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Comparative analysis of district heating markets: examining recent prices, regulatory frameworks, and pricing control mechanisms in Poland and selected neighbouring countries

Abstract: Recent dynamic changes in global fossil fuels markets and the European carbon dioxide emission allowances system have significantly impacted the energy sectors. These fluctuations also influence district heating (DH) markets where coal and natural gas remain dominant energy vectors in numerous European countries. District heating markets are distinct from other commodity markets due to their local nature and distribution requirements. Consequently, they can operate under various market models and have different price design policies depending on the country and region. With these considerations, this study aims to review and analyse the current market models and regulations of price formulation in the context of final prices in selected district heating markets. The primary objective is to conduct an in-depth analysis of the key district heating markets in Poland and compare the outcomes with the markets of neighbouring countries, including the Czech Republic, Slovakia, Lithuania, Latvia, Estonia, and Germany. Poland is taken as an example due to its high dependence on fossil fuels and its vulnerability to current global price fluctuations. The results indicate that Poland has one of the most regulated district heating markets, and these regula-

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tions can impact the profitability of district heating companies with high prices of fuel and carbon certificates observed in global markets. To create incentives for potential investors and incumbent companies to develop more sustainable and low-emission district heating markets in Poland – where energy transition processes are still underway – it is recommended to increase the frequency of formulation and approval of tariffs.

Keywords: district heating, heat, heat tariffs, ex-ante, ex-post, market

Introduction

District heating (DH) markets are distinct from other commodity markets, including different energy markets like those for natural gas, oil, coal, and electricity (Hall and Buckley 2016; Söderholm and Wårell 2011). This distinction is due to their local nature, usually limited to a single city or agglomeration (Gorroño-Albizu and de Godoy 2021). Heat, defined as thermal energy in hot water or steam, cannot be transported more than the range of one or a few urban centers due to the significant losses, unlike the transport of other energy vectors (Leppänen et al. 2021; Zheng et al. 2022). Given the local nature of district heating markets, constraints in heating generation and transportation, and the characterization of heating as a public good, classical market mechanisms are generally not applicable (Magnusson 2012).

As a result, district heating prices do not settle at equilibrium prices, as is common in perfectly competitive markets (Kirschen and Strbac 2019). Therefore, heating markets are often regulated, with prices usually approved in the form of tariffs by the energy regulatory authorities, monitored and controlled, or having established price caps (Djørup et al. 2020). The subject of trade in these markets is district heating, which comprises both the product – usually energy in the form of hot water or steam – and its distribution to end consumers (Colmenar-Santos et al. 2016). District heating is transported by heating networks, consisting of interconnected devices and installations, facilitating its transmission and distribution from the source of generation to final consumption points (Shabanpour-Haghighi and Seifi 2016).

Companies that own heating and/or combined heat and power plants and distributors represent the supply side of the market. These heating producers are accountable for their production and maintaining specific values in terms of temperature and pressure of energy carriers, while distributors ensure delivery to end consumers and maintain the network infrastructure. Distribution companies are often those that sign contracts with consumers and play the role of sellers. Consequently, the participants of the district heating markets include producers (either one or several, depending on the size of the district heating market), distributors, end consumers, and regulators. It should be noted that in some local heat markets, a single company may manage (i) production and distribution, (ii) distribution and sale, or (iii) production, distribution, and sale. These unique features characterize DH markets as natural monopolies, in which the regulator

plays a significant role in protecting consumers and mitigating potential negative consequences arising from the operation of a singular company (Wissner 2014).

The conditions, prospects, and challenges of district heating in European countries were discussed by Colmenar-Santos et al. (2016). The authors highlighted the advantages of cogeneration power units, emphasizing their role in enhancing the energy efficiency of power systems, improving energy security, and reducing carbon emissions. The study reveals that although adopting an energy strategy where district heating is pivotal would necessitate substantial capital -intensive investments, the long-term effects could yield savings in energy consumption and fuel purchases. However, the study did not explore the price formulation mechanisms and final prices in the European district heating markets. Manz et al. (2021) similarly highlighted the potential of heating derived from other processes. Their research suggests that utilizing excess heat from industry could positively affect the reduction of fuel costs and carbon emissions within the European Union. This comprehensive analysis primarily focused on the prospects and challenges associated with such approaches.

Studies on district heating markets are often focused on their monopolistic nature. Pažėraitė et al. (2022) performed a contemporary analysis of conceptual frameworks of district heating markets in European countries. The authors examined the impact of market opening to competition on consumer prices, considering the implementation of third-party access and one-side auctions. Egüez (2021) analyzed the scenario of an unregulated natural monopoly in district heating markets. The findings suggest that prices in privately owned district heating networks are comparatively higher than those in municipally owned networks, with notable differences, particularly in the fixed components of the price. The differences are especially observed in the fixed components of price. While these studies offer significant insights into potential price shaping in competitive markets, they do not draw comparisons of prices within existing market structures.

Research on Polish district heating has primarily focused on the introduction of more efficient technologies and their potential for reducing carbon emissions. Pająk et al. (2020) reviewed geological and hydrogeological data to assess the potential of geothermal water resources to cover the heating needs in Poland. Jaskólski and Bućko (2021) modeled a long-term transition from coal-dependent systems to low-emissions alternatives, identifying geothermal energy as a potential means to achieve long-term decarbonization goals. Kinelski et al. (2021) proposed the application of smart technologies to lower emissions from district heating, estimating a reduction of approximately 275 kt of CO_2 due to the proposed changes. The authors also emphasized that the evolution of district heating systems is a crucial element of smart city strategies (Kinelski et al. 2022). Furthermore, Wyrwa et al. (2022) explored the potential of the integration of renewable energy resources into district heating systems, analyzing six regions in Poland. They indicated that an anticipated increase in natural gas and CO_2 emission allowances might accelerate the development of solar heating plants.

1. Study contribution

The conducted literature review allowed one to identify the research gap concerning district heating markets in the European Union. Due to the local nature of district heating markets, there are limited studies on their comparison, including district heating prices in different countries and regions. While numerous academic works explore the features of district heating features, most focus on the impact of transitioning market structure to more competitive ones or analyze the potential of district heating transition in the coming year. As a result, the research problem addressed in this study involves conducting an analysis of the district heating markets in Eastern and Central Europe. The selection of these countries results from a comprehensive literature review and preliminary processing of collected data. Consequently, the study draws comparisons between Poland and the following countries: the Czech Republic, Slovakia, Lithuania, Latvia, Estonia, and Germany.

To the best of the authors' knowledge, no study has yet compared district heating markets and prices in Poland and neighboring countries. Therefore, the main objective of the study is to carry out an analysis of regulatory frameworks and district heating tariffs offered to consumers and compare DH features and prices between the local markets in Poland and other countries, including the Czech Republic, Slovakia, Estonia, Lithuania, Latvia, and Germany. As a result, the present study and obtained results contribute to the existing literature in the following ways. First, it provides an overview of the regulations and features of district heating markets in Poland and neighboring countries. Second, it presents and discusses the differences in the largest district heating markets in Poland, including Warsaw, Kraków, Wrocław, Gdańsk, Lublin, Poznań, and Łódź. Third, it gathers and compares the district heating prices in Poland, the Czech Republic, Slovakia, Estonia, Lithuania, Latvia, and Germany. Finally, it analyzes and indicates the challenges and prospects of the Polish district heating companies in light of the current fluctuations in fuel markets and experience from neighboring countries.

The remainder of the paper is organized as follows. Section 2 describes the research areas and methodology framework. Section 3 discusses the results of the analyses of the district heating markets in Poland and neighboring countries. Section 4 draws conclusions and recommendations for the district heating sector in the current market conditions.

2. Materials and methods

As mentioned, the study examines the district heating regulatory frameworks and prices in Poland and six European countries: the Czech Republic, Slovakia, Lithuania, Latvia, Estonia, and Germany. The Czech Republic, Slovakia, and Germany are selected for the analysis due to

their fuel supply mix in district heating, including a large share of coal and natural gas, similar to Poland, while Lithuania, Latvia, and Estonia are selected as nearby countries with a significant share of natural gas, what is expected in Poland as a consequence of ongoing energy transition. These countries are also analyzed to examine the impact of the recent dynamic increases in the prices of coal and natural gas in the international markets on the district heating prices in Eastern and Central Europe.

Figure 1 shows the fuel supply mix of district heating in these countries and the average structure in the European Union (EU-27). As mentioned, district heating in Poland, the Czech Republic, Slovakia, and Germany is produced mainly in facilities based on fossil fuels, while the fuel structures in Lithuania, Latvia, and Estonia also include biomass and biofuels, apart from natural gas in their generation units. The energy mix for district heating in the European Union shows that fossil fuels account for over half of production, presenting significant decarbonization challenges in meeting zero-emission climate goals.

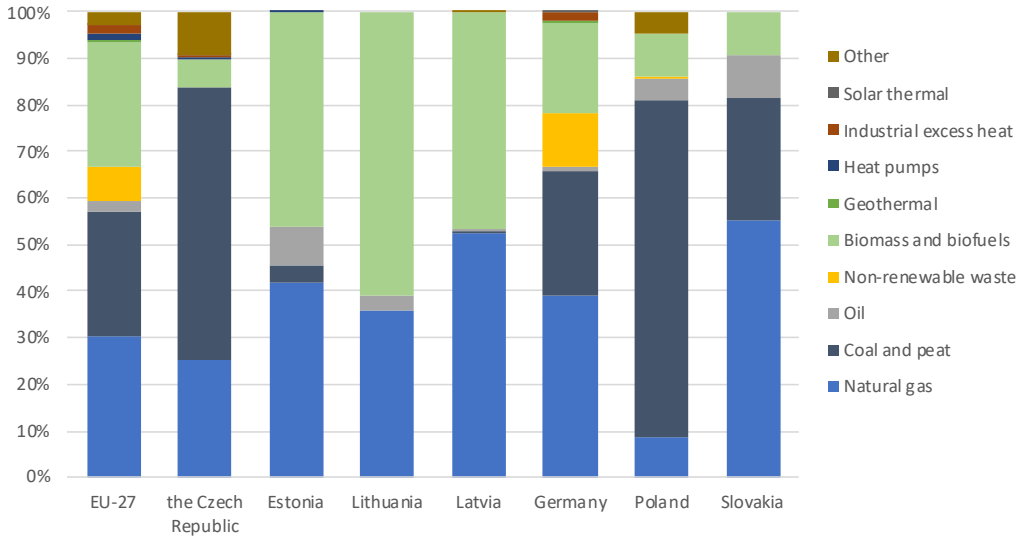

Fig. 1. Fuel supply mix in district heating
Based on: European Commission (2022)

Rys. 1. Struktura paliwowa ciepłownictwa systemowego

Figure 2 presents the research framework applied in the study. The methods include desk research, data collection, data processing, and comparative analysis. The analysis covered the in-depth analysis of European Regulations and analyses of the European Commission in the area of district heating regulations. Besides the European document, the national regulations of selected countries were analyzed, including mandatory documents in Poland, the Czech Republic, Slovakia, Lithuania, Latvia, Estonia, and Germany.

Data used in the study was derived from European and national databases, including Eurostat, data published by Energy Regulatory Offices of the analyzed countries, data and information published by heating companies, and online services dedicated to energy and heating sectors. Finally, the comparison of district heating prices in Poland, the Czech Republic, Slovakia, Lithuania, Latvia, Estonia, and Germany are obtained. All monetary amounts are provided in €2022.

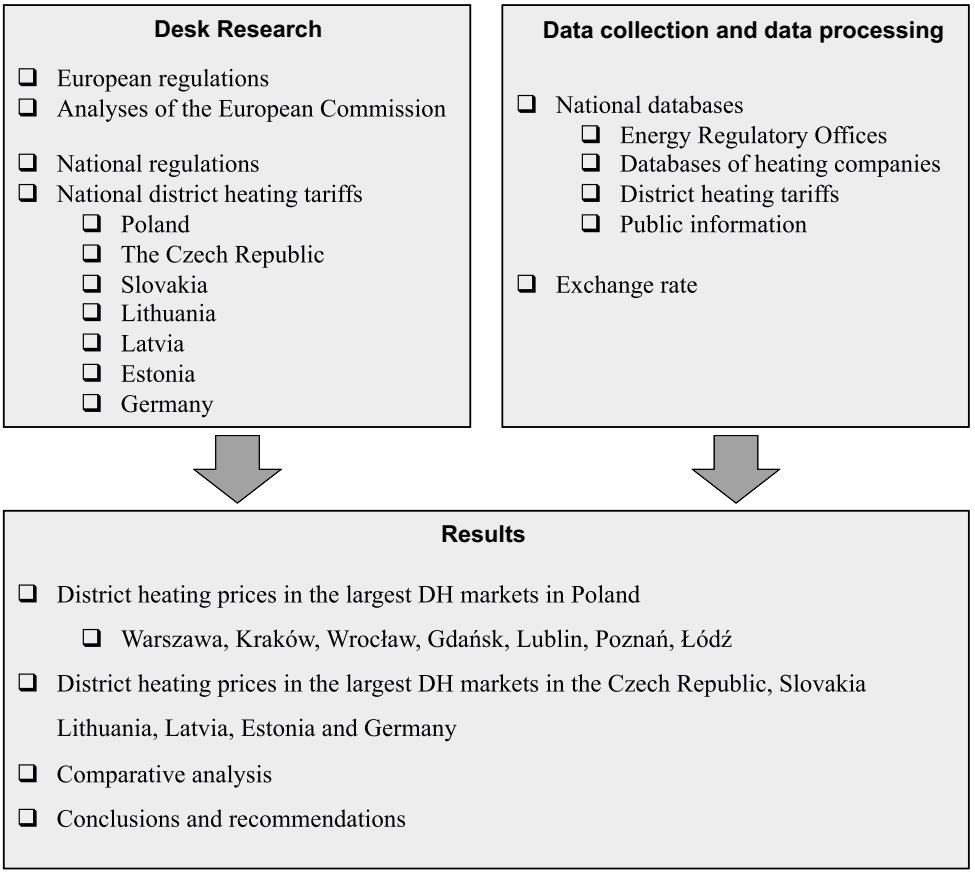

Fig. 2. The research framework

Rys. 2. Metoda badawcza

3. Results and discussion

This section presents the analysis results and discussion regarding regulations and district heating prices. Due to the local nature of the district heating markets, the prices were collected

from various regions in each country and from various district heating companies. The issue of one- or two-component prices is also included in the study. As a result, the section presents district heating prices published by different DH companies and the ranges for each country, considering the price components and fuels used for district heating generation. First, the district heating regulations, markets and prices in the largest cities in Poland are analyzed and compared, including Warsaw, Kraków, Wrocław, Gdańsk, Lublin, Poznań, and Łódź. Second, the documents and the largest markets in the Czech Republic, Slovakia, Latvia, Lithuania, Estonia, and Germany are examined. Finally, the comparison of district heating regulations and prices is presented and discussed.

3.1. Poland

District heating markets in Poland operate as natural monopolies, and DH prices are regulated and approved by the Energy Regulatory Office (ERO). The tariff system is regulated under the Energy Law (Journal of Laws 1997 No. 54 item 348) and Regulation on Detailed Rules for Shaping and Calculating Tariffs and Settlements for Heat Supply (Journal of Laws 2020 item 718). These documents define rules and requirements for companies engaged in the generation, storage, processing, transmission, distribution, or trading of district heating. DH prices are usually calculated and submitted once a year and submitted in the tariff system. District heating companies calculate their prices based on the average costs of production and/or distribution of heat, maintenance costs, and return on investment costs. The prices are based on cost-plus methodology, i.e., the prices consist of cost components and profit margin. Depending on the business area of the heating company, the tariffs may include (i) variable fees for district heating and energy carrier (e.g., hot water) and a fixed fee for thermal capacity (only generation DH companies), (ii) variable fees and a fixed fee for distribution (only distribution DH companies), or (iii) all components of variable and fixed fees for generation and distribution (generation and distribution DH companies).

In the case of combined heat and power plants, a simplified method based on planned revenues is used instead of a cost-plus method. Although the method should provide a less complicated approach, the employment of this method is fraught with the risk of not covering the investment costs on time and is highly vulnerable to the short-term volatility of market prices of fuels and emission allowances. As a result, the planned revenues are often insufficient to ensure CHP units' profitability, and this method does not provide sufficient incentives to invest in new generation capacities.

Depending on the region in question, the district heating is supplied in the following configurations in Poland. First, one company is responsible for generation and distribution (e.g., Poznań, Łódź). Second, one company owns generation units, and another is responsible for distribution (e.g., Warsaw, Wrocław). Third, one company is responsible for the distribution, and several others can possess generation units (e.g., Kraków, Lublin).

The largest district heating market in Poland has been developed in Warsaw. The system has 1,800 km of network and covers 80% of the heat demand in Warsaw. The key market participants are PGNiG Termika SA, which possesses four generation units, and Veolia Energia Warsaw SA, which is responsible for heat distribution and maintenance of the network infrastructure. PGNiG Termika SA owns the following generation units: Siekierki combined heat and power (CHP) plant with a thermal capacity of 2,065 MWt (coal-fired unit), Żerań CHP plant with a thermal capacity of 1,736 MWt (coal-fired and natural gas-fired units), Kawęczyn heating plant with a thermal capacity of 465 MWt (coal-fired unit), and Wola heating plant with a thermal capacity of 348 MW (light oil-fired unit). The largest generation units are the Siekierki CHP plant (55% of the total heat consumption in Warsaw) and the Żerań CHP plant. Whereas the Kawęczyn and Wola heating plants operate only during periods of peak demand. In 2022, prices of district heating generated in the plants owned by PGNiG Termika SA were as follows. In the Siekierki CHP plant – PLN 81.23/GJ (hot water) and 80.07/GJ (steam), in the Żerań CHP plant – PLN 137.86/GJ (hot water) and PLN 46.70/GJ (steam), in the Kawęczyn heating plant – PLN 60.67/GJ and in the Wola heating plant – PLN 116.91/GJ. Additionally, the heat was also produced by the Municipal Cleaning Company of Warsaw, with a price of PLN 18.81/GJ in 2022 (Energy Regulatory Office 2022). If more than one heating generation unit is supplied to the network, the price is a weighted price, and it is presented in the tariff of the company responsible for heat distribution. In 2022, the weighted average price of district heating in Warsaw was PLN 77.46/GJ, and the distribution price ranged from PLN 12.16 to PLN 23.92/GJ, depending on the tariff group (Veolia Energia Warsaw SA 2023).

The Kraków district heating system includes three generation units and a municipal district heating network. The largest thermal capacity is installed in the Kraków-Łęg CHP plant, owned by PGE Energia Ciepła SA (1,644 MWt, coal-fired unit). The heat produced in this CHP plant supplied almost 73% of consumers. Depending on the tariff, the heating price ranged from PLN 64.65/GJ to PLN 81.11/GJ in 2023 (Energy Regulatory Office 2023). The district heating covered the Kraków demand is also produced in the CEZ Skawina generation unit, with a thermal capacity of 655 MWt (coal-fired unit). This unit supplied 25.32% of end consumers in 2022 at the price of PLN 61.41/GJ and PLN 69.08/GJ, depending on the tariff group (Energy Regulatory Office 2023). The third heat generation unit is the Waste Thermal Treatment Plant, with an average annual heat production of 280,000 MWh, which constitutes around 2.5% of the total district heating market in Kraków. In 2023, the average prices were PLN 63.03/GJ and PLN 75.09/GJ in Kraków, depending on the tariff group. The municipal heating network of 846 km is owned by the MPEC SA. In 2023, the variable distribution price ranged from PLN 17.16/GJ to 35.04/GJ (MPEC SA 2023).

In Wrocław, heat is generated in three CHP plants owned by the ZEW Kogeneracja SA, including the Wrocław CHP plant with a thermal capacity of 812 MWt (coal-fired), the Czechnica CHP plant with a thermal capacity of 247 MWt (coal-fired) and the Zawidawie CHP plant with a thermal capacity of 2.55 MWt (natural gas-fired) (ZEW Kogeneracja SA 2023). The Wrocław and Czechnica CHP plants supplied the municipal heating system, whereas the Zawidawie CHP plant supplies an island heating system. In 2023, the heating price was equal for all consumers

and was PLN 74.84/GJ (Energy Regulatory Office 2023). Fortum Power and Heat Poland Sp conduct the network infrastructure and distribution. z o.o. Their price ranged from PLN 11.07/GJ to PLN 16.08/GJ in 2023, depending on the tariff group (Fortum Sp. z o.o. 2023).

The supply side of the district heating market in Gdańsk includes two key companies. PGE Energia Ciepła SA is responsible for heat generation, whereas GPEC System Sp. z o.o. distributes the product to the end consumers in Gdańsk and neighboring Sopot. District heating is produced in the coal-fired CHP plants in Gdańsk with a thermal capacity of 822 MWt (PGE Energia Ciepła 2023). The DH price in tariff was PLN 83.23/GJ (hot water) and PLN 81.02/GJ (steam) in 2023 (Energy Regulatory Office 2023). The distribution costs ranged from PLN 26.74 to PLN 29.80/GJ (Energy Regulatory Office 2023).

District heating in Lublin is produced in the Wrotków CHP plant owned by PGE Energia Ciepła SA and the Megatem CHP plant owned by Megatem EC-Lublin Sp. z o.o. The Wrotków CHP has a thermal capacity of 592 MWt (PGE Energia Ciepła SA 2022), whereas the Megatem CHP plant is a coal-fired one with a thermal capacity of 138.47 MWt (Megatem EC-Lublin Sp. z o.o. 2023a). The prices of DH generation in 2022 were PLN 70.37/GJ and PLN 95.43/GJ in the Wrotków CHP plant and Megatem CHP plant, respectively (Energy Regulatory Office 2023; Megatem EC-Lublin Sp. z o.o. 2023b), giving the weighted average price of PLN 74.68/GJ. The length of the network is 465 km and is managed by LPEC SA, which also distributes DH to the consumers. The variable fee for distribution ranged from PLN 19.17 to PLN 23.80/GJ in 2023 (LPEC SA 2023).

Poznań and Łódź are examples where – in contrast to other district heating markets analyzed – the heating generation and distribution are conducted by the same companies, Veolia Energia Poznań SA in Poznań and Veolia Energia Łódź SA in Łódź. In Poznań, the Karolin CHP plant is a key power generation unit with a thermal capacity of 900 MWt. In addition, in the region of Poznań agglomeration, there are 76 other heat sources with a total thermal capacity of 234 MWt. The total length of the network is 703 km. The average price of the district heating in 2023 was PLN 81.82/GJ in the case of generation and PLN 22.10/GJ in the case of distribution.

As mentioned, the structure of the district heating market in Łódź is similar to the one in Poznań. One company, Veolia Energia Łódź SA, owns and manages the generation units and municipal district heating network. The district heating is produced in two coal-fired CHP plants with a thermal capacity of 830 and 804 MWt, respectively (Veolia Energia Łódź SA 2023). The company supplies approximately 60% of end consumers in Łódź and provides the district heating also to the neighboring Konstantynów Łódzki. The total length of the district heating network is 860 km. The average price of the district heating was PLN 71.58/GJ (generation) and PLN 24.21/GJ (distribution) in 2023 (Energy Regulatory Office 2023).

Consequently, the district heating landscape in Poland shows considerable variation in terms of operational models, generation capacities, and pricing. The largest systems in Warsaw and Kraków heavily rely on coal-fired plants, indicating an emphasis on high-emission energy sources. Prices vary significantly across cities and plants, reflecting differences in operational costs, fuel types, and network efficiencies. These variations highlight the complexity and diversity of Poland's approach to district heating, tailored to different regional needs and resources. The

average prices of district heating in the largest cities of Poland in 2023 are shown in Figure 3. The prices are converted from the Polish currency to EUR, assuming the average exchange rates from the tariff periods (EUR 1 = PLN 4.48 (as of 23.08.2023)). Depending on the city, the DH prices ranged from EUR 15.19/GJ in Kraków to EUR 18.26/GJ in Poznań. The presented prices are net prices.

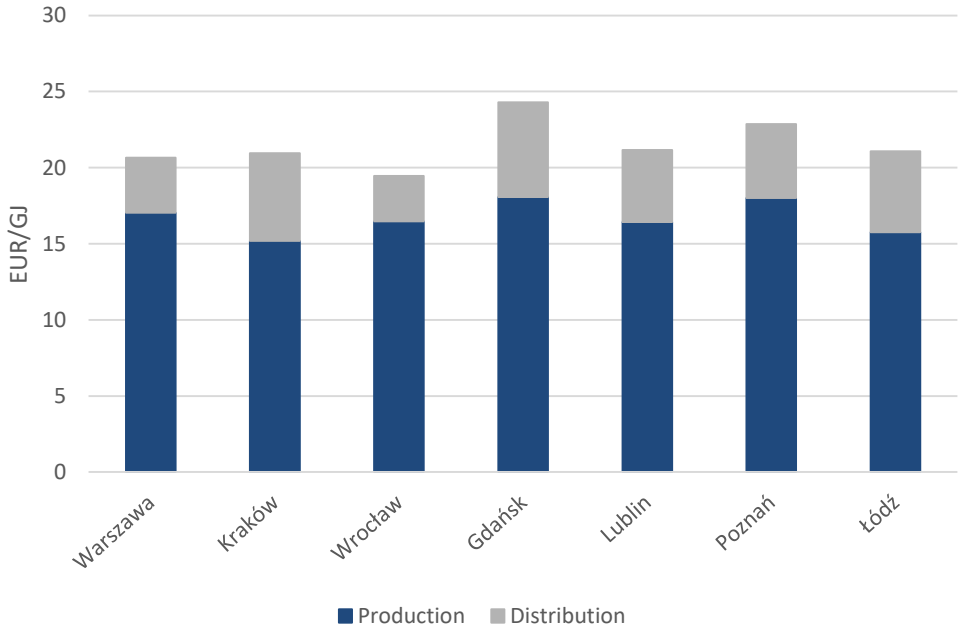

Fig. 3. Average prices of district heating in the largest cities of Poland (2022)
Based on tariffs of the Polish district heating companies

Rys. 3. Średnie ceny ciepła systemowego w największych miastach Polski (2022)

As mentioned, the CHP plants that generate district heating in the market analyzed are mainly hard coal-fired and natural gas-fired ones (Matuszewska et al. 2020; Pałka et al. 2023). Therefore, the prices are vulnerable to the recent fluctuations in the international fuel markets and changes in the prices of carbon certificates. Although the prices are higher compared to those in previous years, these increases do not include the dynamics of recent changes in coal and natural gas markets. As a result, further growth in prices is expected in the coming years, reflecting the rising prices of fuels and CO_2 emissions allowances.

The Polish heating system also faces challenges related to decarbonization and the transition towards more sustainable systems based on renewable energy sources (Hubert et al. 2023). Since most heating plants and CHPs are based on fossil fuels, the transition requires the introduction of key strategic goals at the local level of heating companies to meet objectives presented in the European and national strategic documents. According to these documents, at least 85% ener-

gy-efficient district/cooling systems compared to the current level of 20% are planned. As a result, market incentives and additional support mechanisms should be introduced to encourage potential investors to refurbish or build new low- or zero-emission facilities. Currently, the cogeneration premium and capacity market are among the mechanisms. However, the instruments are mainly constructed for thermal units, and experience shows that they do not impact on the development of renewable capacities (Kaszyński et al. 2021).

3.2. The Czech Republic

Local district heating markets in the Czech Republic are also regulated. The key document is the Czech Energy Law, and the duties of the regulatory authorities are performed by the Czech Energy Regulatory Office (Zákon č. 458/2000 Sb). District heating prices are set based on cost components of DH production and distribution and reasonable profit. Unlike in Poland, companies are not required to submit their tariffs for approval by the regulator. In the case of suspicion of infringement of the rules of the competition and the use of monopolistic practices, the energy regulatory office conducts audits on request.

District heating markets in the Czech Republic are mainly concentrated in cities located almost all over the country, except for the central part. Small systems are at the disposal of administrative units, similar in their scope to Polish communes, whereas large systems are owned by private companies. Thirty-nine DH companies operate on the market, of which seven have a dominant share: Innogy Energo (19%), Pražská teplárenská (13%), CEZ (12%), MVV Energie CZ (9%), Veolia Energie (7%), E.ON Energie (6%), and Elektrarny Opatovice (5%) (European Commission, 2021). The Czech Energy Regulatory Office publishes the average district heating prices, depending on the fuels used in the generation units. In a report published in November 2022, the heating produced in coal-fired units costs EUR 27.02/GJ, whereas the heating from natural gas-fired units cost EUR 36.78/GJ (ERU 2022). Compared to the previous years, an increase in prices is observed. However, the increase did not yet reflect the growth in fuel prices after the outbreak of war in Ukraine.

This growth is observed in the tariffs of the companies published in the second half of the year. The tariffs reflected the heating produced in natural gas-fired CHP plants owned by Innogy Energo were as follows. In Beroun – EUR 50.67/GJ, in Bolatice – EUR 59/GJ, in Hlinky – EUR 49.97/GJ, in Mladecko – EUR 46.44/GJ. In Náchod – EUR 44.75/GJ, in Limuzská – EUR 54.11/GJ, in Odolena Voda – EUR 48.32/GJ, and in Rumburk – EUR 42.33/GJ (Innogy Energo 2023). All prices are one-component prices and include costs of generation and distribution. The prices in Prague (Pražská teplárenská) were EUR 26.93/GJ (a variable component of the two-component price), whereas in Ústí nad Labem (CEZ) they were EUR 30.35/GJ (ČEZ Teplárenská 2022). Both CHP plants are also natural gas-fired units. The prices of heating produced in coal-fired CHP plants were EUR 25.67/GJ in Bílina – areál Doly, EUR 37.81/GJ in Braňany, and EUR 45.73/GJ in Brnířov (ERU 2023).

Although the methodologies for calculating DH prices in the Czech Republic vary depending on the company and fuels used in generation units, a significant difference is observed between these prices and those in Poland. Comparing the variable part of the two-component price in Prague, it can be observed that it is almost two times higher than average prices in Poland. The energy carrier is also different. In Poland, hard coal is mainly used in CHP plants, while in the Czech Republic, natural gas is a key fuel in the largest district heating systems. Considering the prices in the Czech hard coal-fired CHP plants, the sum of the generation and distribution tariffs in Poland from the second half of the year was equal to generation tariffs in the Czech Republic from January 2022. With dynamic changes in international markets in mind, a further increase in Czech companies is also expected in the years to come.

3.3. Slovakia

Slovakia's regulatory and administrative body is the Slovak Network Sector Regulatory Authority, which controls the prices submitted by heating companies. District heating markets are mostly regulated by the provisions of the Act on Regulation of Network Sectors (250/2012 Z. z.). According to this document, regulations cover three configurations of the business areas: (i) production and supply, (ii) production, distribution, and supply, and (iii) distribution and supply. District heating prices are regulated by applying the maximum price calculation method. The method includes taking into account economically justified costs incurred for the production, distribution and/or supply to consumers, economic efficiency (expressed as the ratio of incurred expenditures to their economic effects) and justified profit of the company. The rules for calculating tariffs, including the indices for determining the maximum price, depending on the fuel used in facilities (e.g., coal, natural gas, biomass) and the justified costs related to the heating activities, are also defined by regulations.

In Slovakia, almost a third of the citizens are supplied with heat by district heating systems. Heating companies with the largest market share include Bratislavská teplárenská, Tepláreň Košice, Žilinská teplárenská, Veolia Energia Slovensko, Trnavská teplárenská, Zvolenská teplárenská and Martinska teplárenská. The dominant model of the DH markets is a model where one company is responsible for heating generation and distribution, similar to the market models observed in Poznań and Łódź, in Poland. An increase in DH prices is also observed in the Slovak markets. According to official reports, the average heat price was EUR 23.22/GJ in 2020, which was over 10% more than the average price in 2017 (Regulatory Office for Network Industries 2021). However, the prices published in the official reports do not reflect the recent changes in the international markets. These changes are reflected in the tariffs of the DH companies, approved by the regulatory office in 2022 (URSO 2023).

In natural gas-fired CHP plants, prices ranged from EUR 30.92/GJ in Martin (Martinska teplárenská) to EUR 37.08/GJ in Košice (Tepláreň Košice). In Žilina (Žilinská teplárenská), in which hard coal and natural gas are used to heat production, the price was EUR 22.14/GJ,

while in Zvolen (Zvolenská teplárenská), in which hard coal and biomass are used, the price was EUR 17.36/GJ. The tariffs presenting these prices were published in the second half of 2022. Prices do not include VAT. As a consequence, these prices can be compared with those presented for Poland, with the proviso that the dates of updating the price lists in Slovakia took place about 3–4 months earlier in Poland (except prices Tepláreň Košice, where the update was in the second half of the year). The prices are comparable to the prices in Poland. Moreover, since most of them have not been updated since April, it should be expected that in the next decision of the regulator, they will be even higher (as in Tepláreň Košice, updated at the end of July 2022).

3.4. Lithuania

The key document presenting the mechanisms of the district heating price formulation in Lithuania is the Law on the heat sector (No. IX-1565). According to the regulations, the prices are set – as in Poland – using the cost-plus method, and then they are submitted for approval by the National Energy Regulatory Council. DH prices are set based on the costs incurred for the production or purchase of heat, its transmission, and monitoring and quality control systems. The prices of district heating do not reflect the costs of maintenance and repairs of heating systems in buildings. As a result, the prices reflect the long-term costs of generation and/or transmission and are set for a period of at least three years. However, they are annually updated in line with changes in local and international fuel markets and inflation rates. The obligation to submit the tariffs, along with a description of the methodology and assumptions used to calculate the price of thermal energy and/or hot water, applies to heat companies selling a minimum of 5 GWh of heating per year. The DH prices are one- or two-component prices, and the users decide whether they prefer to pay for the district heating at a one- or two-component fee. As in other countries, district heating prices may vary within the local DH markets, depending on conditions of the infrastructure and supply systems, customer groups, demand, energy carriers and their quality, reliability of supplies, season, and metering methods.

District heating markets operate in sixty Lithuanian cities, covering 57% of the heating needs in the country and 80% of the heating needs in cities. The largest share in the markets are as follows: AB Vilniaus šilumos tinklai (38%), AB Kuno Energija (24%), Klaipėdos (13%), Dalkia (12%), AB Panevėžio energija (9%), and AB Šiaulių energija (7%). Biofuel is the dominant fuel in heating and CHP plants. DH suppliers in Lithuania, depending on the quantity of their annual sales, are classified into one of five groups (National Energy Regulator Council, 2022): group I – over 150 thousand MWh (7 companies), group II – 90–150 thousand MWh (5 companies), group III – 50–90 thousand MWh (7 companies), group IV – 25–50 thousand MWh (15 companies), group V – below 25 thousand MWh (15 companies). In August 2023, the ranges of DH prices (generation and distribution) for these groups were as follows (National Energy Regulator Council, 2023): group I – EUR 13.72–19.69/GJ, group II – EUR 16.39–20.52/GJ, group III – EUR

16.83–23.14/GJ, group IV – EUR 18.03–29.86/GJ. group V – EUR 22–37.67/GJ. It can be noted that the highest prices are observed in groups with the lowest volumes of generation. However, regardless of the size of the company and the fact that biofuel is the dominant energy carrier in heating and CHP plants, the DH prices are much higher than in Poland.

3.5. Latvia

In Latvia, the DH prices are approved by the Utilities Commission on the basis of an application submitted by the district heating companies. The prices usually contain only one component, although, in exceptional cases, a two-component price may be requested. As in Poland, prices are formed using the cost-plus method, i.e., taking into account the costs incurred for heating generation and/or distribution and a reasonable margin. The tariff system covers the entire heat supply chain, from generation, transmission, and distribution to trading. The regulations of the Latvian district heating markets are presented in the Act on Regulators of Public Utilities. Although the supply of district heating is regulated, derogations are allowed in some cases. The small systems are not covered by the same regulations as large ones in order to limit the administrative load of small companies and reduce some costs that could be passed on to end users in tariffs. As a result, the prices are not regulated if the total amount of heat does not exceed 5 GWh/year (approximately 7% of the total district heating market in Latvia) (SPRK 2023).

There are seventy-four district heating systems in Latvia. Similar to Lithuania, the dominant fuels are biofuels and natural gas. DH prices varied by region and ranged from EUR 14.3 to EUR 59.61/GJ in the second half of 2022 (generation and distribution). Comparing the prices in Latvia to those in Poland, the former were usually two times higher than the latter. The lowest prices were observed in Koknese (EUR 21.87/GJ), Plavinas (EUR 27.1/GJ), Kraslava (EUR 14.30/GJ), Preili (EUR 15.07/GJ), Vecstropu (EUR 15.61/GJ), Jaunolaine (EUR 16.69/GJ), Karsava (EUR 17.94/GJ), Smiltene (EUR 16.21/GJ), Kuldiga (EUR 19.59/GJ), and Iecava (EUR 19.02/GJ), while the highest ones were noted in Rezekne (EUR 59.61/GJ), Saulkrasti (EUR 59.01/GJ), Kekava (EUR57.99/GJ), and Brankas (EUR 53.96/GJ) (SPRK, 2023).

3.6. Estonia

In Estonia, district heating prices are regulated and approved by the Estonian Competition Authority under the District Heating Act. According to the regulations, DH companies are obliged to calculate and prepare tariffs for consumers. The tariffs should reflect the costs incurred by companies for heat generation and/or transmission. The approach to the DH markets and regulations is similar to other countries described, where the tariffs must be approved by the regulatory bodies.

There are 230 district heating systems in Estonia. The dominant market shares are as follows: AS Utilitas Tallinn (40.0%), Tartu Keskkatlamaja AS (11.5%), Narva Soojusvork AS (9.0%), VKG AS (6.3%), and Fortum Eesti (4.3%). In Estonia, price caps are set by the regulatory office, depending on the region. In July 2023, the DH prices were equal to the limits and amounted to EUR 16.72/GJ in Valga, EUR 21.08/GJ in Kardla, EUR 19.84/GJ in Keilia, EUR 21.86/GJ in Haapsalu, EUR 20.74/DJ in Jogeva, EUR 25.20/GJ in Rapla, and EUR 21.97/GJ in Tallinn (generation and distribution) (AS Utilitas 2023). Due to the increase in the prices in fuel markets, the regulator increased the price limits to the next billing periods, from a dozen to as much as 44%. Comparing the DH prices in Estonia with those in Poland, it can be concluded that they can be even twice as high as in Poland in some regions.

3.7. Germany

The district heating market in Germany is the only example from those analyzed where price-setting mechanisms are more liberalized. As a result, the companies are not obliged to submit tariffs to the energy authority for approval before they introduce them to their end users. They are obliged to use the pricing methodology specified in the national regulations and to present it to their customers, together with the values of all factors used in their calculations to keep transparency (Federal Ministry of Justice 1976). Each price change must include new calculations and explanations of factors used in tariffs and be sent to consumers. In the case of the suspicion of infringement of the regulations on transparency in price formations, the National Antimonopoly Office (Bundeskartellamt) conducts inspections of heating companies.

District heating systems in Germany are mainly concentrated in cities. The largest ones are in Berlin, Heidelberg, Stuttgart and Munich. The largest companies are Vattenfall Wärme Europa AG, Stadtwerke München GmbH, Wärme Hamburg GmbH, EnBW, E.ON, Uniper, Innogy, Dalkia, Engie, and Getec. Natural gas and hard coal are the main fuels fired in heating and CHP plants. The district heating prices consist of basic and variable fees, depending on consumption. In order to compare prices in Germany to those in Poland, the variable components in 2023 were selected for analysis. In Butzbach, the price was EUR 30.53/GJ in 2023 (Energy and Supply Butzbach GmbH 2023), in Hamburg – from EUR 25.54 to EUR 40.52/GJ (Wärme Hamburg GmbH 2023), in Berlin – EUR 32.82/GJ (Vattenfall Wärme Berlin AG 2023), in Passau – from EUR 49.36 to EUR 58.25/GJ (Stadtwerke Passau GmbH 2023) and in Munich – EUR 38.36/GJ (Stadtwerke München GmbH 2023). In some cases, the prices were more than three times higher than prices in Poland.

3.8. Comparison

Table 1 summarizes the regulations and control systems of district heating prices in the analyzed countries. Except for Germany, all analyzed markets are regulated by energy regulatory bodies. Price control systems are present in each country, but with different levels of monitoring, i.e., prices can be controlled using the ex-ante or ex-post mechanisms. In the ex-ante mechanism, district heating companies are obliged to submit tariffs to the energy regulatory authorities and obtain their approval before using them in offers and contracts with their customers. This mechanism is in force in Poland, Slovenia, Lithuania, Latvia, and Estonia. In the ex-post mechanism, DH prices are controlled upon request when there is a suspicion of abuse of monopolistic practices. They are in force in the Czech Republic and Germany.

Table 1. Regulations and control systems of district heating prices

Tabela 1. Regulacje i systemy kontroli cen ciepła systemowego

Country	Regulation of the DH prices	Prices control	Ex-ante or ex-post
Czech Republic	✓	✓	ex-post
Estonia	✓	✓	ex-ante
Germany		✓	ex-post
Latvia	✓	✓	ex-ante
Lithuania	✓	✓	ex-ante
Poland	✓	✓	ex-ante
Slovenia	✓	✓	ex-ante

Source: based on (European Commission 2021).

The study conducted by the European Commission (2021) points out that regulations of district heating prices are also present in Bulgaria, Croatia, Denmark, the Netherlands, Romania, Slovenia, and Hungary. In other European countries, district heating markets are more liberalized, and prices are not approved by the regulatory authorities. On top of the countries analyzed in the study, the ex-ante mechanism applies in Bulgaria, Croatia, France, Hungary, Romania, and Slovenia, while the ex-post mechanism is in Denmark, the Netherlands, Austria, Finland and Norway (European Commission 2021).

Figure 4 shows the ranges of the district heating prices in the countries analyzed. The highest prices, over EUR 40/GJ, are observed in Germany, the Czech Republic and Latvia in 2023. However, these countries also have the largest ranges of prices, depending on region and fuels used for heat generation. In Germany, district heating prices ranged from EUR 25.54 to EUR 58.25/GJ, in the Czech Republic, from EUR 25.67 to EUR 59/GJ, and in Latvia, from EUR 14.3 to EUR 59.61/GJ. In Lithuania and Slovakia, the district heating prices were similar and ranged from EUR 13.72 to EUR 37.67/GJ and from EUR 17.36 to EUR 37.08/GJ, respectively. The

lowest prices were noted in Estonia and Poland. In Slovakia, DH prices were from EUR 16.72 to EUR 25.2/GJ, whereas in Poland, they ranged from EUR 15.19 to EUR 18.26/GJ.

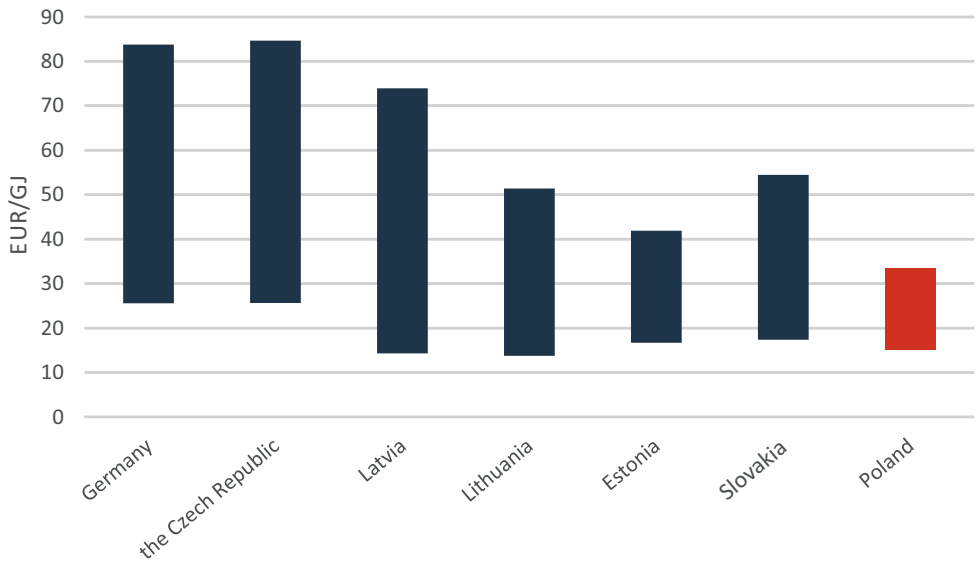

Fig. 4. The ranges of district heating prices, September 2022

Rys. 4. Zakresy cen ciepła systemowego, wrzesień 2022 r.

Although the minimum prices are similar in the countries analyzed (except for the Czech Republic), they are much less frequent than prices close to the maximum prices, as pointed out in the analyses presented in the previous subsections. In the majority of district heating systems, the DH prices are much higher than prices in district heating markets in Poland. In most countries, they have already reflected the dynamic fluctuations in the international markets of fossil fuels. As a result, they facilitate the generation of profits by district heating companies, and they are incentives to invest in new facilities and refurbish existing ones.

It should be noted that heating companies (CHP plant owners) could try to distribute their costs between electricity and heat production. Therefore, in some cases, the increasing costs of fuels and EUAs could be covered by the electricity prices that are produced in the same process. Our study is limited to the comparison of the prices in the form of heat tariffs that are important for consumers and local heating distributors. However, numerous papers consider the issue of cost distribution in CHPs. Ye and Li (2013) proposed a heat-electricity cost allocation in cogeneration. Atănăsoae (2023) provided a method for the allocation of joint costs and price settings for electricity and heat generated in CHPs. In contrast, Tereshenko and Nord (2015) analyzed the uncertainty of the allocation factors in heat and electricity production in CHPs. The proposed methods and findings could be helpful in further studies comparing the costs of heating products in the analyzed countries.

The systems in Germany, the Czech Republic, Estonia, Slovakia and Poland are still mainly based on fossil fuels. As a result, they required a fundamental transition to fulfill European objectives related to sustainable district heating and cooling systems, which are parts of strategies focused on achieving carbon neutrality in the EU (Majchrzak et al. 2021). Apart from increasing the heat produced in cogeneration, the ambitious plans related to the development of renewable technologies are presented in national documents, both in district heating markets and individual consumers (Mirowski and Orzechowska 2015).

In Germany, electrically driven heat pumps are considered to balance fluctuations resulting from variable generation from wind farms and solar photovoltaics (Buffa et al. 2019). The integration of industrial waste and solar thermal energy is also examined to assess the potential of those technologies to decarbonize the DH systems due to their presence in the Climate Action Plan 2050 for Germany (Pelda et al. 2020). In the Czech Republic and Slovakia, biomass and waste are considered to be alternative fuels that could replace coal in the DH systems. Additionally, heat pumps are indicated in strategic documents as technologies that could help accelerate the reduction of coal use (Sila and Frohm 2023; The World Bank 2019). In Estonia, the further development of biomass-based technologies is considered to replace natural gas to produce district hearing and fulfill decarbonization objectives in the long term (Volkova et al. 2020). In Poland, the increase in renewable energy is planned by the growth of the use of biomass, biogas, geothermal energy, and solar energy (Ministry of Climate and Environment 2021). As a result, the district heating systems are expected to perform a deep transformation and face economic, technological, environmental and social challenges (Koďousková et al. 2023).

Conclusions

The study analyzed and compared the Polish district heating systems, regulations, price formulations, and district heating prices with those of selected neighboring countries. The conclusions from the review read as follows:

- The specific features of district heating as a tradable product result in natural monopolies being the most common market structure in the countries analyzed.
- The regulations of district heating systems and prices vary between analyzed countries, and the Polish market is one of the most regulated. The tariffs developed by district companies must be approved ex-ante by the President of the Energy Regulatory Office. Similar mechanisms are introduced in Slovakia, Lithuania, Latvia, and Estonia. District heating prices in the Czech Republic are regulated, but ex-post and only upon request. In Germany, the market is more liberalized, and prices may be controlled upon request when the exercise of market power is presumed.
- Prices of district heating in Poland are the lowest among the countries analyzed in the study and range from EUR 15.19 to EUR 18.26/GJ, including fees for generation and distribution.

The prices correspond to the heat produced in coal-fired and natural gas-fired generation units. The highest prices are observed in Germany (EUR 25.54–58.25/GJ), the Czech Republic (EUR 25.67–59/GJ) and Latvia (EUR 14.3–59.61/GJ).

- The simplified tariff system based on planned revenues for combined heat and power plants in Poland results in an increase in the risk of problems with not covering the investment costs on time and is highly vulnerable to the volatility of market prices of fuels. Regulated markets do not provide sufficient incentives to invest in new generation units or to refurbish the existing ones.
- Considering the recent increase in prices of fossil fuels and European emission allowances, district heating prices are expected in the years to come, especially in countries where hard coal and natural gas are key energy vectors used for heat production. However, the regulators should facilitate the inclusion of increasing fuel prices in district heating prices on time.

The study focused on the critical discussion of district heating regulations and final DH prices in the volatile global fuel prices environment in order to identify investment incentives supporting the deployment of new technologies aimed at the decarbonization of the district heating systems. Following the European and national regulations and development strategies, an increase in renewable thermal capacity is expected in the analyzed regions. As a result, the changes in fuel mix will influence the district heating prices and decrease their dependence on fluctuations in coal and natural gas markets.

District heating systems face numerous challenges these days. The decarbonization and environmental issues became urgent, while the new investments require substantial funds, and their development could be limited by the current district heating prices that, in some countries, do not cover the operating costs of generation units. Future work will take into account the prospects and challenges related to the transition of the DH systems toward those that are more sustainable and environmentally friendly. Further studies will also consider the multi-scale-urban modeling systems for Weather Research and Forecast models to reflect environmental issues. Using the advanced approach allows one to include the impacts of urban heat islands on regional weather, climate, air quality, public health, and water resources and management and extend the study with the prospect of the district heating systems in the medium- and long-term.

This research has the following limitations. Firstly, the diversity of the district heating infrastructure across the EU complicates straightforward comparison. Each member state has its unique set of regulations, market structure, and subsidies, which influence the prices of district heating. Secondly, variations in regulatory environments related to CHPs add to the complexity. Cross-subsidization within companies offering both heating and CHP services renders the task of clearly identifying and comparing the individual costs for each service more challenging. Due to the complex nature of the district heating markets, regulations and differences in price formulation, further study should also focus on the comprehensive analysis of the difference between heating and combined heating and power plans with the consideration of cross-subsidization and potential cost distribution between heat and electricity supply cost within the same company.

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Analiza porównawcza rynków ciepła systemowego: badanie cen, ram regulacyjnych oraz mechanizów kontroli cen w Polsce i wybranych krajach sąsiadujących

Streszczenie

Obserwowane w ostatnim czasie dynamiczne zmiany na globalnych rynkach paliw kopalnych oraz uprawnień do emisji dwutlenku węgla mają znaczący wpływ na sektory energetyczne. Fluktuacje te wpływają także na rynki ciepła systemowego, gdzie węgiel i gaz ziemny nadal pozostają dominującymi nośnikami energii pierwotnej w wielu krajach europejskich. Rynki ciepła systemowego różnią się od rynków innych produktów ze względu na ich lokalny charakter i wymagania związane z transportem i dystrybucją. W związku z tym, w zależności od kraju, mogą one funkcjonować w różnych modelach rynkowych oraz mieć odmienne polityki kształtowania cen. W związku z powyższym, niniejszy artykuł ma na celu przegląd i analizę obecnych modeli rynkowych oraz regulacji kształtowania cen w kontekście cen na wybranych rynkach ciepła systemowego. Głównym celem jest przeprowadzenie dogłębnej analizy największych rynków w Polsce i porównanie wyników z sąsiadującymi państwami, tj. z Czechami, Słowacją, Litwą, Łotwą, Estonią i Niemcami. Polska została wybrana jako przykład ze względu na znaczną zależność od paliw kopalnych i podatność na obecne fluktuacje cen na rynkach międzynarodowych. Wyniki przeprowadzonej analizy wskazują, że Polska ma jeden z najbardziej uregulowanych rynków ciepła sieciowego, a regulacje te mogą wpływać na rentowność firm ciepłowniczych. W celu wypracowania zachęt dla potencjalnych inwestorów i obecnych przedsiębiorstw ciepłowniczych do rozwijania zrównoważonych i niskoemisyjnych systemów ciepłowniczych, rekomendowane jest rozważenie możliwości zwiększanie częstotliwości formułowania i zatwierdzania taryf ciepłowniczych.

Słowa kluczowe: ciepło sieciowe, ciepło, taryfy ciepłownicze, ex-ante, ex-post, rynek