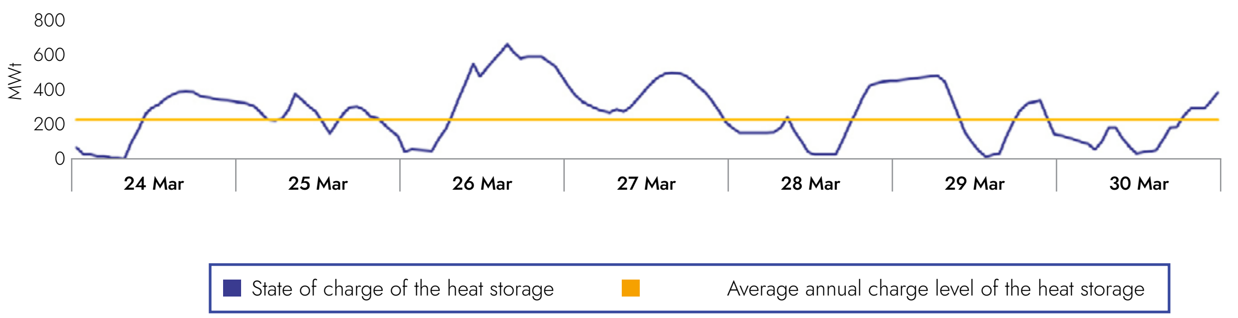
The entire analysis prepared is for the entire year 2024, however, in this section, to best illustrate the interaction between the district heating system and the NPS, the weeks of systems operation in the period of 24 March – 30 March 2025 have also been included. This is an interesting case presenting a transitional period during the year, when there is still a high demand for heat on the part of the heating industry, and there are price fluctuations on the part of the NPS due to higher spring generation from photovoltaic and wind farms. During this period in 2025, there were already hours with negative energy prices in the midday and very high prices in the evening. The results of the hourly analysis were compiled for the entire period of January 2024 – March 2025 for the indicated technology options. The results summarizing the annual operation apply to 2024 only.

OPTION 1 – A SYSTEM OF COAL-FIRED COGENERATION, COAL-, GAS- AND OIL-FIRED BOILERS, AND A HEAT ACCUMULATOR

Below is a diagram of heat production in a process system based on coal-fired cogeneration, coal-fired boilers, gas-fired boilers, oil-fired boilers and a heat accumulator.

Fig. 17. Operation of equipment in Option 1 in a period from March 24 to 30, 2025.



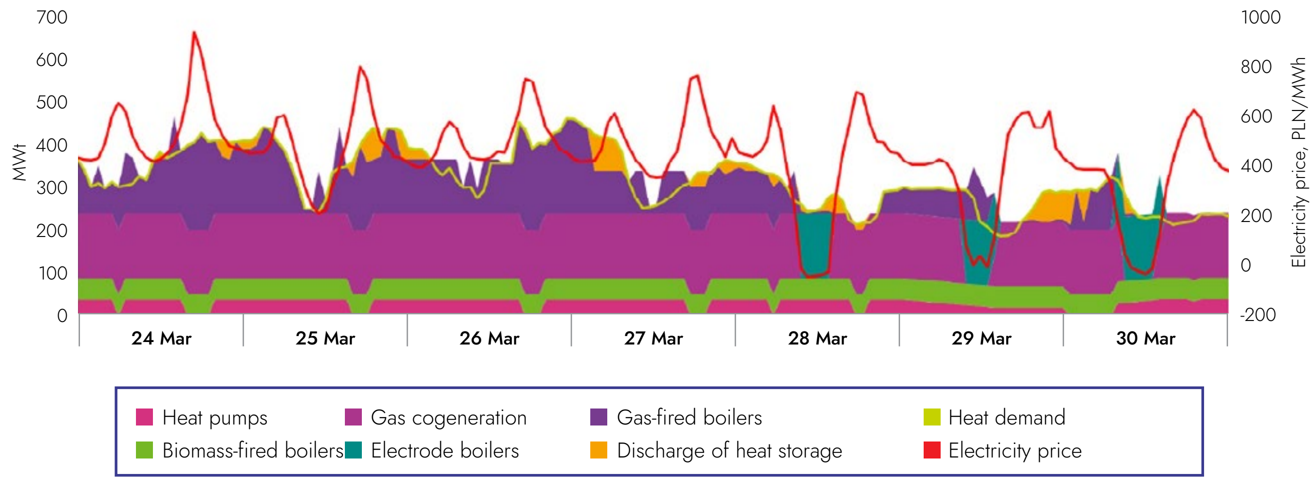


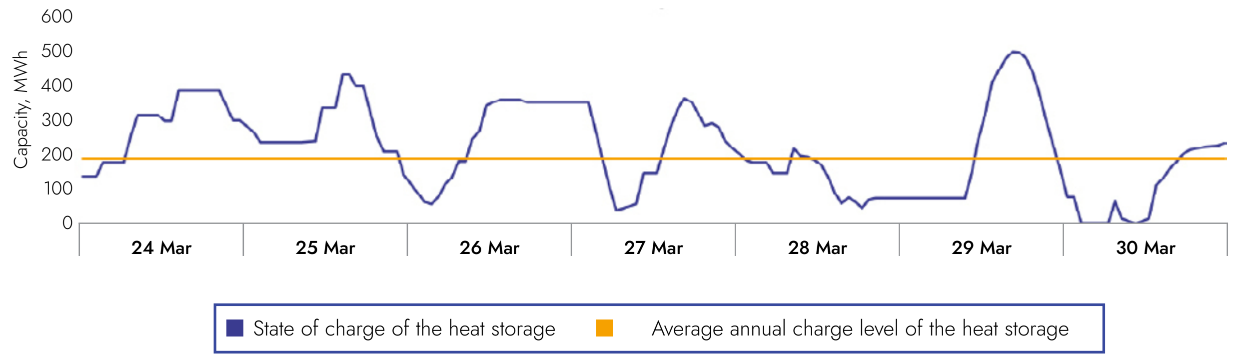
The base of the district heating system in this option uses coal-fired cogeneration, which has limited operating flexibility. For most of the hours, the units covering the heat demand are coal-fired units. They operate to meet the needs of the district heating system or recharge the heat storage. At times of low energy prices, when the operation of these units is less profitable, they are reduced and replaced by coal-fired boilers or the heat storage. This is an low-flexibility system – the heat storage can support the operation of coal-fired units, but even so, the variable nature of coal-fired units' operation throughout the year means a higher number of their start-ups, which translates into the increase in failure rates and the decrease in the life of generating units.

OPTION 2 – A SYSTEM OF GAS-FIRED COGENERATION, BIOMASS BOILERS, GAS-FIRED BOILERS, ELECTRODE BOILERS, HEAT PUMPS AND A HEAT ACCUMULATOR

Below is a diagram of heat production in a process system based on gas-fired cogeneration, heat pumps, biomass boilers, gas-fired boilers, electrode boilers, and a heat accumulator.

Fig. 18. Operation of equipment in Option 2 in a period from March 24 to 30, 2025.



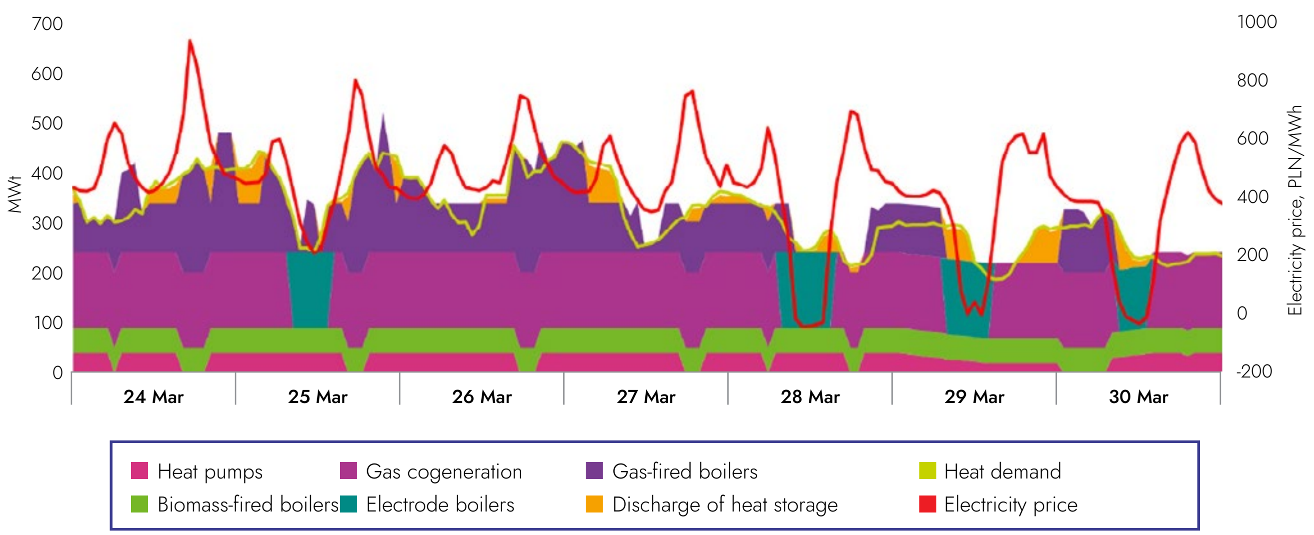


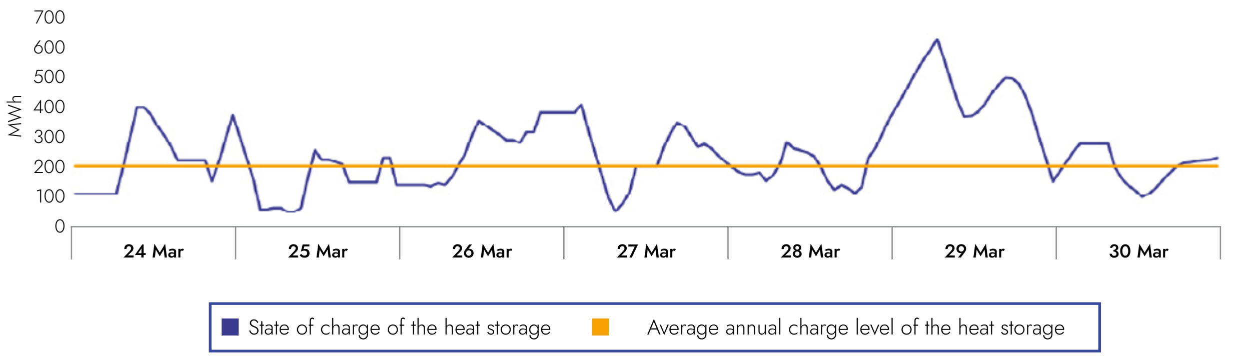
This option has a strongly diversified system of generating units. The basis of the system operation is the heat pump, biomass boiler and gas-fired cogeneration. The heat pump is turned off at times of high electricity prices and peak load units – in this case gas boilers or heat storage – are activated in its place. Under the model operation, which is optimum in terms of the system economy, electrode boilers will be activated only in the event of very low electricity prices or as peak load units supplementing the required capacity at the highest demand (mainly in winter). Gas-fired cogeneration is also characterized by base operation for a large number of hours per year, but is reduced during periods of low electricity prices – heat production is then supplemented by electrode boilers. This system has the best flexibility and interaction with the power system in terms of electricity production and consumption during low-price periods.

OPTION 2B – IDENTICAL IN TERMS OF EQUIPMENT SELECTION TO OPTION 2 WITH ADDITIONAL FORCED OPERATION OF ELECTRODE BOILERS AT SURPLUS ENERGY FROM RES IN THE NPS

Below is an additional diagram, which in its source structure is similar to Option 2. It verifies how the pattern of source operation and the level of heat prices will change, assuming that the electrode boiler is forced to operate at a time of high RES generation (more than 40%) and emerging renewable energy surpluses.

Fig. 19. Operation of equipment in Option 2B in the period of 24 March – 30 March 2025



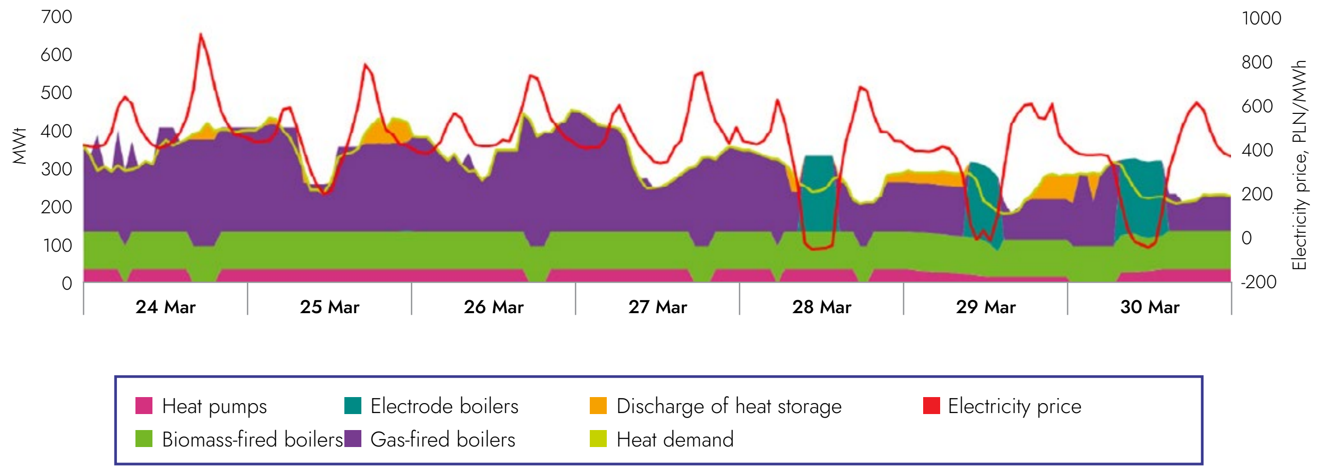


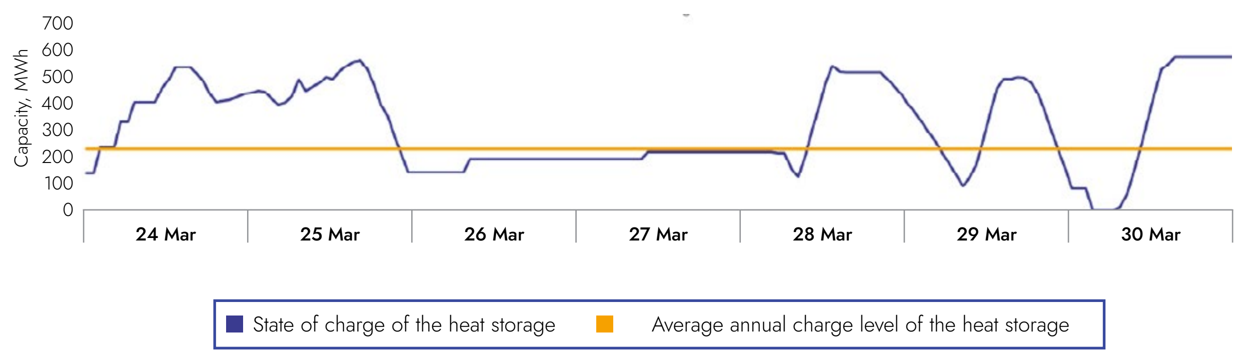
In the case of hypothetical operation of electrode boilers as balancing units and responding to increased RES shares in the network (in order to increase the share of RES in heat production for the definition of an energy-efficient district heating system), it would be necessary for this equipment to operate even at times of higher electricity prices and for a greater number of hours during the year. In this option, at times of increased share of RES energy (exceeding 40%), the average purchase price of this energy for electrode boiler operation was PLN 273/MWh, while for heat pump operation it amounted to PLN 430/MWh. At times of higher RES shares in the NPS, cogeneration units are reduced on the district heating side, and Power to Heat technologies are incorporated to replace them. Under the described assumption, the effect of the operation of these sources is a higher cost of heat production, but at the same time a higher share of electricity from RES in heat production. For such a system to operate in reality, additional operating support will be needed for the Power to Heat units to reduce the price of heat for the end user. The heat storage is recharged by gas-fired cogeneration, but also electrode boilers, making the most of the availability of low prices.

OPTION 3 – A SYSTEM WITHOUT GAS COGENERATION. GAS BOILERS, BIOMASS BOILERS, HEAT PUMPS AND ELECTRODE BOILERS

Below is a diagram of heat production in a process system based on biomass boilers, gas boilers, heat pumps and electrode boilers with a heat accumulator.

Fig. 20. Operation of equipment in Option 3 in a period from March 24 to 30, 2025.





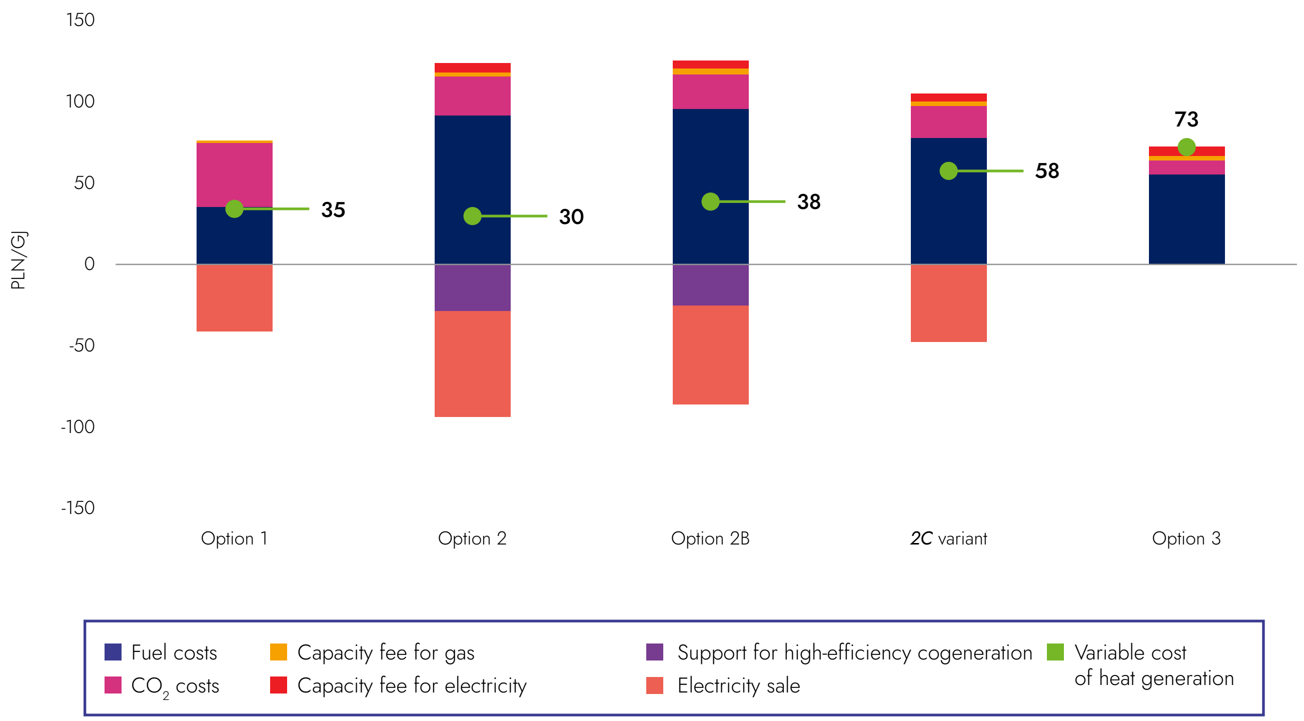
This option features a diversified layout of generating units, but does not include cogeneration systems. The basis of the operation is a heat pump and a biomass boiler. The heat pump works in the base but its operation is reduced in situations of high electricity prices. The biomass boiler, due to its fixed, relatively low, costs, runs without much change during the year. Gas-fired and electrode boilers supplement peak heat demand, with electrode boilers running during periods of low electricity prices. In such an equipment configuration, heat storage is used less. In the absence of cogeneration units, the only time to charge the battery is when the electrode boilers are operating. With this assumption, there are more frequent times when the state of charge of the storage does not change. This system has a moderate level of cooperation with the NPS – only in terms of energy consumption in periods of low electricity prices (no electricity production).

4.2. Comparison of annual results

a. Variable cost of heat generation

Conclusions from variable cost analysis:

Fig. 21. Comparison of variable costs of heat generation in the analyzed options



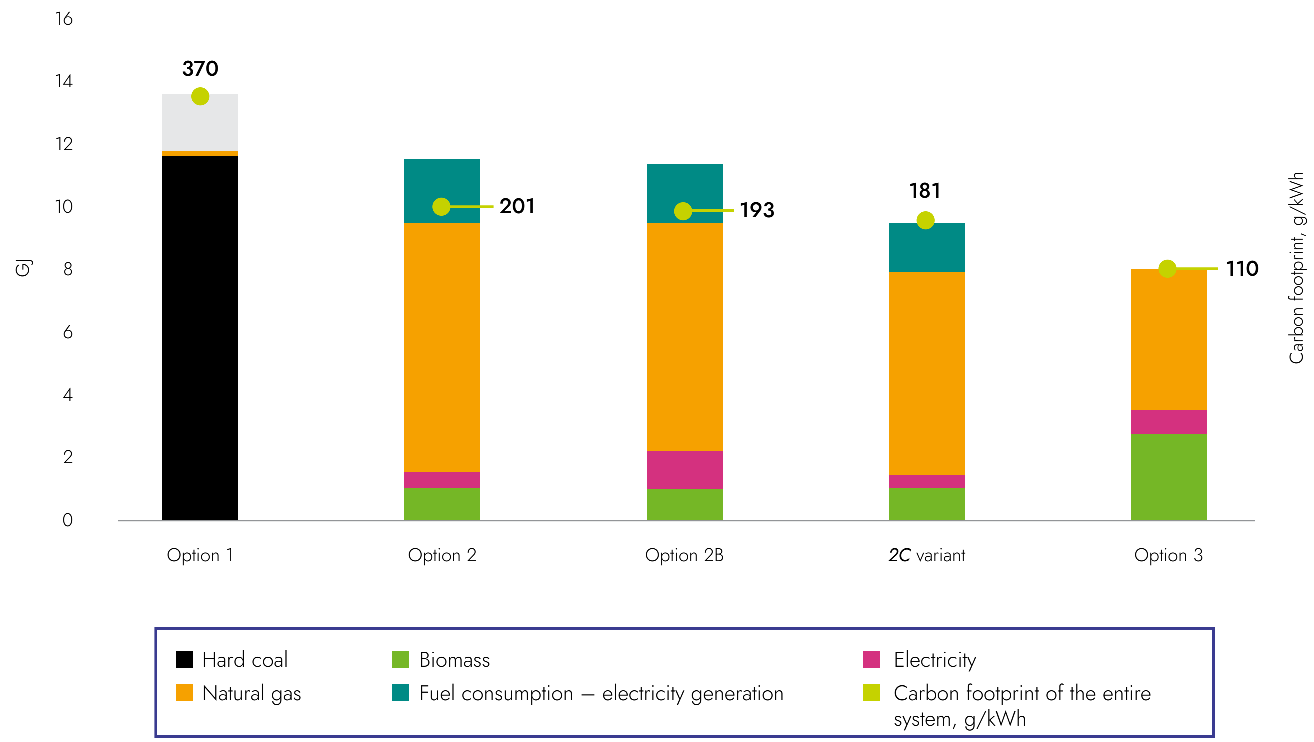
- Option 2, using Power to Heat and cogeneration sources, has the lowest variable costs for heat generation (PLN 30/GJ) thanks to electricity production. However, the impact of the support mechanism for high-efficiency cogeneration is important – in Option 2B, without additional revenue, the cost of heat generation is 93% higher.
- In the alternative Option 2 (Option 2B) with forced electrode boiler operation, the variable costs of heat generation increase by 26%. At the same time, the average purchase price of electricity for the operation of electrode boilers increases to about PLN 273/MWh compared to Option 2, where the average price oscillates around PLN 137/MWh. The higher power purchase price comes from operating more hours, not necessarily with the lowest price, but with high RES shares. In order for such an arrangement to work in reality, additional operating support will be needed for Power to Heat units to reduce heat prices for the end user. In Option 3 without cogeneration units, the cost of heat generation is the highest. The lack of revenue from electricity and support for cogeneration results in a 143% increase in the unit cost of heat generation compared to Option 2.

Table 10. Comparison of electricity purchase price for Power to Heat units in Option 2 and 2B

Comparison of electricity purchase	Option 2	Option 2B
Electrode boiler	PLN 137/MWh	PLN 273/MWh
Heat pump	PLN 430/MWh	PLN 430/MWh

b. Fuel consumption and carbon footprint of the system

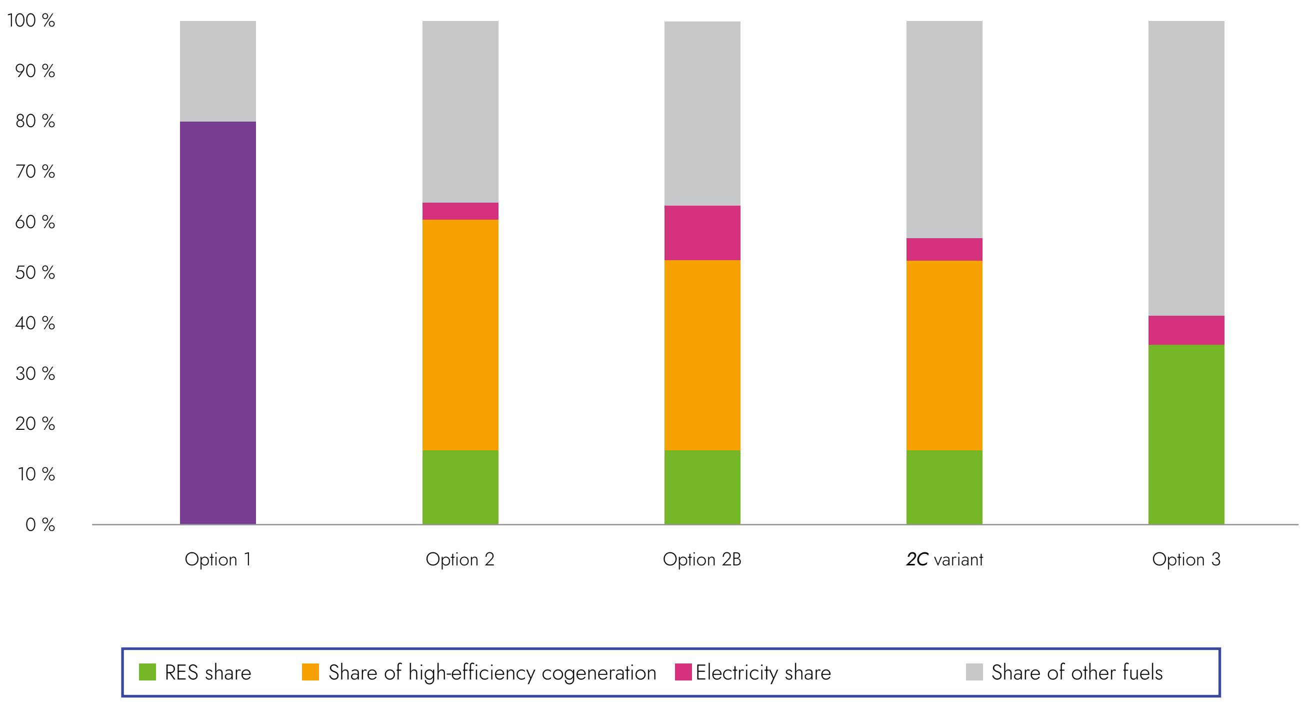
Fig. 22. Comparison of fuel consumption, electricity consumption and carbon footprint in the analyzed options



- Option 1, based on coal sources, shows the highest carbon footprint per unit of energy generated.
- Replacing coal with gas, biomass and electric units (in the other options) significantly reduces the carbon footprint. The lowest carbon footprint is characterized by Option 3, but with no electricity production, this option simultaneously has the highest cost of heat production.
- Increasing the use of electrode boilers in Option 2B lowers the carbon footprint as electrode boilers use high RES electricity during operation, but increases the cost of heat generation.
- Biomass makes a noticeable contribution to heat production in each option. Option 3, where the higher installed capacity of biomass boilers is analyzed, has the lowest system carbon footprint. The availability of biomass equipment, even if it is not the backbone of the system, lowers the carbon footprint and helps achieve milestones for the definition of an efficient district heating system.

c. Meeting the criteria for an efficient district heating system – RES and electricity shares

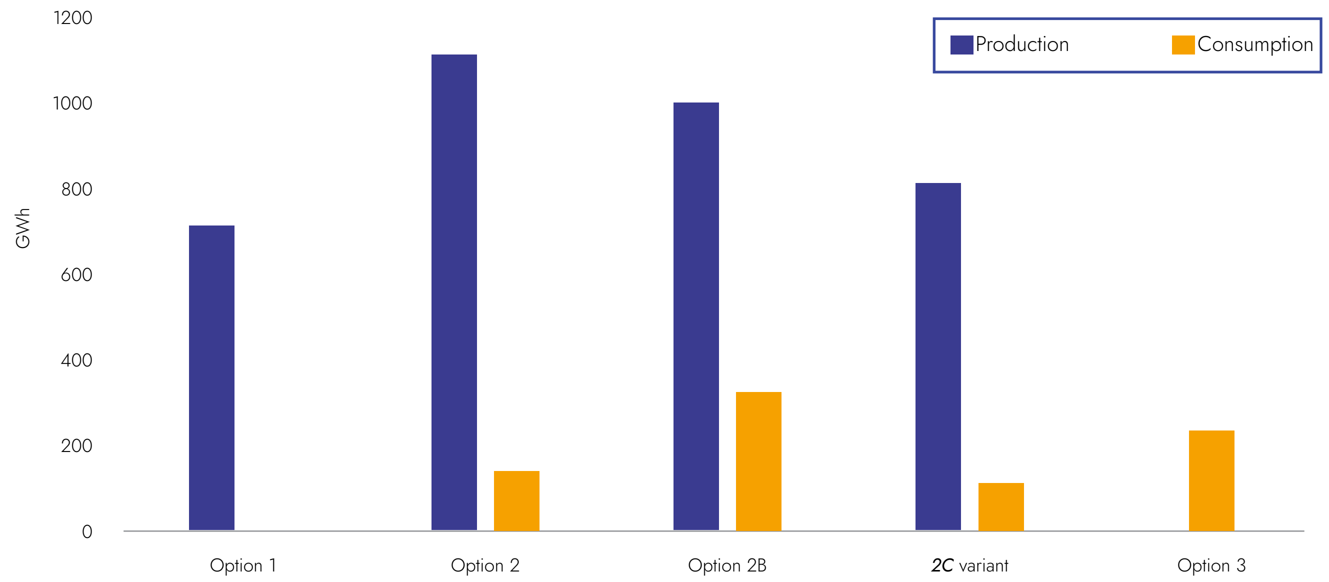
Fig. 23. Comparison of the volume shares of heat sources required to meet the status of an efficient district heating system



- The optimal option in terms of the ability of the district heating system to achieve efficient status is Option 2, which combines the advantages of high-efficiency cogeneration, RES and Power to Heat. Option 2B allows for a larger share of electricity, but to lower the generation cost will require support for Power to Heat.
- Electricity consumed from the network by Power to Heat equipment during hours when there is a high RES share can (with the recognition of heat from electricity as RES) effectively help achieve the requirements of an efficient system. An electrode boiler produces heat with an efficiency close to 100%, so the RES share of heat production would be similarly high. This is evident in Option 2B, where electricity accounts for more than 10% of heat production.
- The use of biomass facilities, even if they are not the basis of the system, helps to achieve the status of an efficient system, in each of the analyzed options (except coal) biomass accounted for 9% of RES.
- In Option 1, production from coal-fired cogeneration makes it possible to meet the requirements of an efficient district heating system until the end of 2027. However, such a district heating system may benefit from a derogation from the obligation to meet the emission requirements for cogeneration until 2034, provided a carbon footprint reduction plan is submitted. This, however, involves replacing coal-fired cogeneration with another source or gas-fired cogeneration.

d. Electricity production and consumption

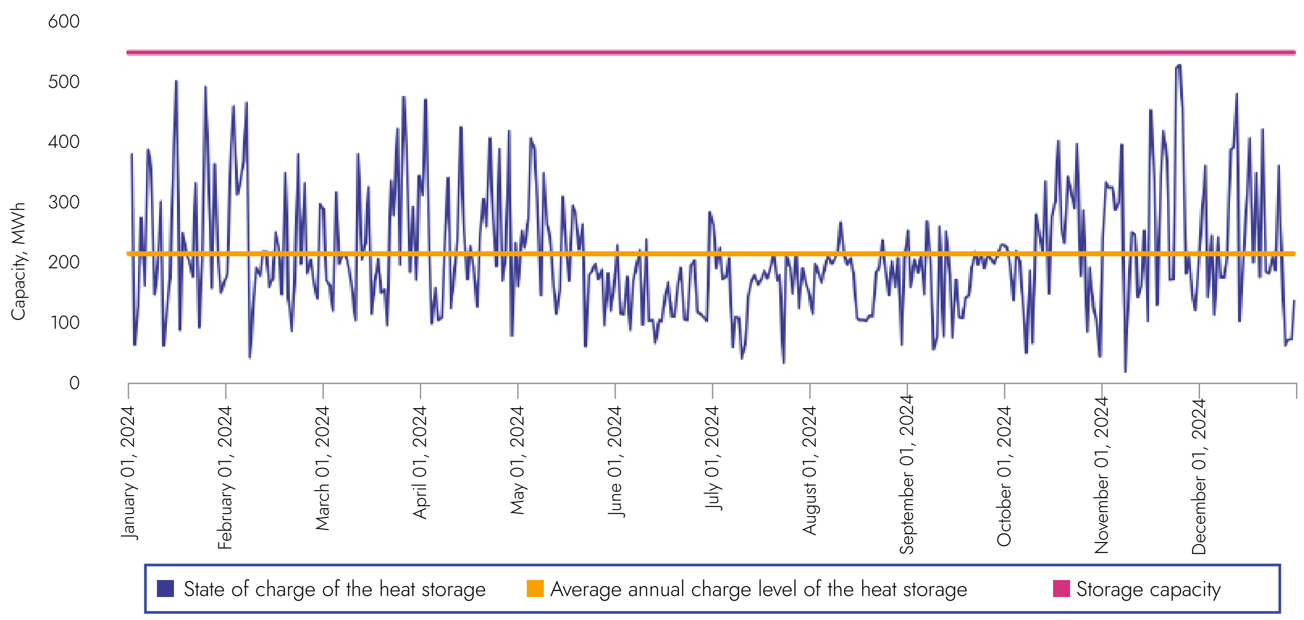
Fig. 24. Comparison of electricity production and consumption in the analyzed options



- Option 1 depicting the status quo, consisting of coal-fired units, produces about 700 GWh of electricity per year that is delivered to the NPS. Depending on the transformation business model adopted, decarbonization of district heating may involve reduced electricity production. According to Polish Association of Heat Energy, it will be important to properly choose equipment to achieve a trade-off between consuming and delivering electricity to the grid.
- The option best suited for cooperation with the National Power System is Option 2, which assumes the production of energy from cogeneration units at times of high demand – high electricity prices – and the consumption of electricity at times of surplus RES generation in the NPS by Power to Heat technology.
- Option 2 shows higher electricity production than Option 1.
- Option 3 achieved the lowest emissions, high RES shares, but does not produce electricity.

e. Option 2 – heat storage operation

Fig. 25. Annual operation of heat storage in Option 2



- Each of the analyzed options included a heat storage facility that was charged and discharged on a daily basis. This improved the operation of generating equipment, which is less flexible. In addition, it allowed the sources to operate during periods when heat demand was below the minimum capacity, because the surplus heat could be transferred to the storage facility.
- The storage facility transfers heat at times of high heat demand. Another period of operation is when electricity prices are low, when it is not profitable to operate cogeneration units. During such periods, the storage facility can operate by replacing emission units.
- In each option, the heat storage facility accounted for approx. 7% of the heat transferred to the district heating network.

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4.3. Summary and conclusions of the analysis

The analysis carried out was intended to quantitatively and qualitatively illustrate the cooperation of the district heating system based on a mix of cogeneration equipment and Power to Heat equipment with the power system. The systems analyzed included hypothetical models, reflecting the configuration of equipment that may only appear on a larger scale in the district heating system in a few years, but whose operation could be cost-effective and beneficial for district heating and the NPS already now. It was examined how such systems could operate in the current conditions of energy markets, with dynamically changing electricity prices and large shares of generation from RES in the NPS. The calculations were performed on an hourly basis, which best captured the operation of Power to Heat equipment and cogeneration units.

The analysis showed that the use of Power to Heat technology in combination with gas-fired cogeneration units already today could help meet the future requirements for district heating systems. The decarbonization of the sector and achieving the status of an efficient system in line with the objectives of EU regulations is of primary importance. Thus designed, the system district heating sector can successfully achieve synergies with the power sector, finding solutions to the challenges of energy transition, such as balancing the operation of the NPS, managing surplus electricity and the security of operation of the National Power System.

Conclusions:

- The best flexibility of operation and cooperation with the power system is offered by a hybrid system including cogeneration and Power to Heat equipment. The hybrid system promotes the optimization of variable costs of heat production and the increase in the share of renewable energy in the district heating system, as well as the reduction in RES generation in the NPS by collecting surplus and producing renewable heat.
- Gas cogeneration, by optimally producing electricity at times of peak demand in the NPS, allows heat to be produced at the lowest cost. Systems equipped with cogeneration units provide high electricity production, which is beneficial to the NPS. The decarbonization of district heating will involve shutting down coal-fired units and generating less electricity, so it will be important to choose the right equipment to ensure a compromise between consuming and returning electricity to the power network. The best combination between electricity consumption and production is characteristic for the option with cogeneration and equipped with Power to Heat equipment.
- Electrification can significantly support district heating and reduce the cost of heat generation, but it is necessary to properly optimize the use of such units. According to Polish Association of Heat Energy analysis, if a significant portion of heat generation is electrified by building electrode boilers at the base load, an increase in annual demand of 500 MW (in each hour of 2024) would raise the average annual price of electricity in 2024 by 5%; and an increase of 1,000 MW would mean a 10% higher price.
- The system without gas cogeneration was characterized by the lowest emissions and fuel consumption, but nevertheless met the requirements of an efficient district heating system to the smallest extent and had the highest heat generation costs. Regardless of the options adopted, an important role in the system is played by biomass, which, due to its low variable costs, is able to operate for a significant period during the year and helps achieve the objectives of an efficient district heating system.
- Electricity consumed from the network by Power to Heat technologies during hours when there is a high

16. More information on specific technologies and the limitations on their use can be found in Polish Association of Heat Energy 2024 reports: *"The potential for the use of Power to Heat technologies in the transformation of the system district heating sector in Poland"* and *"The impact of EU regulations on the transformation of the system district heating sector in Poland, assessment of effects and recommendations for national regulations".*

share of RES generation can (with the recognition of heat from electricity as RES) effectively help achieve the requirements of an efficient system. The decarbonization of district heating through increased electrification will require operating support systems to cover some of the costs associated with the purchase of electricity by these units. Otherwise, heat prices could become a barrier to the use of the technology at an appropriate scale.

- The element that increases the cost of heat generation in systems with electric sources covers the fixed costs associated with the fee for contracted capacity. These costs for electricity are – with respect to thermal power of Power to Heat equipment – disproportionately higher than similar fees for natural gas, for example. This is particularly noticeable in the case of equipment that produces a relatively small volume of heat during the year. An example of this are electrode boilers, which can be units of several tens of MW, and which, currently with optimal economic operation and balancing of the NPS, produce heat for approx. 15% of the hours of the year. It is necessary to develop a system to reward these units for balancing the NPS or increasing the share of RES in the district heating system by reducing fixed costs. Any mechanisms are also of interest, that allow the contracted capacity to be exceeded during the hours of the day indicated by the NPS operators, without incurring additional fees relating to the connection capacity.
- A heat storage facility is a device that in any option increases the flexibility of system operation and reduces fuel consumption. It improves the daily operation of district heating equipment, supporting its flexibility, as well as reducing unit shutdowns and thus reducing repeated commissioning procedures.
- District heating networks are also important in the integration of RES with district heating and district heating with the NPS. Heat pumps or heat storage facilities can use electricity from the network, but these technologies may not be able to provide high parameters of the district heating network. This can be done by electrode boilers, but in order to take full advantage of the available Power to Heat technologies, it is important to invest in low-temperature networks and receiving infrastructure in buildings.
- Cooperation is needed between the district heating industry and the NPS, so that district heating systems that consume and generate electricity are located in places that are optimal from the point of view of both systems (district heating system and electricity system), as well as are able to operate at times that allow for the best possible benefits from the point of view of the NPS and system heat consumers.

5. Recommendations – proposed regulatory changes

The purpose of this chapter is to show a cross-section of the regulatory changes that should be made to strengthen cooperation between the system district heating and power sectors. For clarity of our position, we have divided the postulates into thematic areas covering regulatory issues assigned to each segment. Each of the following modules proposes the regulatory changes necessary to create a regulatory environment that enables the development of sector coupling.

1. ADMINISTRATIVE PROCEDURES – DEREGULATION OF THE INVESTMENT PROCESS

The changes outlined in the table are solutions necessary to promote sector coupling through the impetus for development of heat pump and electrode boiler technologies.

Direction of the change	Assumptions of the change	Document
Exemption from the obligation to obtain a building permit and submit a notification, the performance of construction works involving the installation of, i.a., heat pumps, regardless of their installed capacity	The postulated solution in the form of an exemption from the obligation to obtain a building permit and submit a notification for construction works involving the installation of, i.a., heat pumps, regardless of their installed capacity, will support the decarbonization of district heating based on heat pump technologies.	The Construction Law
Limitation of the number of permissible requests for removing deficiencies in a building permit application	The introduction of the possibility of requesting the applicant once to correct deficiencies in the building permit application will entail the necessity for the architectural and construction administration authority to identify all the noted deficiencies and request the applicant once to correct them. The solution presented can significantly shorten administrative proceedings for building permit cases.	The Construction Law
Deadline for the issuance of a building permit for the implementation of a RES investment, including heat pumps and electrode boilers, as well as a sanction mechanism against the architectural and construction administration authority in the case of failure to issue the building permit on time	The purpose of the amendment is to oblige the architectural and construction administration authority to issue a building permit for investments involving the construction or reconstruction of RES plants, including heat pumps and electrode boilers, within 90 days from the date of submission of the permit application. The proposed solution will significantly reduce the duration of administrative proceedings in such cases. At the same time, if the statutory deadline for issuance of the permit is exceeded, it would become possible to impose a penalty on the authority responsible for issuing the permit for each day of delay.	The Construction Law

Direction of the change	Assumptions of the change	Document
Streamlining and accelerating the licensing procedure for the activity in the field of electricity or heat generation in RES plants, electricity storage and heat generation with the use of heat pumps and electrode boilers	The 30-day deadline for processing an application to grant or modify a license would apply to the following activities: ■ electricity or heat generation in RES plants, ■ electricity storage in electricity storage facilities, with a total installed capacity of more than 10 MW, ■ heat generation in a heat pump or electrode boiler with a total installed thermal capacity of no more than 20 MW. The aforementioned deadline would be counted from the date of receipt by the President of ERO of the application for granting or modifying the license.	The Energy Law
Changes in the variable fee for heat pumps – making this fee dependent on the amount of energy taken (not used)	Making the variable fee dependent on the amount of energy taken (under the currently applicable regulations – on used) by systems using water, 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 taken and not directly intended for heating or cooling.	The Water Law
Change in fees for water services for heat pumps	The discharge into surface water of water used in heat pumps should not be subject to a variable fee that depends on their temperature – exceeding the temperature of 26°C of the discharged wastewater; in the cases where the temperature of the water taken is so high that, despite running it through the heat pump, it cannot be cooled down below 26°C	The Water Law
Facilitating the investment process in the field of construction or alteration of district heating networks	Simplifying the procedure for the preparation and implementation of investments in the field of construction, alteration or retrofit of district heating networks (in particular, in terms of facilitating the obtaining of approvals for entering an area).	Adopting a dedicated Act or amendment to the existing provisions of various legal acts

2. COOPERATION OF THE SYSTEM DISTRICT HEATING SECTOR WITH THE NATIONAL POWER SYSTEM

The system district heating sector may play an important role in stabilizing the operation of the National Power System through the production of heat and electricity in cogeneration. The ability of the district heating sector to utilize surplus electricity generation from renewable energy sources, convert it to RES heat and store it also needs to be emphasized. For this transformation to happen, the regulatory changes described in the table below are necessary.

Direction of the change	Assumptions of the change	Document
Qualifying the entire stream of heat generated in heat pumps as heat from RES to meet the efficient district heating system criteria.	Including the heat generated by heat pumps in the qualification of a given district heating system as an energy-efficient district heating system. The change supports the decarbonization of district heating based on heat pump technologies. Such a calculation of the amount of heat from heat pumps is compliant with Commission Recommendation (EU) 2024/2395 of 2 September 2024 setting out guidelines for the interpretation of Article 26 of Directive (EU) 2023/1791 of the European Parliament and of the Council as regards the heating and cooling supply.	The Energy Law
Qualifying the heat generated in electrode boilers as heat from RES to meet the energy-efficient district heating system criteria	Including the heat generated by electrode boilers in the qualification of a given district heating system as an energy-efficient district heating system The measure will be aimed at decarbonization of district heating with the use of electrode boiler technology. 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 Energy Law, Renewable Energy Sources Act

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3. FINANCIAL MECHANISMS TO SUPPORT SECTOR COUPLING

The achievement of maximum benefits of sector coupling is inextricably linked to the need for transformation of the system district heating sector, for which significant capital expenditures are required. Considering the need to intensify investments in "greening of district heating system", while ensuring for end-users heat prices at an acceptable level, a new support mechanisms for specific technologies should be introduced or the existing programs should be modified. The postulates in this regard are presented in the table below.

Direction of the change	Assumptions of the change	Document
Improving the support mechanism for high-efficiency cogeneration units	Key postulates: ■ extension of the deadline for the first generation of electricity from high-efficiency cogeneration in a new cogeneration unit or a substantially retrofitted cogeneration unit from the date of the auction settlement from 48/60 months to 60/72 months, respectively; ■ change in the designated deadline for obtaining a final building permit by extending it from 12 to 24 months. This modification will mitigate the risk of generators losing the support they receive in the event of changes to investment implementation schedules; ■ elimination of the risk of failure of companies that won the auction for a cogeneration bonus/call for applications for an individual cogeneration bonus to meet their first generation obligation within the prescribed period (3 years) – repealing sanctions. Other postulates include: ■ the possibility of increasing the support granted under either the adjusted cogeneration bonus or the adjusted guaranteed bonus in the event of a subsequent reduction in state aid for investment implementation; ■ exemption from submitting a report on the volume of electricity introduced into the network and sold, together with an opinion of an accredited entity (prepared on the basis of an audit conducted at the generator's premises, stating the correctness of the data contained in the report) by the generator in the event that the support is PLN 0 per MWh – an unnecessary obligation; ■ a one-time update of the data contained in the proposal, that won the call for applications/auction.	the Act on promotion of electricity from high-efficiency cogeneration
Increase in the pool of funds allocated for auctions for cogeneration bonuses by transferring unused funds due to pending calls for applications for an individual cogeneration bonus	In view of the failure to resolve several consecutive calls for applications for the individual cogeneration bonus since 2020, due to the absence in the call for applications of at least one proposal that met the requirements of the Act on promotion of electricity from high-efficiency cogeneration, we advocate redirecting the funds allocated for the payment of individual cogeneration bonuses, unused due to the unresolved calls for applications, to expanding the budget allocated for the auctions for cogeneration bonuses.	Regulation of the Minister of Climate and Environment on the maximum amount and value of electricity from high-efficiency cogeneration covered by support and unit amounts of the guaranteed bonus
Mechanism to reward availability of key units from the perspective of balancing the National Power System	The availability mechanism would operate on the basis of Regulation (EU) 2024/1747 of the European Parliament and of the Council of 13 June 2024 amending Regulations (EU) 2019/942 and (EU) 2019/943 as regards improving the Union's electricity market design. It is necessary for the mechanism to comply with state aid regulations.	adoption of a legal act dedicated to the new support system
Operational support mechanism for Power to Heat technology	Operational support for heat pumps and electrode boilers through the creation of a mechanism addressed at energy companies operating in the area of the system district heating sector. At the same time, operating support should also be available for the introduction of heat into a heat storage facility, prior to its introduction into a public district heating network.	adoption of a legal act dedicated to the new support system
Continuing investment support programs for high-efficiency cogeneration	Maintaining the existing forms of support (primarily under the Modernization Fund), which provide both a grant and a loan for natural gas-based technologies. Resolving – in a manner that takes into account the needs of the district heating sector – the problem of assessing the compliance of gas projects with the EU taxonomy.	Maintaining the existing investment support program
Expanding the possibility of support from the Modernization Fund after 2030 for cogeneration units.	It would be advisable to continue to gain support for generating units in the district heating sector beyond 2030, including those using high-efficiency cogeneration. A starting point for discussion concerning this issue may comprise the review of operation of the ETS, scheduled for 2026.	EU ETS Directive
Increasing the access of companies to aid funds and raising permissible state aid levels	Revision of the relevant state aid regulations, in particular the thresholds for permissible aid intensity under the GBER to 60%, increasing the notification threshold to EUR 100 million per project.	GBER Regulation
Providing support for the construction of heat storage facilities as independent projects	The postulate is compliant with the GBER aid guidelines, which indicate that the heat storage facility can be financed under public aid as a separate project.	New support program implemented by the National Fund for Environmental Protection and Water Management (Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej – NFOŚiGW) from the Modernization Fund, including heat storage facilities as independent investments
Investment support for the construction of electrode boilers that generate heat for district heating systems	Providing investment support for the construction of electrode boilers dedicated to heat generation for district heating systems	New support program or modification of the existing program "RES – heat source for district heating"
Adopting a program for the retrofit and development of infrastructure relating to district heat distribution	Subsidizing investments in the field of improvement of the efficiency and reliability of network infrastructure operation, relating to the distribution of district heat to consumers, as well as adapting network infrastructure to the parameters of low-temperature networks.	Adopting a new support program for district heating networks

4. HEAT MARKET MODEL

The promotion of development of sector coupling requires changes in the area of heat tariffs and modification of technical aspects of heat market operation. In the table below, we have compiled the main postulates relating to the heat market model.

Direction of the change	Assumptions of the change	Document
Tariffing of cogeneration units	Maintaining the simplified method tariffing model and ensuring uniformity in revenue formation for all cogeneration units.	Heat tariff regulation
Tariffing of heat storage facilities	Introduction of regulations to allow the tariffing of heat storage facilities.	The Energy Law, Heat tariff regulation
Introduction of minimum revenue regulations	Restoring the previously modified provisions relating to the minimum revenue, the application of which was postponed until 2028.	Heat tariff regulation
Distribution tariff dedicated for heat pumps and electrode boilers	The postulated change will affect the effect of synergy with the power system by abandoning an increase in the fixed component of the network rate due to the use of different volumes of contracted capacity.	The Energy Law, Electricity tariff regulation
Preferential tariff treatment for heat pumps and electrode boilers	Exemption of heat pumps up to 20 MW from tariff approval requirement by the President of ERO.	The Energy Law
Additional component of the capital cost formula	Introducing into the model a bonus for generating RES heat or using waste heat, and increasing the share of renewable sources or waste heat in heating and cooling.	The Energy Law, Heat tariff regulation
Additional component of the equity capital cost formula	Allowing, in the calculation of the reinvestment bonus for heat generation, the settlement of capital expenditures within x(5) years from the cost being actually incurred.	Heat tariff regulation
Dedicated regulations for remuneration of investments that support the transformation of district heating	Covering the reasonable costs of activity in the field of construction, retrofit and connection of generating units that are RES plants, in order to reward efforts to decarbonize and stimulate the development of renewable energy sources.	Heat tariff regulation
Updating the design parameters used in the design of heating loads in buildings	The changes in climate zones and updating standards for design temperatures are needed, as they are outdated and do not match the currently observed winter temperatures, resulting in significant oversizing of the heating needs of buildings.	The Energy Law, Heat tariff regulation, Standard: PN-EN 128311-1:2017-08 and national Appendix

5. EDUCATION AND SOCIAL COMMUNICATION

The development of sector coupling should be supported by active communication activities at the national and local government levels, as well as education and support for employees to acquire the competencies necessary to work in dynamically transforming sectors. In view of the above, in the table we present directions of activities for the benefit of sector coupling in the areas of education and social communication.

Direction of the change	Assumptions of the change	Document
Dissemination of the idea of sector coupling at the local government and national levels.	Raising the awareness among local and national decision makers about the benefits of sector integration. Including sector coupling in municipal strategies, e.g., heat supply plans, regional energy plans.	
Training of highly specialized technical personnel.	Influence on the development of the sector in educational terms by training highly specialized personnel dedicated to operating new, integrated energy systems.	


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