Co-funded by the European Union

Programme for the Environment and Climate Action

LIFE Clean Energy Transition sub-programme

Topic: LIFE-2022-CET-DH

Call: LIFE-2022-CET

Project : 101119793

Project acronym: LIFE22-CET-SET_HEAT

Supporting Energy Transition and Decarbonisation in District Heating Sector

Report on future opportunities and functionalities of district heating systems in targeted countries

June 2024

SET HEAT

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Aalborg, June, 2024

Key document data

Work Package No	WP1
Related task(s)	T1.3
Deliverable Number	D1.6
Deliverable Name	Report on future opportunities and functionalities of district heating systems in targeted countries
Lead Beneficiary	AAU
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Contributor(s)	-
Type	Report
Language	English
Dissemination Level	Public
Due Date (month)	10
Due Date (calendar month)	July 2024
Actual submission date	23/07/2023
Description	English language document in pdf format
Version No.	1.0
Number of pages	181

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Foreword

This deliverable for the SET_HEAT project addresses opportunities for district heating development with a point of departure in the literature and in the prospects seen by district heating companies in the four SET_HEAT countries – Poland, Lithuania, Romania and Croatia. The work on the deliverable is lead by AAU, Denmark, with contributions from partners from the four SET_HEAT countries.

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1. Introduction

District heating covered around 9% of the global final heating demand in buildings in industry in 2020 [1], but with a global distribution skewed in favour of Northern and Eastern Europe, China and Russia. In Europe, District heating shares reach or exceed 50% in Denmark, Lithuania, Slovakia, Estonia, and Sweden (in descending order), and while countries like Lithuania and Estonia have renewable energy shares in district heating above 30% [2], on a global level renewable energy in district heating is a much more modest with fossil fuels accounting for around 90% of the production [1].

In Figure 1-1, the systems in the 27 member countries of the European Union at the time of the study are shown. While the above-mentioned countries rank high in the share of the heating market, it is also noticeable that district heating does not follow climatic logic. There is more district heating in Spain than in Scotland, to mention one observation that goes against climatic logic.

While district heating thus is modest globally and currently has a high fossil fuel reliance in general, there are definitive merits where it has been deployed as well as important virtues, which are major strengths in relation to overall efficiency gains and facilitation of the transition to sustainable, carbon-neutral energy systems in the future.

Main drivers pushing for district heating expansion throughout the world vary, but important is general greenhouse gas emission mitigation policies of local and national governments, as well as companies wishing to meet consumers' energy demands in a sustainable fashion. In the European Union (EU), the European Green Deal and the Fit for 55 package are measures assisting in reaching the EU's target of reducing greenhouse gas emissions by at least 55% by 2030 and achieving climate neutrality by 2050. An important part of this and aligned with said measures, is the Energy Efficiency Directive (EED). The EED is a critical component of the EU's strategy to improve energy efficiency, reduce energy consumption, and transition towards a more sustainable and energy-efficient economy. It was first adopted in 2012 and has undergone several revisions to strengthen its measures since. The main objectives of the EED are to reduce energy consumption, improve energy efficiency across various sectors, and support the EU's climate and energy goals. The EED explicitly supports the use of combined heat and power (CHP) systems and promotes efficient district heating and cooling networks.

Perception of district heating varies across Europe, thus while countries such as Sweden and Denmark look at it favourably, citizens in countries like the Netherland and Lithuania are less positive [3]. Cost, regulation, and ownership seem to have an influence on the perception, so in order to increase district heating in a country, a more holistic outlook must be taken into account and it must be ensured that it meets consumer demands – including competitive processes.

This section looks into the main technical motivators for DH introduction and expansion starting with the cogeneration of heat and power, scale effects of district heating, waste heat exploitation, air pollution, and competition with individual heating solutions. The rationale that has driven district heating development as presented in this section still holds for present days development and applications – but is supplemented by future prospects presented in Section 2.

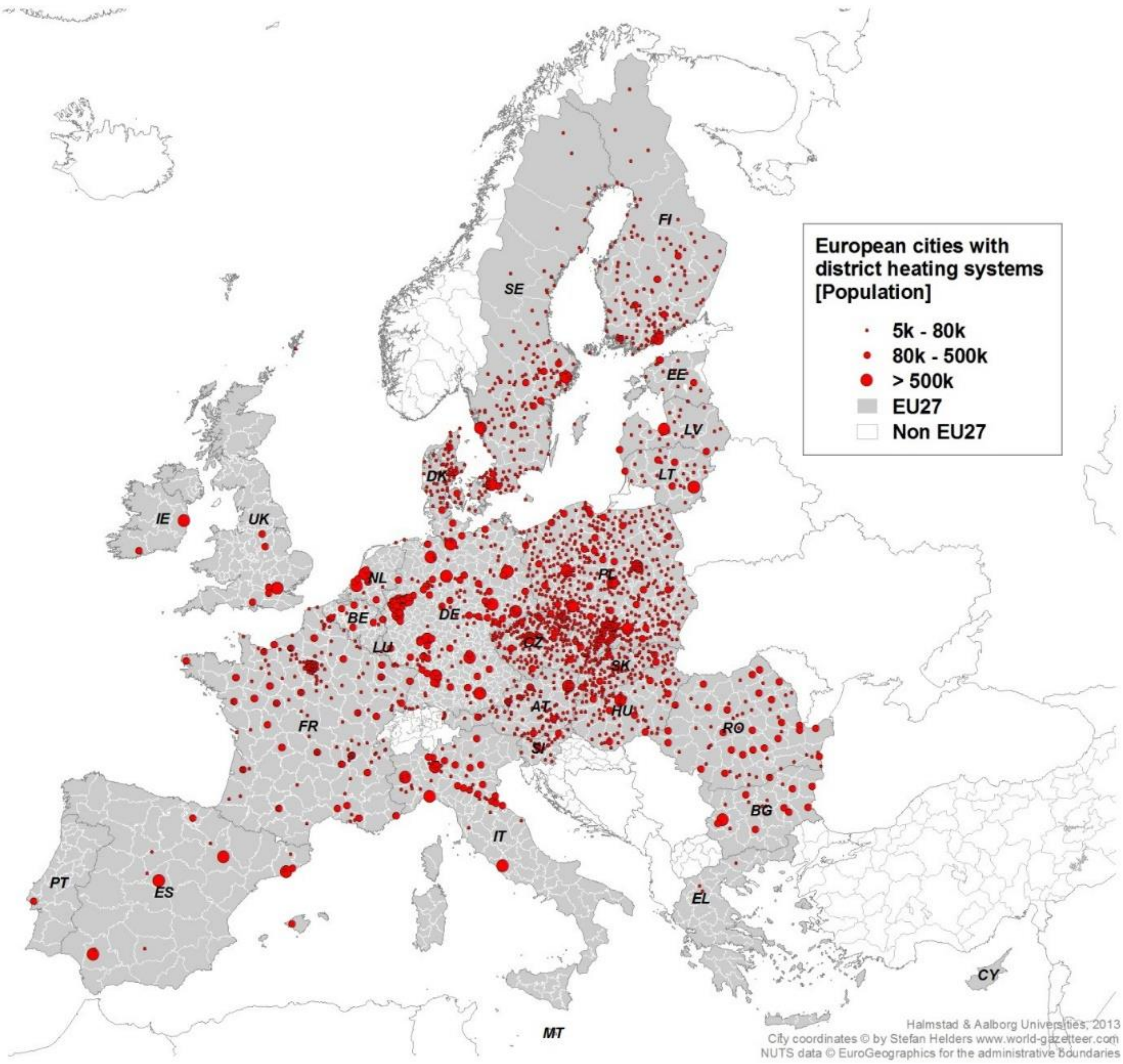


Figure 1-1: District heating systems in Europe. Source[4]

1.1 Efficiency improvement through the usage of cogeneration of heat and power

Many if not most large-scale district heating systems have exploited the synergy from cogeneration of heating and power (CHP), where power generation from combustion processes inevitably leads to large thermal losses due to the Carnot factor. With efficiencies for power generation in the range of 35-45%, the potential for heat extraction for heating purposes is in the vicinity of 50% of the fuel input. The exploitation of this synergy has generated incentives for a spatial distribution of electricity generation, which matches the demand for heating in various countries, though the extent to which this principle has been applied varies.

In Denmark, power generation has largely been decentralised to the extent that approximately 65% of the heating demand is covered by district heating. This has entailed introducing district heating typically with CHP in not only major cities but also in towns and villages down to a few 100 houses. In 1990, 59% of the heat generation came from plants with CHP[1] and this increased to 65% in 2022 [5]. This indicated the increase in district heating in Denmark, and even here in 2024, there is a significant push towards further district heating expansion to replace natural gas-fired boilers where feasible.

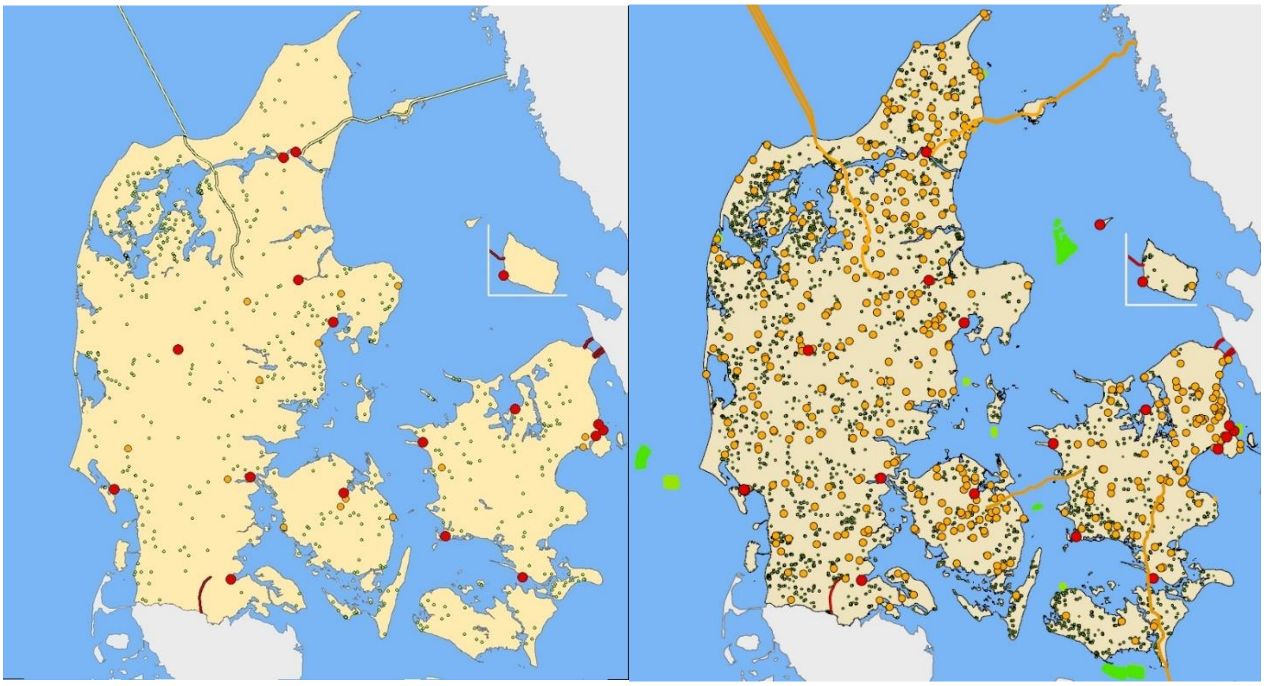


Figure 1-2: The Danish energy system in 1985 (left) and 2013 (right). Red circles are central CHP stations, orange circles are smaller CHP plants, and green dots are wind turbines. Source: [6]

[1] However this does not mean that it was produced in CHP mode; only that the possibility was largely there as it is a market-based system, where based on the temporary and dynamic electricity prices, other technologies may be more feasible than CHP operation in a given operation hour[122].

As shown in the two maps in Figure 1-2, it is clear the the geography of Danish electricity supply has changed dramatically in the three decades from 1985, with power production following heating demands. Thus with the exploitation of waste heat from electricity generation, the spatial understanding of the energy system has changed in Denmark.

In Poland, the DH share is 42% [2], and the exploitation of the CHP synergy is common. There are even examples of small-scale neighbourhood DH systems based on gas engine CHP for aggregations of apartment buildings. With a DH share of 56% [2], Lithuania is also prominent in DH. In 2022, CHP plants accounted for around 31% of all heat supplied to DH systems, of which 13% was produced by power plants operated by heat supply companies and 18% by independent heat producers (IHP) [7]. Around 14 % - thus nearly half the entire CHP-based DH generation in Lithuania, came from waste-based CHP plants in Vilnius, Kaunas and Klaipėda [7]. The largest working CHP station in the country is the newly built Vilniaus Kogeneracinė jėgainė biomass CHP 70 MW_e/170 $MW_{Th.}$

In Croatia, DH is in major towns and cities only, covering only approx. 6% of the heating demand [2]. In total, 16 Croatian cities have DHs with different sizes and types. CHP-based DH is modest, having an average heat generation from CHP of 35 MW in 2019 with 22.5 MW natural gas-based (based on annual production data from [8]). In Romania, the DH share is 23% [2] with Bucharest representing about 50% of the national demand – mainly CHP based. CHP is also moving beyond Bucharest with new installations in Constanta – here based on gas engines.

Thus, CHP has and still does play a large role in DH Europe. This can also be exemplified by the installation of a new natural gas-based CHP station in Zagreb which will enter into commercial operation in 2024

1.2 Scale-effects and waste heat utilisation

One of the benefits of district heating is the scale effects. Clearly, some technologies are only relevant at large scale. This includes traditional CHP units based on gas turbines or steam turbines whether run on gas, coal, biomass, oil, waste, nuclear, or other options – whereas fuel cell-based and piston engine-based CHP can potentially also be systems of more modest sizes.

The exploitation of excess/waste heat from industry is an important new entrant in DH systems, with wide potential for application as demonstrated by studies of China [9], Europe [10], and the urban level [11]. For the European study [10], an industrial excess heat of 2710 PJ/year was established. Similarly, Papapetrou and coauthors made a study of waste heat resources in the EU with a focus on industrial sectors and waste heat temperatures [12], finding a potential of around 300 TWh per year (around 1080 PJ/year) – and while less than half the estimate of [10], still significant. In terms of temperature levels, they found "one third corresponding to temperature level below 200 °C, which is often referred to as low-temperature waste heat, another 25% in the range 200–500 °C and the rest above 500 °C (mostly in the range 500–1000 °C)" [12] The high-temperature share is significant in this study, but probably a testament to the sectors included.

In Heat Road Map Europe [4], excess heat from all processes (i.e., also power generation) was established across the EU (See Figure 1-3) with noticeably high potential to be harvested in many places. In the map, each cell shows the ratio between heat demand and available excess heat, thus in large regions, excess is significantly larger than demand. For this map, nuclear power is not included as a source of excess heat. This could be the case.

In the Stratego project in 2015, it was estimated that 43% of the total energy input to industry and electricity generation could be recovered as waste heat for district heating purposes [13].

In Denmark, industrial waste heat is already a big player, with e.g. the cement factory Aalborg Portland supplying around 30000 dwellings in the city. Data centres are also new players in the market. Meta (the mother company of Facebook) supplies waste heat to Odense and after long delays, it is expected that Apple will start supplying DH to Viborg; something that could cover half the demand of the system with 20,000 consumers and lower the price with 3-4000 DKK per dwelling per year – 400-550 EUR [14]. Also in Denmark, the Danish Energy Agency expects the electricity demand for data centres to increase significantly in the future. A projection from 2020 to 2035 shows an increase from approx. 1 TWh per year to approx. 10 TWh [15] – thus, waste heat will increase correspondingly.

Waste heat utilisation is clearly an area with an important scale effect, where exploitation is not relevant for single consumers but only for large-scale systems – i.e., district heating systems.

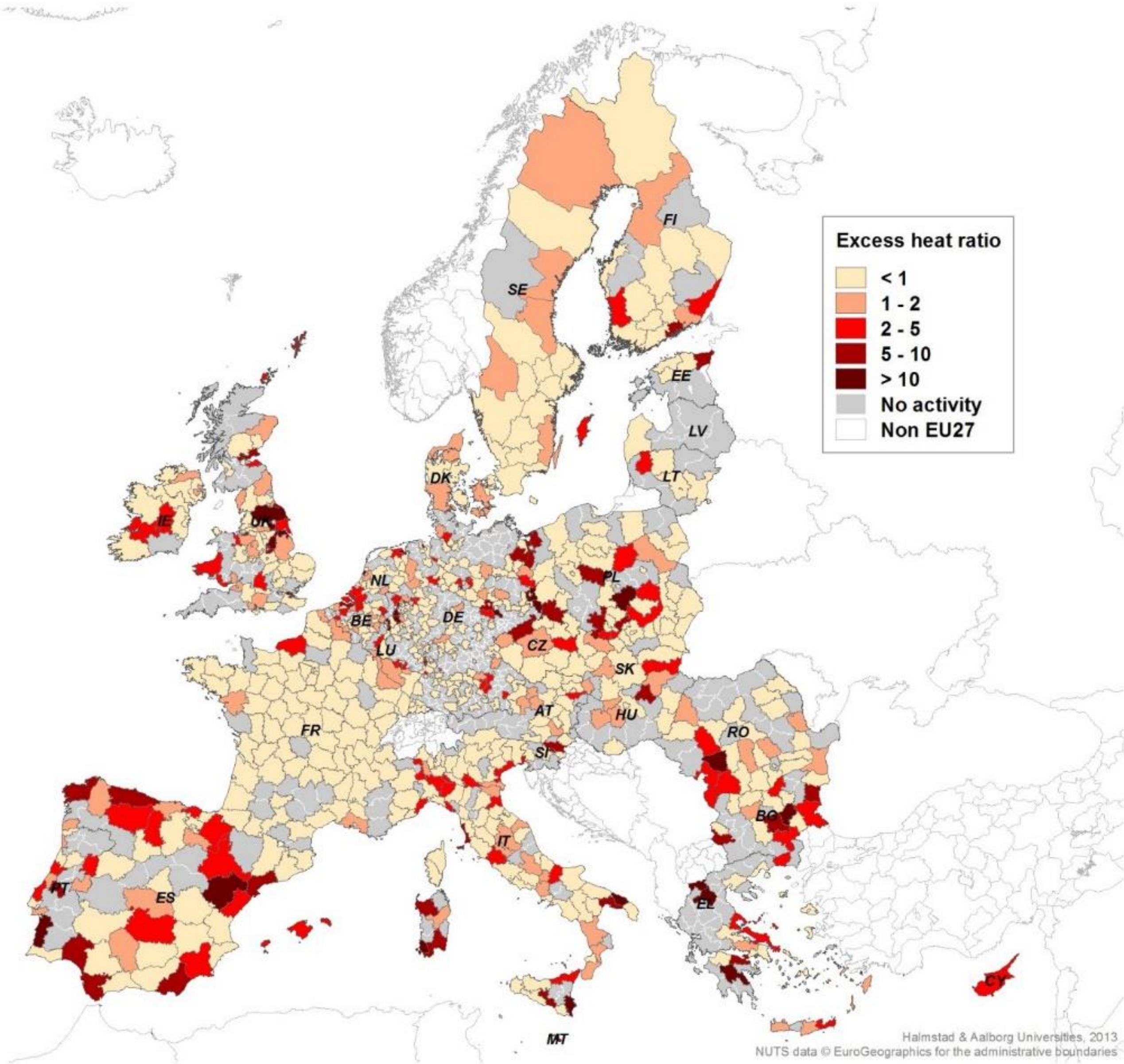


Figure 1-3: NUTS3[2] regions in 27 then EU member countries with indication of excess heat ratio - i.e. their share of excess heat relative to low temperature heat demands in residential and service sectors[4].

One of the technologies foreseen to have an important role in future heating systems – whether individual heating systems or district heating systems – is heat pumps [16,17]. Heat pumps have a scale effect – though in terms of investment, it is not significant. Observing Figure 1-4, air-to-water single-family heat pumps have investment costs at the same level of small 1 MW DH system heat pumps, though the cost of the latter end up about one third lower at the largest size of 10 MW shown. Larger systems of 320 kW for a block of flats are cheaper the individual heat pumps and sea water-based heat pumps of 20 MW are similarly

[2] NUTS is Nomenclature of Territorial Units for Statistics; a geographical unit used for statistical purposes.

priced per MW output compared to air-to-air 10 MW heat pumps – while larger CO_2-based sea water heat pumps are more expensive.

The comparison here is based on air-to-water heat pumps for individual buildings. If using ground-to-water heat pumps, the investment cost increases to over 2 M EUR/MW for the individual solution, and thus above the investment cost for DH heat pump solutions. Here it should be noted, that while there are DH systems with air-to-water heat pumps that function without problems, air-to-water heat pumps for individual houses have potential issues regarding noise, particularly in densely populated areas. In such areas, ground source heat pumps may not be optimal either for space reasons.

The coefficient of performance for larger heat pumps is generally larger than for small units – particularly if they have access to sources of excess heat, so here is a clear scale effect, as waste heat resources and other novel heat sources are typically not available for small-size applications.

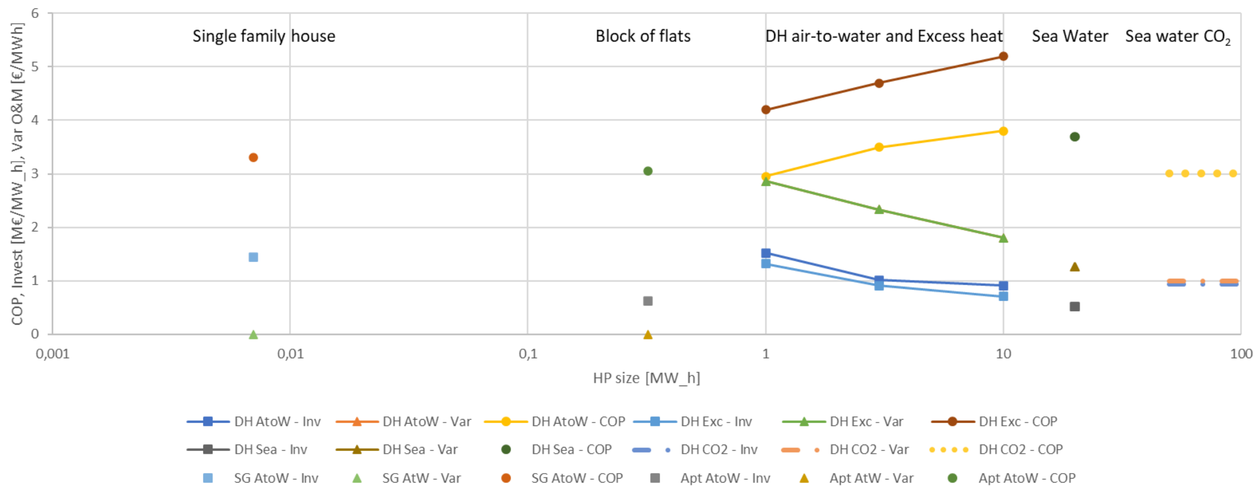


Figure 1-4: Investment cost, variable O&M and annual average COP for different sizes of heat pumps. Data for 2025 (central estimate) from [18]. *Investment costs are shown using squares, Variable O&M using triangles and COP using bullets. Variable O&M for the smaller units is zero, as it is considered included into a fixed O&M.*

Storage has a clearer scale effect than heat pumps. Not only is the economy improved significantly with larger sizes as shown in Figure 1-5, but losses are also. Surface area to volume and thus losses are inversely proportional to the size[3], thus losses for large systems are significantly lower than for small systems. This also means that large systems can serve a different purpose than small-scale systems. Small-scale systems for house installations are typically only serving the needs when domestic hot water demands exceed momentary production capacity, while larger central storage systems can serve the system needs. Also, it is very relevant noticing that the largest systems are 1000 cheaper per unit of storage than the single-house installations.

[3] Assuming size increases equally in three dimensions as in a cube or a sphere.

The size shown in Figure 1-5 – i.e., 3 kWh for individual storage – is very small compared to, e.g., the 50 kWh average daily demand for heating and domestic hot water in a typical daily house[4]. This would correspond to appro 1½ h of average demand. By comparison, district heating plants in Denmark, typically have a storage capacity of 8h of heat supply [19], to enable these to operate flexibly on the electricity market, but there is a tendency for even more storage – and as stated in [19], *"Increased thermal storage is a no-regrets option in district energy plants"*.

Larger sizes of storage than the size required for engaging actively in the electricity market also means that the district heating system is better adapted for utilising waste heat resources from, e.g., industry or data centres where temporal profile can be fairly constant. It will also assist the integration of sources where production is in opposition to demand – notably solar energy. Thus all in all, DH provides good storage options – and also storage options with implications beyond the heating sector, and thus a means to facilitating the integration of variable renewable energy sources (RES) into the electricity system.

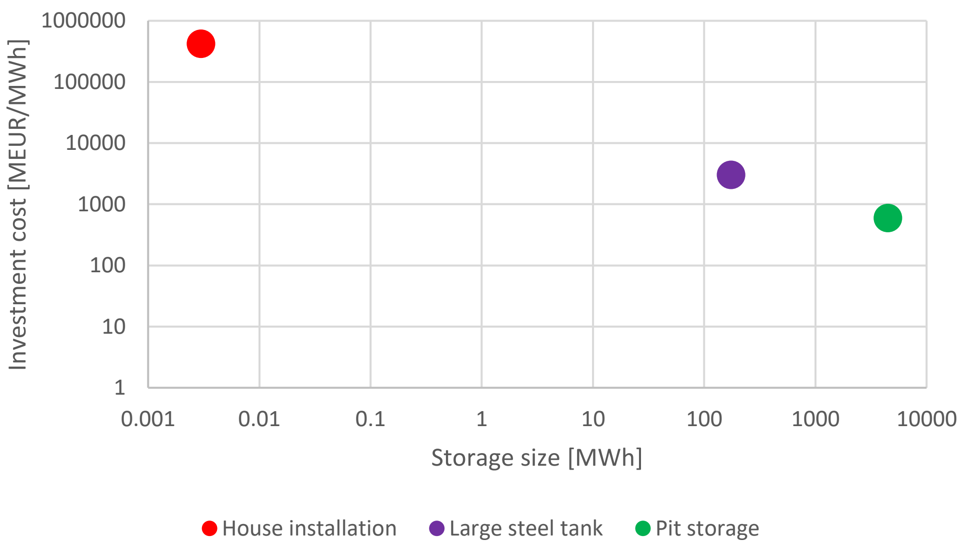


Figure 1-5: Investment cost for different sizes of heat storage. Data for 2020 (central estimate) from [18].

1.3 Air pollution

While public attention has largely shifted to the emission of greenhouse gasses, traditional air pollution remains notable. In a 2020 report on air quality in Europe, the European Environment Agency finds that 96% of the EU population is subjected to air pollution levels above the limit set by the World Health Organisation. In 2020, this resulted in 238,000 premature deaths in the EU – in addition to which comes loss of quality of life[20].

[4] Based on a yearly demand of 18 MWh for typical Danish house as used for statistical purposes for the Danish District Heating Association.

Looking at the spatial distribution of air pollution in Europe, there are clear signs that pollution levels are higher in Eastern Europe with notable dark spots in central Poland, Southern Poland, Eastern Czech Republic, Serbia, the Po Valley in Northern Italy, and more sporadic patches in the Balkans in general.

In terms of sources, according to [21], *"Residential, commercial and institutional energy consumption was the principal source of particulate matter in 2020"*. As air pollution has detrimental effects - [22] lists *"Air pollution is one of the greatest risks to health, by causing stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma"* with residential heating and cooking being significant contributors – curbing this is essential for health reasons but there are also associated costs. Ref [22] finds that annual cost in the EU27+UK is at EUR 29 billion – or 0.2 % of the GDP. In their analyses, Poland comes out with the highest cost per household.

The cost comes primarily from the direct use in dwellings (94 % of the cost) – and only very limited (6%) indirectly through electricity supply and district heating supply. This thus shows the disproportionate pollution arising from home use of fossil fuels and biomass. Even if using the same fuels for heating houses, due to scale effects, end-of-pipe options are simply better for district heating systems than for individual boilers – and combustion is also better due to a more controlled process. For instance, a modern individual wood chip or wood pellet boiler would have PM2.5 emissions of 14 g/GJ_{Input} while a large heat-only boiler for district heating would have total particle emissions of 0.3 g/GJ_{Input}. The individual solution would also release 25 g SO_2 per GJ_{Input} , while the DH boiler would remove 98%. For NO_x, emissions are similar – depending of course on combustion technique and potential de-NOx in the DH version.

Some heating transition roadmaps explicitly argue from an air pollution perspective – and not only, as else seen, from a greenhouse gas emission mitigation perspective. An example is the appropriately titled *"Heat Roadmap Chile: A national district heating plan for air pollution decontamination and decarbonisation"* [23], in which the same biomass resource is used in the reference as well as in the alternative scenario, but with far lower emissions. Particulate matter is reduced by nearly 40% in their 40% DH scenario compared to one of the Chilean Government's future scenarios – and by 97% compared to the 2017 situation [23].

1.4 Renewable energy exploitation

District heating has many of the same potential renewable energy sources as individual heating solutions have. This includes biomass boilers, solar collectors, and air-source heat pumps. In addition, scale effects open the door for other possibilities notably piston engine, gas turbine, or steam turbine CHP technologies operated on biogas or biomass fuels, which have been a traditional way of getting more renewable energy into district heating systems. Geothermal energy and other heat sources for heat pumps including fresh-water supply, and ambient water (rivers, lakes, sea) are also seen applied in different extents in different places.

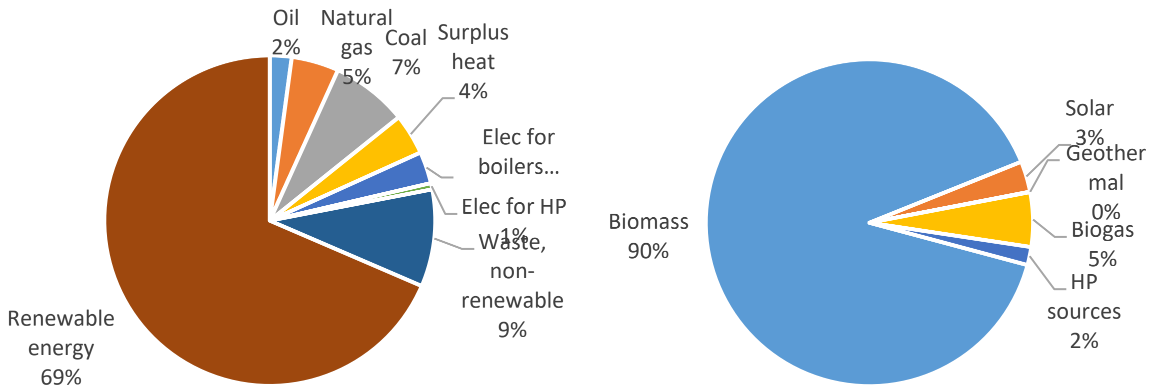


Figure 1-6: District heating supply in Denmark according to fuel type. Overall supply on the leaft and a focus on RES on the right. Based on data from [5].

District heating – and particularly district heating based on RES, have very localised characteristics. Thus, systems need to tap into the relevant sources in the given local context. In Denmark, district heating has largely managed to make a shift from fossil fuels to other sources including surplus heat from industrial processes, combustion of municipal solid waste (which is partly fossil-based), and various RES, as seen in Figure 1-6.

While Denmark has managed to supply DH which is 69% based on RES (and the other eight percent from surplus heat and electricity inputs to boilers and heat pumps), it has largely been through a strong focus on biomass as seen in the right-hand pie chart in Figure 1-6. This situation is detailed further in Section 2.6 where trends are addressed, but for now, it is relevant to observe not only the wide variety of sources in Danish DH but also the dominance of biomass, which can pose a problem as a restricted resource, a resource with biodiversity implications and a resource where careful carbon accounting and regrowth needs to be considered.

What is not included is the fact that electricity for heat pumps and electric boilers to a large degree is renewable based also. Not all electricity in the grid is renewable energy-based, but with a tendency for low-price periods to correlate with an abundance of wind and solar, there is an over-representation of renewables in the electricity mix during the hours when district heating plant operators opt to purchase electricity for heat pumps or even electric boilers. In Denmark, heat pumps can in fact be competitive against other heat supply technologies even when prices are not at their lowest levels.

Solar is also noteworthy among the renewable energy sources exploited for district heating in Denmark. Despite its northern latitude, insolation is sufficient to have made this interesting for district heating plant operators, and clearly, and even higher insolation (as in Croatia or Romania) would have made the option even more interesting. It must be noted though, that developments in technology costs have made the solar option less economically attractive than a combination of wind turbine or PV and heat pumps [24] under Danish conditions, though taxes can clearly change the playing field from one country to the other.

Geothermal potentials vary widely with local conditions, but it must be stressed that geothermal energy does not necessitate Icelandic hot pools or geysers. Even under geologically stable conditions, temperatures increase with the depth – in Denmark, e.g., typically 40K/km, but exploitation requires also subterranean porosity if for instance using free flow between extraction and injection wells. Other systems may use closed systems

Sea water has been applied for large-scale district heating systems in Stockholm and Gothenburg in Sweden for decades, and this is thus an old and well-established technology, though more novel in other places. In the mentioned system in Stockholm, the system can deliver 80°C hot DH water from a resource temperature of 2°C with a coefficient of performance of 2.8. This is based on lower levels of Baltic sea water.

In Aalborg, a part of the replacement of a coal-fired CHP station is a 132 MW_{Th} sea water-based heat pump which will produce just under one-third of the entire district heating production on an annual basis. The system based on three 44 MW_{th} heat pumps exploits an existing cooling canal to the power station, available land on site as well as strong existing connections to both DH and electricity grids

Different projects like Seenergies [25] and Heat Roadmap Europe [26–28] have looked more into local possibilities in a variety of European countries. Section 4 addresses some of the potentials in the four SET_HEAT countries.

1.5 Competition with individual solutions

This section explores the competitiveness of district heating in the SET_HEAT countries as well as in Denmark.

1.5.1 Croatia

The cost comparison is presented for Zagreb. HEP Toplinarstvo d.o.o. supplies heat to households and industrial customers, providing heating water, steam, and hot tap water. The basic tariff for heat energy (hot water) is 0.0238 EUR/kWh for households and 0.0477 EUR/kWh for industrial customers, covering both energy production and distribution. Steam for industrial customers is priced at 40.22 EUR/t. Additionally, there are tariffs for space heating: 0.092 EUR/m²/month with hot water preparation in the heat substation, and 0.066 EUR/m²/month without hot water preparation. These space heating tariffs apply equally to both household and industrial consumers.

Regarding electricity prices, all electricity users in the Republic of Croatia are subject to a tariff model for calculating their electricity consumption. There are two types of meters in use: single-tariff meters and multi-tariff meters. Single-tariff meters apply a constant rate per kilowatt-hour (kWh) regardless of the time of day. Conversely, multi-tariff meters allow for variable pricing structures based on the chosen tariff model. The "Blue" tariff model maintains a uniform rate throughout the day, similar to the single-tariff meter. The "White" tariff model, however, differentiates between higher and lower rates depending on the time of day. It is important to note that the base prices for electricity do not include additional costs such as those for the distribution and transmission network or the special fee aimed at promoting the production of electricity from renewable energy sources.

Table 1-1. Basic electricity prices.

Tariff models		Energy tariff items (€/kWh)			Supply fee [€/month
		EN_{JT}	EN_{VT}	EN_{NT}	
Low voltage	Red		0.194110	0.114182	4.645
	White		0.222818	0.131070	4.645
	Blue	0.193521			4.645

Table 1-2. Costs of using the distribution and transmission network.

Tarifni model		Tariff element					
		Energy			peak power	Excessive reactive energy	Fee for accounting measuring point
		JT	VT	NT			
		[€/kWh]	[€/kWh]	[€/kWh]	[€/kW]	[€/kvarh]	[€/month]
	Tariff items						
		1	2	3	4	5	6
Blue	7	0.029199	–	–	–	–	1.540
White	8	–	0.034508	0.015927	–	–	1.540
Red	9	–	0.022563	0.010618	3.252	–	5.481

Duration of higher and lower daily rates:

- winter time: VT from 07:00 to 21:00, NT from 21:00 to 07:00,
- daylight saving time: VT from 08:00 to 22:00, NT from 22:00 to 08:00;

Tariff model Blue

- Low voltage customers who have a single-tariff or multi-tariff meter can choose the Blue tariff model.
- The Blue tariff model contains tariff items for the following tariff elements:
- working energy at a single daily rate (€/kWh),
- excessive reactive energy (€/kvarh),
- fee for the accounting metering point (€/month).

Tariff model White

- Low voltage customers with a multi-tariff meter can choose the White tariff model.
- The White tariff model contains tariff items for the following tariff elements:
- working energy at a higher daily rate (€/kWh),
- working energy at a lower daily rate (€/kWh),
- excessive reactive energy (€/kvarh),
- fee for the accounting metering point (€/month).

Tariff model Red. The Red tariff model applies to network users with a connection power of more than 22 kW and contains tariff items for the following tariff elements:

- working energy at a higher daily rate (€/kWh),
- working energy at a lower daily rate (€/kWh),

- calculated peak working power (€/kW),
- excessive reactive energy (€/kvarh),
- fee for the accounting metering point (€/month).

Regarding natural gas, the tariffs depend on the quantity of consumption and are divided into 12 categories:

- TM1 Accounting metering point with annual gas consumption less than or equal to 5,000 kWh
- TM2 Accounting metering point with an annual gas consumption of more than 5,000 kWh, and less than or equal to 25,000 kWh
- TM3 Accounting metering point with an annual gas consumption of more than 25,000 kWh, and less than or equal to 50,000 kWh
- TM4 Accounting metering point with an annual gas consumption of more than 50,000 kWh, and less than or equal to 100,000 kWh
- TM5 Accounting metering point with an annual gas consumption of more than 100,000 kWh, and less than or equal to 1,000,000 kWh
- TM6 Accounting metering point with an annual gas consumption of more than 1,000,000 kWh, and less than or equal to 2,500,000 kWh
- TM7 Accounting metering point with an annual gas consumption of more than 2,500,000 kWh, and less than or equal to 5,000,000 kWh
- TM8 Accounting metering point with an annual gas consumption of more than 5,000,000 kWh, and less than or equal to 10,000,000 kWh
- TM9 Accounting metering point with an annual gas consumption of more than 10,000,000 kWh, and less than or equal to 25,000,000 kWh
- TM10 Accounting metering point with an annual gas consumption of more than 25,000,000 kWh, and less than or equal to 50,000,000 kWh
- TM11 Accounting metering point with an annual gas consumption of more than 50,000,000 kWh, and less than or equal to 100,000,000 kWh
- TM12 Accounting metering point with an annual gas consumption of more than 100,000,000 kWh.

Table 1-3. The tariffs of natural gas by category.

Type of tariff item	Tariff item code	Tariff model	The cost of gas purchase	The cost of gas distribution	The cost of gas distribution	Final gas price	Measuring unit
Tariff item for delivered gas quantity	Ts1	TM1	0.0264	0.0142	0.0085	0.0491	EUR/kWh
		TM2		0.0129		0.0478	EUR/kWh
		TM3		0.0129		0.0478	EUR/kWh
		TM4		0.0122		0.0471	EUR/kWh
		TM5		0.0116		0.0465	EUR/kWh
		TM6		0.0109		0.0458	EUR/kWh
		TM7		0.0103		0.0452	EUR/kWh
		TM8		0.0097		0.0446	EUR/kWh
		TM9		0.0090		0.0439	EUR/kWh
		TM10		0.0077		0.0426	EUR/kWh
		TM11		0.0065		0.0414	EUR/kWh
		TM12		0.0051		0.0400	EUR/kWh
Fixed monthly fee	Ts2	TM1		1.33		1.33	EUR
		TM2		1.33		1.33	EUR
		TM3		2.65		2.65	EUR
		TM4		3.98		3.98	EUR
		TM5		5.31		5.31	EUR
		TM6		7.96		7.96	EUR
		TM7		13.27		13.27	EUR
		TM8		19.91		19.91	EUR
		TM9		26.54		26.54	EUR

		TM10		39.82		39.82	EUR
		TM11		53.09		53.09	EUR
		TM12		66.36		66.36	EUR

The comparison of heating cost of district heating, individual gas boiler and heat pump for an apartment in Zagreb with an area of 70.78 m^2 is presented in Table 1-4. Heat consumedTable 1-7. Cost of heat from air-source heat pump for 70.78 m^2 apartment. As it can be noticed, district heating is currently competitive with both individual gas-fired boilers and air-source heat pumps.

Table 1-4. Heat consumed

Month	Delivered energy [MWh]	Power [kW]	Heated floor area [m^2]
Jan	1.02	4.964	70.78
Feb	0.957	4.964	70.78
Mar	0.676	4.964	70.78
Apr	0.63	4.964	70.78
May	0.274	4.964	70.78
June	0.119	4.964	70.78
July	0.186	4.964	70.78
Aug	0.139	4.964	70.78
Sep	0.227	4.964	70.78
Oct	0.446	4.964	70.78
Nov	0.759	4.964	70.78
Dec	1.332	4.964	70.78
Total	6.765	-	-

Table 1-5. Cost of heat from district heating system for 70.78 m² apartment

Month	Energy price [EUR/kWh]	Specific price of power [EUR/kW]	Supply charge [EUR/m2]	Buyer charge [EUR]	Total cost of heating [EUR]
Jan	0.0238	0.763	0.091	6.48	34.57
Feb	0.0238	0.763	0.091	6.48	33.07
Mar	0.0238	0.763	0.091	6.48	26.37
Apr	0.0238	0.763	0.091	6.48	25.28
May	0.0238	0.763	0.091	6.48	16.80
June	0.0238	0.763	0.091	6.48	13.11
July	0.0238	0.763	0.091	6.48	14.70
Aug	0.0238	0.763	0.091	6.48	13.58
Sep	0.0238	0.763	0.091	6.48	15.68
Oct	0.0238	0.763	0.091	6.48	20.90
Nov	0.0238	0.763	0.091	6.48	28.35
Dec	0.0238	0.763	0.091	6.48	42.00
Total	-	-	-	77.78	284.41

Table 1-6. Cost of heat from gas boiler for 70.78 m² apartment

Month	Required gas energy (boiler efficiency of 95%) [MWh]	Gas price [EUR/kWh]	Fixed fee [EUR]	Energy cost [EUR]	Total cost of heating [EUR]
Jan	1.073	0.048	1.33	51.32	52.65
Feb	1.007	0.048	1.33	48.15	49.48
Mar	0.711	0.048	1.33	34.01	35.34
Apr	0.663	0.048	1.33	31.69	33.03
May	0.288	0.048	1.33	13.78	15.12
June	0.125	0.048	1.33	5.98	7.32
July	0.195	0.048	1.33	9.35	10.69
Aug	0.146	0.048	1.33	6.99	8.32
Sep	0.238	0.048	1.33	11.42	12.75
Oct	0.469	0.048	1.33	22.44	23.77
Nov	0.798	0.048	1.33	38.18	39.52
Dec	1.402	0.048	1.33	67.02	68.35
Total	7.121	0.048		340.38	356.35

Table 1-7. Cost of heat from air-source heat pump for 70.78 m² apartment

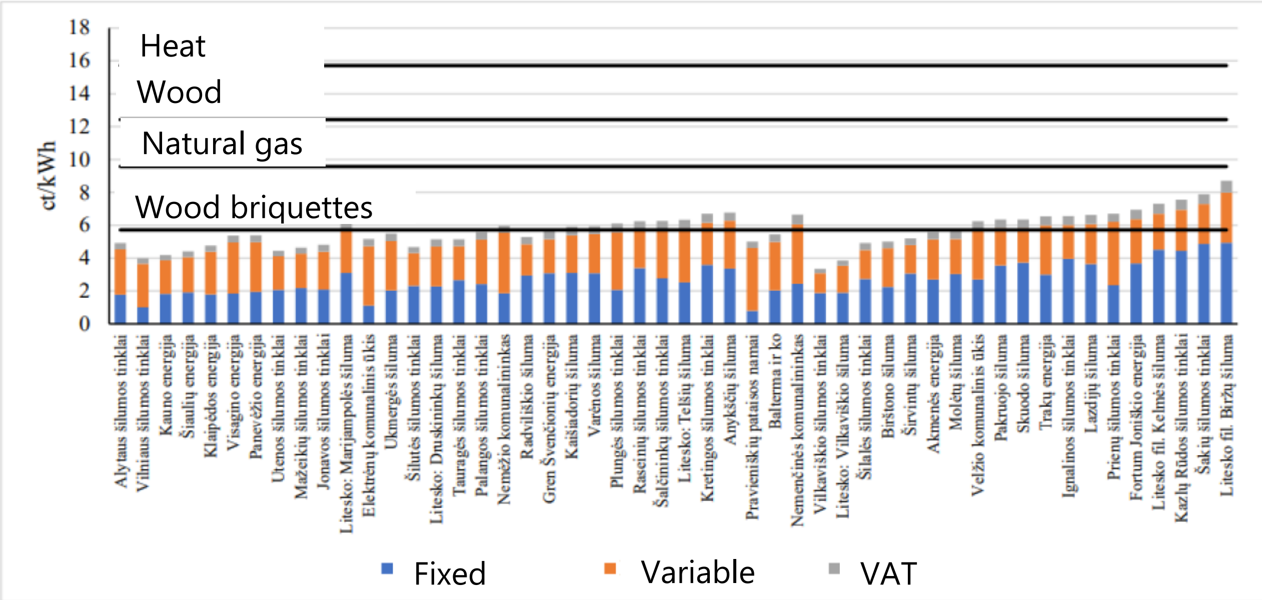
Month	Required electrical energy with COP of 2.5 [MWh]	Energy price [EUR/kWh]	Fixed fee [EUR]	Energy cost [EUR]	Total cost of heating [EUR]
Jan	0.408	0.222	6.18	90.86	97.05
Feb	0.382	0.222	6.18	85.25	91.44
Mar	0.270	0.222	6.18	60.22	66.41
Apr	0.252	0.222	6.18	56.12	62.31
May	0.109	0.222	6.18	24.41	30.60
June	0.047	0.222	6.18	10.60	16.79
July	0.074	0.222	6.18	16.57	22.76
Aug	0.055	0.222	6.18	12.38	18.57
Sep	0.090	0.222	6.18	20.22	26.41
Oct	0.178	0.222	6.18	39.73	45.92
Nov	0.303	0.222	6.18	67.61	73.80
Dec	0.532	0.222	6.18	118.66	124.85
Total	2.706			602.68	676.90

1.5.2 Lithuania

In Lithuania, the marginal cost (i.e., without consideration for investment and operation and maintenance) of heating dwellings using district heating is for all analysed district companies lower than for heating using individual heat pumps, wood pellets or natural gas. Only wood briquettes are competitive with district heating – though not for all Lithuanian systems – see Figure 1-7.

Paveiksle žemiau pateikiamas CŠT sistemų patiektos šilumos ir individualių šaltinių pagamintos šilumos kainų palyginimas.

31 paveikslas. CŠT sistemų patiektos šilumos ir individualių šaltinių pagamintos šilumos kainos 2020 m.



Šaltinis: Studijos autoriai

Figure 1-7: Price comparison between individual heating technologies and district hearting for 50 Lithuanian DH systems with 2020 data. Second bar from the left is Vilnius DH (VST) . Source: [29]

1.5.3 Poland

System heat prices in Poland are not liberalized in the same way as prices for alternative carriers and fuels. Polish DH sector is subject to a regulatory mechanism and the business activity in the area of transmission or distribution of heat is licensed.

According to the information package released by the Department of Electricity and Heat Markets of Energy Regulatory Office (URE), all generation, transmission and distribution companies with an ordered capacity of more than 5 MW are required to hold the relevant licenses and to obtain heat sales tariffs:
"Pursuant to Article 32 item 1 section 3 of the Energy Law Act of 10 April 1997 – (Journal of Laws of 2019, item 755, as amended), hereinafter referred to as the "Energy Law Act", business activity in the following area requires obtaining a licence: transmission or distribution of heat, excluding: transmission or distribution of heat, if the overall ordered capacity does not exceed 5 MW.

As of the end of 2022, 392 enterprises (a total of 816 individual licenses for a given type of heat supply activity, i.e. generation, transmission, and distribution, or heat trading) held licenses issued by the President of the Energy Regulatory Office (URE) for generation and/or transmission and distribution and/or heat trading.

The so-called “tariffs for heat” or “heat tariffs” are sets of prices and rates of charges and the conditions for their application, developed by an energy company and introduced as mandatory for the customers specified therein. In Poland, tariffs are approved by the Energy Regulatory Office.

In case of Opole DH system, when one company (ECO SA) carries out generation, and distribution of heat, the heat tariff addresses two services: sales and distribution (transmission). Both services include fixed and variable fees (prices):

- Price for ordered thermal power (fixed), in PLN/MW/year,
- Fee for transmission services (fixed), in PLN/MW/year,
- Price for heat, PLN/GJ,
- Fee for transmission services (variable), PLN/GJ

In Figure 1-8, district heating system prices and heat prices for different heating systems are compared. Presented prices are only including costs of resources used for heat generation – in the case of DH price only generation and transmission costs are taken into account, in case of individual heating systems only fuel costs (fuel prices and efficiency).
For the comparison analysis, the fuel prices and process efficiencies were assumed as presented in Table 1-1. The heat price of the DH system was calculated on the basis of the available heat tariff for Opole.

Table 1-8. Prices and efficiencies of the analysed heating systems

Fuel/resource for a given technology	**Efficiency**	**Price**	**Unit**
HP air water	4,10	238,1	EUR/MWh
gas boiler	0,95	71,9	EUR/MWh
oil boiler	0,90	1,36	EUR/liter
biomass (pellet) boiler	0,80	340,9	EUR/Mg
individual coal boiler	0,70	363,6	EUR/Mg
electrical heaters	1,00	180,9	EUR/MWh

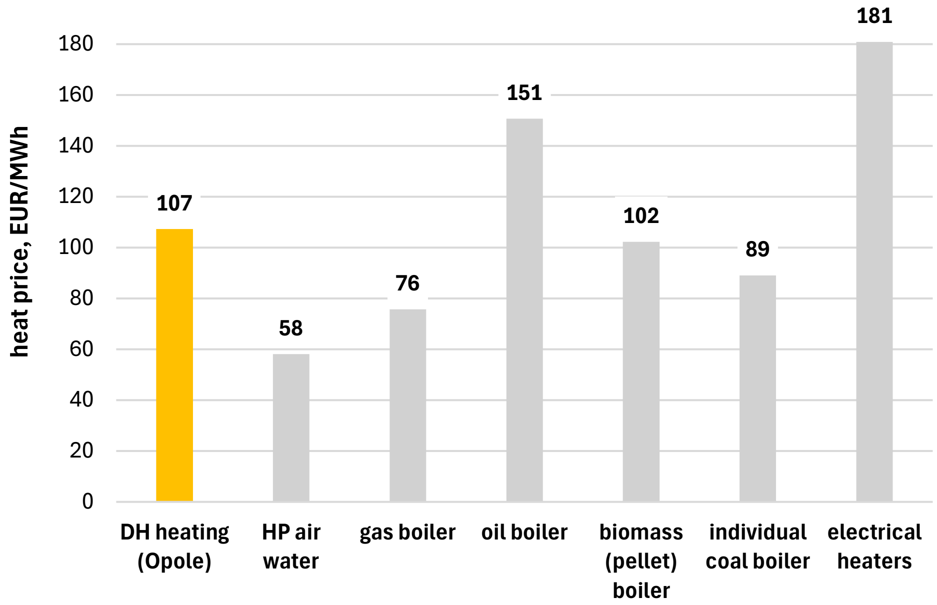


Figure 1-8: Heat prices (only generation costs) from different resources and technologies, in Poland, 2024

Figure 1-9 additionally summarizes heat prices, calculated taking into account the capital expenditures (CAPEX) required to apply a particular heat generation technology. In the case of system heat, the necessity of building a heat substation is taken into account.

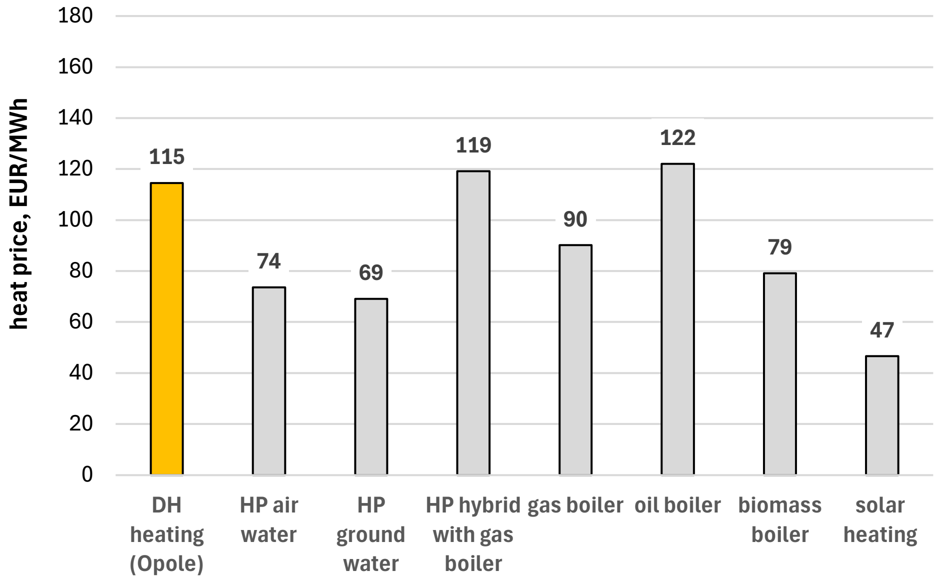


Figure 1-9: End-user heat prices price including return on invested capital from different resources and technologies, in Poland, 2024

Figure 1-10 shows the historical changes in the cost of heating buildings from 1999 to 2023. Costs are related to 1 m^2 of heated area and changes are shown in percent, relative to the base year of 1999. As can be seen from the comparison, the cost of heating buildings with system heat is more stable than gas prices and coal prices, although a clear relationship between the price of system heat and the price of coal is apparent.

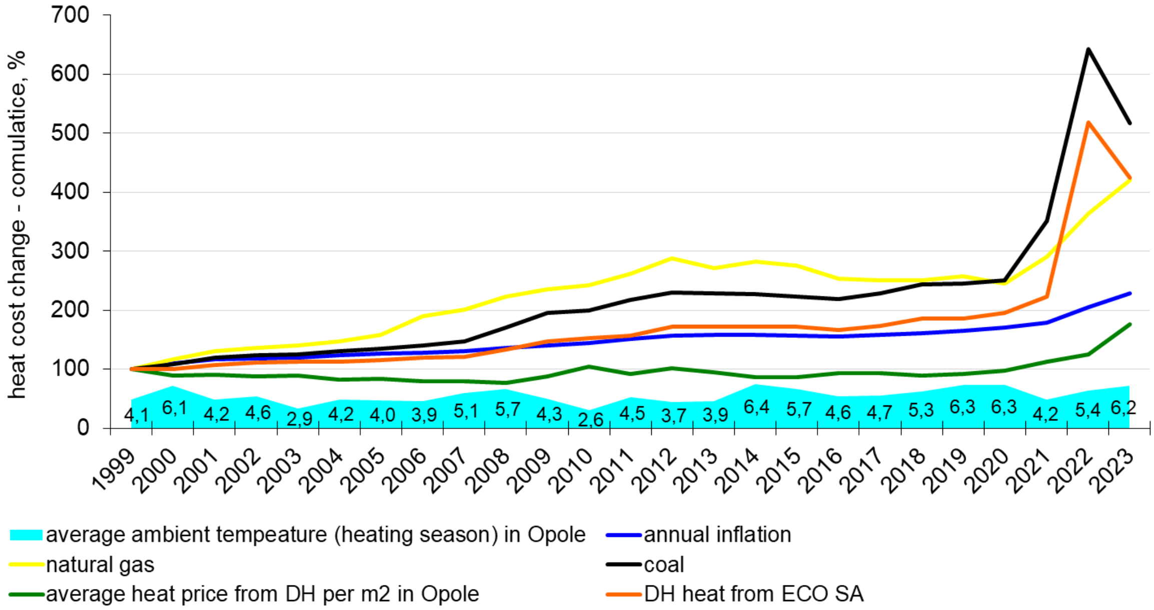


Figure 1-10: Comparison of changes in heat costs for different fuels in Poland

Figure 1-11 shows the results of a comparative analysis of average heat prices in selected district heating systems in Poland. As can be seen, the variability of prices is quite high (from 50 to 190 EUR/MWh of heat delivered to the building), although the vast majority of district heating systems provide heat at prices relatively close to the range between 100 and 130 EUR/WMh.

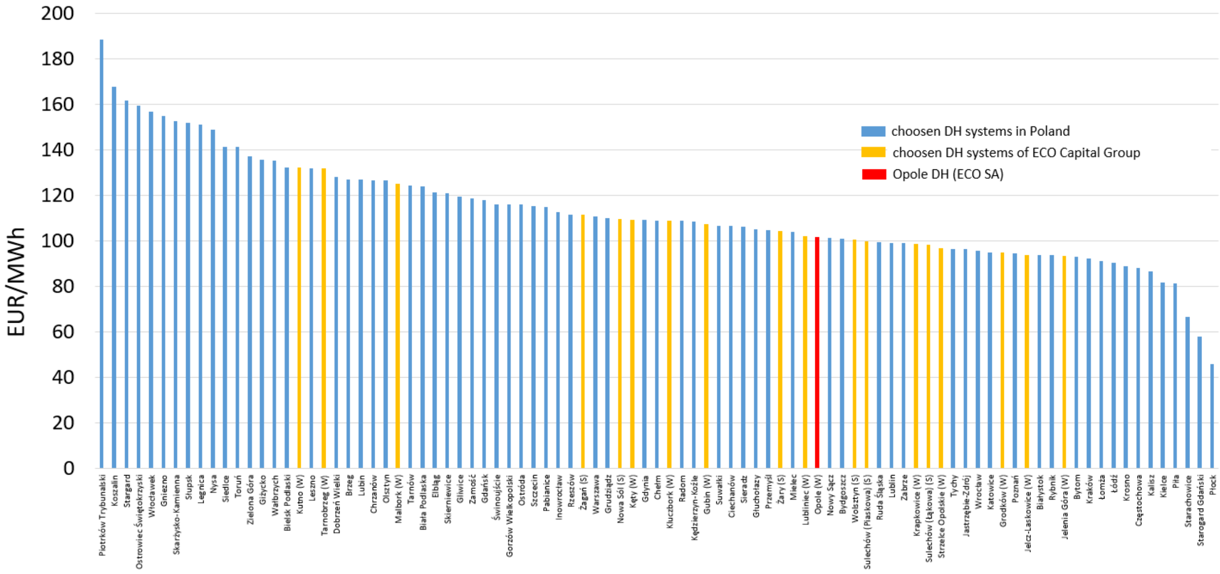


Figure 1-11: Benchmark of heat prices in different cities in Poland, including Opole DH system

1.5.4 Romania

In Romania, the cost for heating a dwelling using district heating is about EUR 80-100 per month. In the first three months of 2024, the price ranged between EUR 50 and 75 per month for heating a flat with 2-4 people. For natural gas, the cost of fuel, auxiliary electricity, and operation and maintenance amounts to EUR 420 to 820 per year for dwellings of 7 to 12 MWh/year. For district heating, 70% of the cost is even supported by the municipality, so the actual cost is closer to EUR 200 per month. In the future, lower losses in networks are expected to drive down the cost. For single-family houses, a 100 m^2 would cost EUR 600 per month if heated with electricity, whereas with NG it would be EUR 160 per month. Thus, DH is currently competitive with electric heating in Bucharest but not with natural gas-based individual heating.

1.5.5 Denmark

In Denmark, DH is to a vast majority of present DH consumers competitive to alternative heating technologies for individual housers. The Danish District Heating association collects pricing information from all DH companies in the country for what they define as a "standard house" – 140 m^2 house with an annual heat demand (combination of space heating and domestic hot water preparation) of 18.1 MWh. Data from 2023 show that for 99.4% of the present DH consumers, the solution is cheaper than if they invested in an oil boiler, for 99% it is cheaper than if investing in a heat pump and for 97.5% their present DH solution is cheaper than if investing in a natural gas boiler (assuming of course that this is indeed an alternative in the given location). This is shown in Figure 1-12, where the total cost of space heating and domestic hot water preparation is shown for practically all Danish DH companies. The width of the horizontal line segments indicates the share of the Danish DH market each company has, and thus, combined, the curve shows the aggregated share of the Danish DH market.

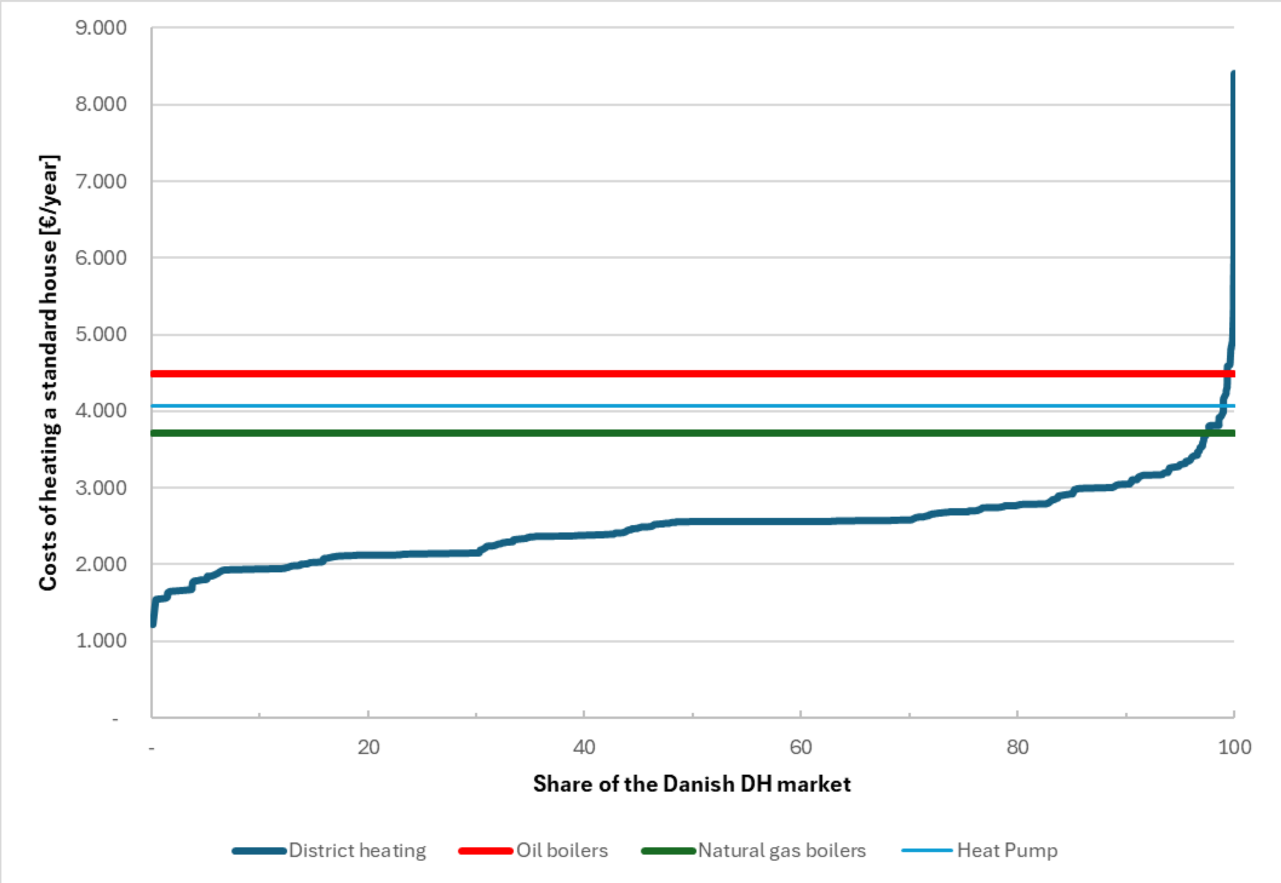


Figure 1-12: Cost of heating a "standard" Danish house with 18.1 MWh with DH compared to the cost with individual oil or natural gas boilers and heat pumps. Data from 2023. Costs include annualised investment costs for relevant technologies as well as operation and maintenacnce and relevant taxes.

These 2023 numbers align well with numbers from the a ten year old study [30], thus the picture in Denmark does not vary considerably over time. Thus, DH is cheaper for most present Danish DH consumers, and it is indeed quite popular to connect to the DH systems in places where this is optional. But it should also be noted, that there are clearly some systems that should not have been made for various factors - small, spatially dispersed, or simply based on wrong economic projections.

When comparing across countries, clearly, taxes play a role in the economic performance of different alternatives, but taxes are not merely fiscal instruments but also incentive structures, thus if favourable from other perspectives, DH can be favoured by taxing alternatives or simply taxing externalities which would favour the efficient alternative.

1.6 Overall development prospects

Europe in general holds large prospects for developing district heating further, and there are many studies looking at specific countries. In addition, some studies look holistically at Europe in general. In addition to the previously mentioned Seenergies project, Heat

Roadmap Europe is one such project with the ambition of analysing district heating potentials across Europe.

Fallahnejad and coauthors [31] presented a study in 2024, where they analysed district heating expansion opportunities for the European Union member countries, finding an optimal district heating share of 31%. In this study, they took a point of departure in European Commission decarbonisation scenarios and investigated impacts for DH primarily based on spatial analyses. This is a doubling compared to the present level.

In the first published Heat Roadmap Europe study, the point of departure was that the European Commission did not consider district heating at all in their scenarios, so the project set out to explore the prospects. One of the key findings was that

"By adding district heating to an EU energy system with very low heat demands, it is possible to use the same amount of fossil fuels and biomass as the EU Energy Efficiency (EU-EE) scenario in the Energy Roadmap 2050 *report, but the total costs for heating and cooling buildings will be approximately 15% lower."* [10]

In the following section, we probe further into opportunities for district heating systems to be integrated with other parts of the energy system.

2. Opportunities for District heating systems in a transforming energy system

This chapter describes some of the overall tendencies affecting district heating systems in terms of operation and development prospects. Both the academic literature and trade literature abound with references to district heating development prospects including terms such as smart energy systems, 4th generation district heating, sector coupling, power-to-heat, prosumers, and more. Thus, this chapter probes into some of these opportunities for district heating systems.

2.1 Smart energy systems and 4th generation district heating

In 2012 the notion of *smart energy systems* was introduced [32]. This came as a reaction to a more focused concentration on smart grids, where the *smart grid* discussion appropriately addresses one of the main technical issues in the energy transition – the technical regulation and balancing of electricity systems based largely on variable RES. The reason for the high focus on variable RES is that these are more abundant than dispatchable RES such as biomass-based power or CHP generation. Thus, the transition in many places relies on variable RES.

Of main importance in future power systems with high amounts of variable RES are ancillary services - keeping the balance between production and demand (and the grid frequency), keeping voltage stability (though a reactive power balance), and ensuring sufficient short-circuit power to withstand disturbances or simply load changes. While some of these issues are handled exclusively inside the electricity system, and thus issues where solutions shall be sought here, a main issue of balancing will result in costly solutions, if solutions are only sought in the electricity system.

The *smart energy system* concept is based on the notion that cheaper solutions are available if looking more holistically across the entire energy system. Energy storage in the electricity system is orders of magnitude more expensive than energy storage elsewhere in the energy system – heating, cooling, gaseous fuels [33]. If hydropower is available, then this has some good properties also for storage, but if electricity balancing issues are solved with batteries only, then the solution is more costly than necessary.

Thus, analysing energy systems more holistically from a smart energy systems perspective can identify heat storage combined with CHP or heat pumps as a flexibility provider relevant for both downwards regulation and upwards regulation. The same can be the case with cold storage – albeit without the power production ability – though upwards regulation can be provided by downregulating the demand and drawing on storage. Similar options are provided from the transportation sector or the industrial sector, though flexibility may be more limited in terms of their actual electricity demand. For the transportation sector, flexibility can be provided on the electricity side from charging/discharging, as already noted decades ago [34,35] and industry, while largely having inflexible electricity demands, can provide flexibility through the production of fuels intended to replace fossil fuels in processes where an actual combustion or simply high temperatures are required.

Focusing on the district heating sector, another metrics of describing or assessing how integrated the sector is with the rest of the energy system is *generation*. Refs [36,37] define first-generation district heating as being based on boilers, and thus clearly without much sector integration with the rest of the energy system. Apart from the very first generation of district heating, now phased out from mainstream district heating throughout the world, district heating is and has thus largely been integrated with electricity supply. Generations 2 and 3 thus both share a CHP element and a primary difference between these is mainly in terms of temperature levels and is thus not an essential difference from a sector-integration perspective. In addition, though, Generation 3 also includes other sources such as waste heat, solar thermal, and more. Full-fledged sector integration comes in Generation 4 with power to heat where PV, wave power, wind power and other electricity sources providing electricity for heat pumps. Generation 4 also includes seasonal heat storage, integration with district cooling systems and a higher variety of sources. Some authors discuss a fifth generation of DH, but the authors of the original generations do not distinguish 4GDH and 5GDH [38].

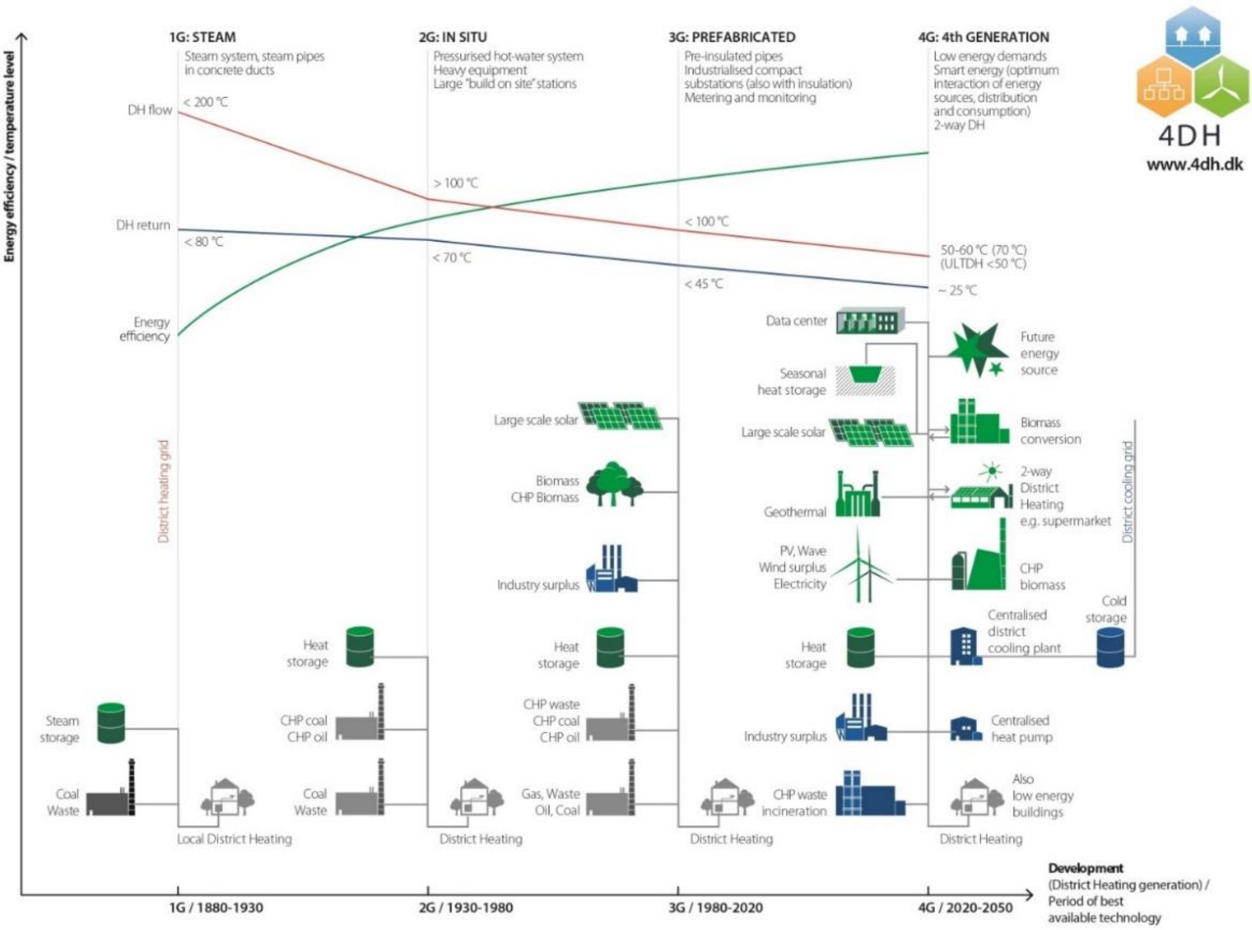


Figure 2-1: The four generations of district heating. Updated version based on [36].

Observing Figure 2-2, this chart shows the operation of a Danish DH station supplying heating for Skagen – a town of approx. 7500 inhabitants at the Northern tip of Denmark. This DH station is equipped with three natural gas-based CHP units, a natural gas boiler, an electric boiler, a compression heat pump and a heat storage. In addition to this, it receives heat from a fish processing facility as well as from a biogas-operated CHP unit installed at the local wastewater treatment plan.

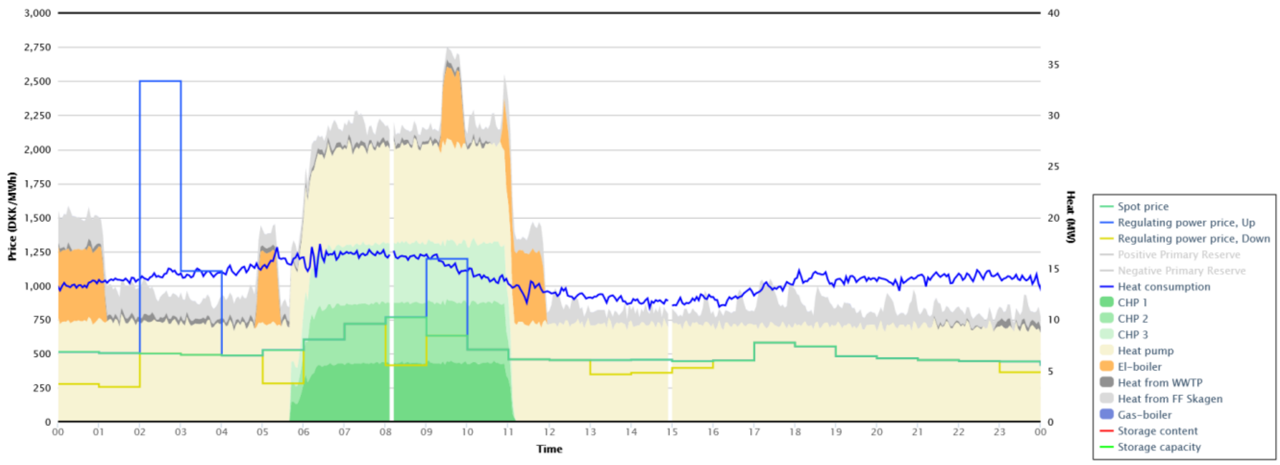


Figure 2-2: A 24 hour production profile for Skagen Kraftvarmeværk (CHP), Denmark, for Monday April 4th 2024. Source: [39]

Operation of the plant is optimised against the Danish day-ahead electricity market, thus as shown in the figure, heat pumps are running all the time; CHP units are running during some hours with higher-than-average electricity prices and the electric boiler is operated in a few time slots. The curves do not immediately indicate the rationale for the electric boiler operation; in theory, they should never operate at the same time as the CHP units as boilers call for low prices and CHP units call for high prices. A likely explanation is that the CHP units are bid in the day-head spot market – and the electric boiler is bid in the intraday market. Thus, the station can make money selling power in an hour – but then due to an imbalance not foreseen in the day-ahead market, additionally earn money by consuming extra power at the same time through a bid in another market. In addition to the various units linking to the power system, heat from the wastewater treatment plant and from the fish processing facility is supplied to the grid depending on availability. The station also includes a natural gas boiler, but this is not utilised in the hours shown. In fact, it was not used in April 2024 (the month of the sample day) – but though used at other times. This DH station is thus an example of a flexible DH station, which draw on various resources.

Another DH station is Hvide Sande, which shares some of the same characteristics as Skagen DH, but in addition, this plant is equipped with a wind turbine and thermal solar collectors. The wind turbine can supply a heat pump and electric boiler directly – or these can be supplied from the grid. This provides even more flexibility.

Both cases are thus cases where DH can be supplied efficiently – and in a manner that assists the rest of the energy systems through their operation against day-ahead markets, intraday markets and regulating power markets.

For district heating, [37] sees these roles: *"In order to be able to fulfill its role in future sustainable energy systems, DH will need to have the following abilities [...]:*

1. *The ability to operate existing, renovated, and new buildings with low-temperature DH for space heating and DHW.*

2. *The ability to distribute heat in networks with low grid losses.*
3. *The ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat.*
4. *The ability to be an integrated part of smart energy systems and thereby helping to solve the task of integrating fluctuating RES and energy conservation into the smart energy system.*
5. *The ability to ensure suitable planning, cost and incentive structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems."*

The operation of the mentioned Skagen and Hvide Sande DH systems are thus well-aligned with Stipulation 4 above and both also engage in Stipulation 3 through industrial excess heat and solar energy exploitation.

An important element in the progression of generations of district heating is temperature levels. While higher temperatures can facilitate the exchange of heat to space heating and domestic hot water, high temperatures also impact overall system efficiency:

1. High temperatures impact losses from DH pipes where losses are proportional to the difference between DH flow medium and soil temperature
2. High temperatures lower the power generation efficiency in CHP stations
3. High temperatures lower the efficiency on heat pumps producing heat
4. High temperatures increase the losses from solar collectors
5. High temperatures decrease the availability of waste heat streams that may be tapped into directly without temperature boosting

While lowering temperatures are in line with the higher generation numbers, limits are set by grid systems as capacity will decrease unless a lowered forward temperature is matched by at least an equally lowered return temperature. Temperature requirements at consumers also affect the possibility of lowering DH temperatures as insulation levels, radiator design and size, and domestic hot water heat exchangers may not be ready for low lower district heating temperatures. The advantages of low-temperature DH, however, are so important, that this is a clear focus point in reaching higher generations of DH in DH companies.

2.2 District heating in local energy hubs

DH systems can be components of a broader concept of distributed multi-energy generation, which is an important direction for future energy systems. This incorporates other concepts such as energy hubs, microgrids, and virtual power plants, which as the smart energy concept extend the smart grid concept beyond the electricity sector towards the optimal interaction of different sectors. Such systems can be designed with different approaches and criteria for energy, environmental, and techno-economic assessment.

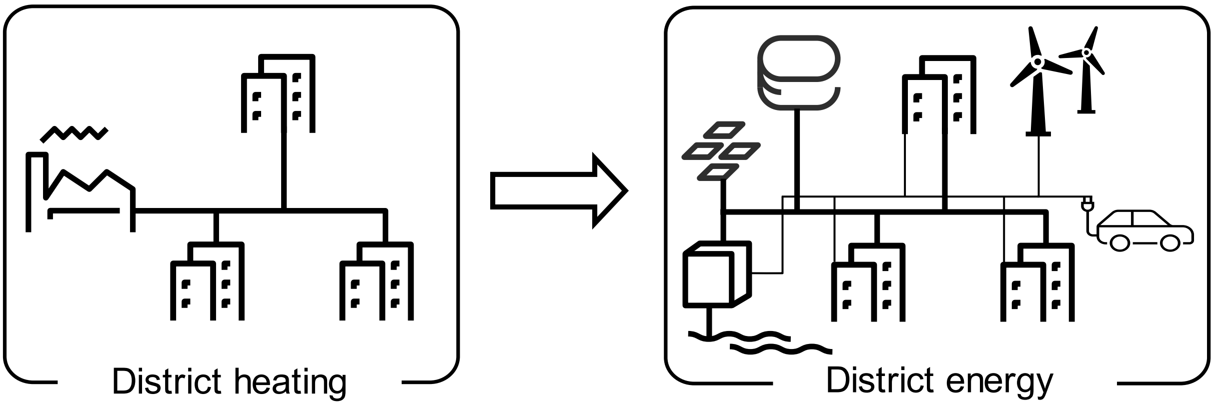


Figure 2-3: Conversion of district heating into district energy systems

New local energy systems can incorporate components that enable the decarbonisation and electrification of local sectors such as transport or industry. In such systems, linkages between different facilities within integrated technological and socio-economic structures, also known as local energy hubs, can be realised. This concept is depicted in Figure 2-4. A local system can be interconnected with multiple product and service markets, which is depicted in Figure 2-5. An example of this type of facility could be a multi-fuel CHP plant with local RES sources, where energy accumulation and production of liquid fuels for the automotive industry are carried out. It can be linked to the local biomass market and the natural gas or hydrogen market. Its local resources may include locally sourced wind and solar energy, as well as water for electrolysis processes. On the output side, it can be linked to the electricity market, the heating and cooling market, and the liquid fuels market as well as providing frequency, voltage or energy storage services to local prosumers. The control volume of the technological system of such a facility will contain the machinery and equipment necessary for all production processes and energy storage.

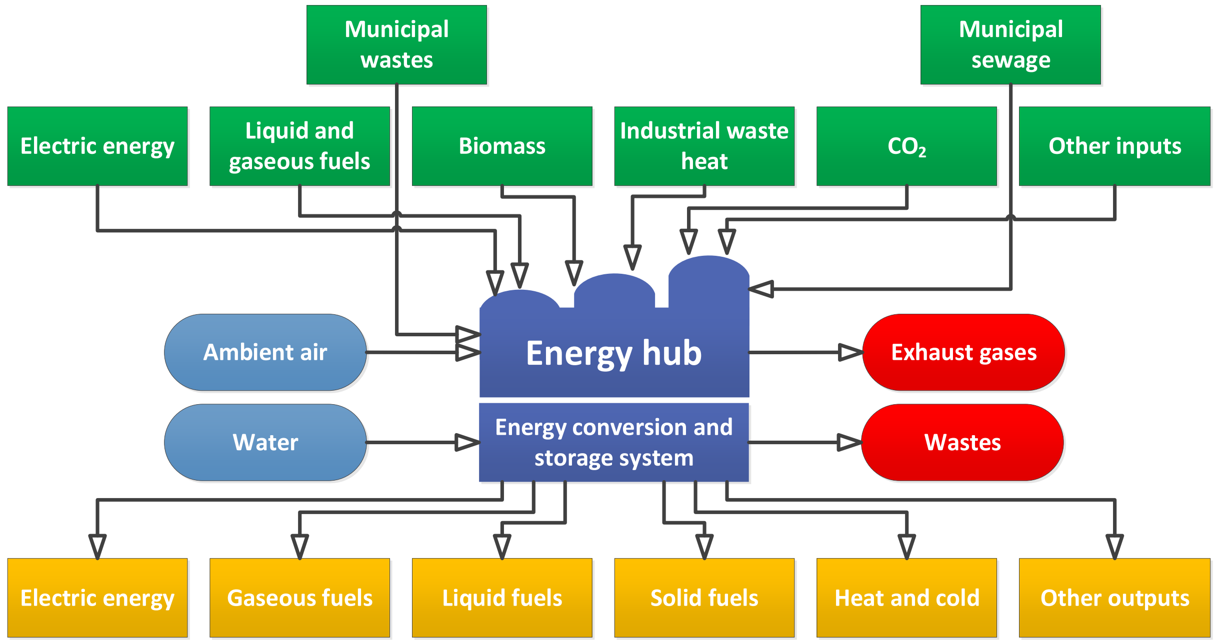


Figure 2-4: Local energy hub concept

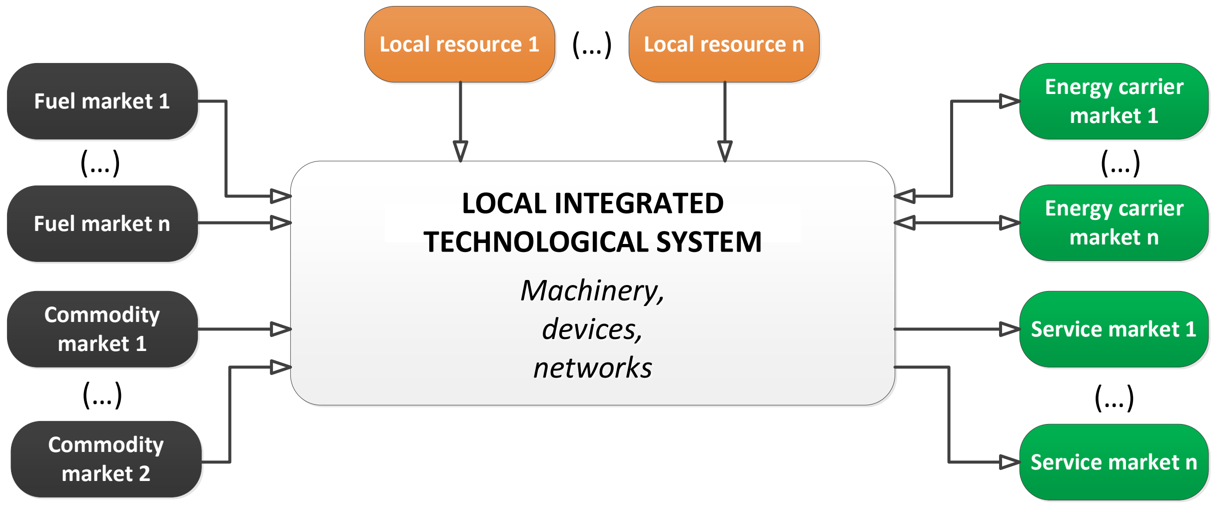


Figure 2-5: Links between the energy plant and the energy market

Energy hubs represent a new concept for the management and supply of energy to end users, whose role in the local energy system in the general case may be significantly different from what we know today. The concept goes beyond the previously known cogeneration or polygeneration, which were based on the generation of multiple energy carriers by the same process through the conversion of one or more fuels. Energy hubs are complex technological systems for energy conversion and storage interconnected to networks for electricity, gas, district heating, hydrogen, carbon dioxide, etc., both on the input and output sides. In the general case, energy carriers can be supplied to such a facility by other means than network transport (e.g. biomass, waste). The primary features of such technological infrastructures are the ability to store different energy carriers over different time scales (i.e. daily storage, seasonal storage), considerable product flexibility and a potentially wide range of functionalities. The latter include:

- Comprehensive supply of consumers with various energy carriers;
- Serving prosumers of electricity, heat, liquid and gaseous fuels;
- Control of distributed energy sources, mainly renewable and waste energy;
- Implementation of energy storage and relocation processes;
- Management of consumers through Demand Side Management (DSM) and Demand Side Response (DSR) activities;
- Sectoral integration - integrating the different subsystems of the national energy system and exploiting synergy effects;
- Provision of flexibility services for an energy system with a high share of RES (e.g. interventionist off-take services);
- Provision of storage services;
- Provision of decarbonisation services to local building and industry sectors;
- Managing energy with economic and environmental quality criteria in focus;
- Ensuring power supply reliability for customers served by the hub;
- Increasing resilience to random events and market shocks;
- Improving the energy efficiency of the local system;

Energy hubs typically use commercially available energy conversion technologies typical for distributed energy systems and the chemical industry, which are combined in complex technological structures that vary depending on the implementation type. The main components usually considered are reciprocating engines fuelled by gaseous or liquid fuels, gas turbines, microturbines, Stirling engines, Organic Rankine Cycle (ORC), compressors, turboexpanders, various types of fuel-fired power boilers, electrode boilers, fuel cells, heat pumps, photovoltaic cells, wind turbines, thermoelectric cells, solar collectors, electrolysers, chemical reactors (e.g. gasification, reforming, methanation, ammonia synthesis, methanol synthesis, etc.), and solar thermal systems, absorption and adsorption refrigeration equipment, and various energy storage technologies. It should be also emphasised that hydrogen and carbon dioxide, which are used as intermediate carriers, and the management of these gases are often important in the case of hubs.

Storage of energy and substance facilities are key components of the technological structures of energy hubs. Since, usually due to the integration of the energy hub with local generation sources and local consumers (e.g. in an industrial zone or in the vicinity of a city), energy hubs are distributed energy systems. The energy storage is therefore considered at a scale suitable for such type of system. Large-scale storage technologies such as pumped storage power plants or compressed air storage in salt caverns are not usually considered.

Based on the type of carrier, energy storage technologies can be divided into five main categories:

– electricity storage,
– heat storage,
– cold storage,
– storage of gases in tanks, including gaseous fuels,
– liquid fuel storage.

Storage of decarbonised fuels in local energy systems may be also an interesting option for decarbonising peak loads in industry and district heating.

From the point of view of the consumer, an energy hub is an intermediate facility for the exchange of energy with the national area energy system. It is also important that the hub provides a two-way energy exchange with the system. It is a facility from which various energy carriers can be taken, but to which these carriers can also be periodically returned. This concept is depicted in Figure 2-6.

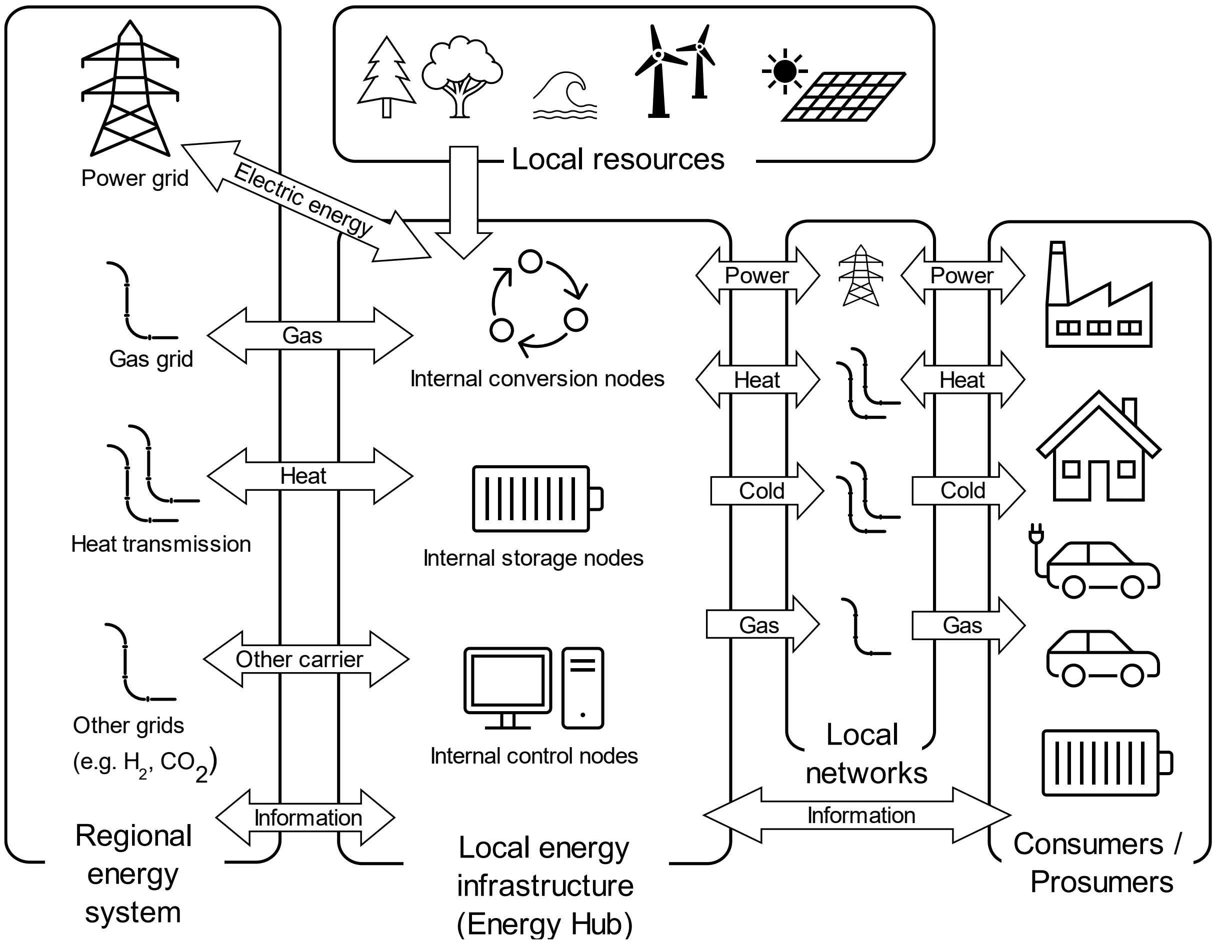


Figure 2-6 Schematic diagram of energy hub concept

The implementation of energy hubs leads to a shift from current energy systems, in which consumers are supplied with energy from separate subsystems of the national energy system by different suppliers, and its energy management is not optimised, to optimised systemic solutions. In this way usually usually considerable losses and increased power supply costs are avoided, making the basis of new business models. This is why energy hubs can provide the technological infrastructure for energy cooperatives or energy clusters. For example, there are currently registered around 170 - 180 energy clusters in Poland. Those are mainly formal organisations without infrastructure enabling active participation in the energy market. New investments in relevant technologies and integration of such technological systems with existing municipal energy infrastructure can make energy clusters important players in the European energy system.

With regard to the physical location of the technology infrastructure of an energy hub, the literature distinguishes between

- centralised hubs, where all equipment is located in the same facility (e.g. the hub of an industrial plant, university or hospital),
- distributed hubs, which consist of several facilities located in close proximity and connected by networks (e.g. municipal hubs).

The integration of district heating with the technological structures of local energy hubs can be used by district heating companies to develop a new local offer of both decarbonised products and services. Integrated local energy system structures can also provide an opportunity for district heating systems to fully meet the requirements of the revised EED to 2050, including the decarbonisation of peak loads. The key issues are however related to triggering new business, investment process, and acquiring the necessary capital. As activities in the electric energy storage, fuel and chemicals sectors are out of the scope of district heating operations, the establishment of new local multi-energy infrastructure requires the cooperation of many stakeholders, at both local and national levels.

Local opportunities related to the P2X electric energy storage pathways are not obvious and somehow must be triggered by the cooperation of various stakeholders. First of all, relevant investments should be brought to cities and appropriate industrial symbiosis should be established by different actors. Those investments must cover the specific energy conversion and storage technologies as well as local energy transmission and distribution infrastructure (e.g. CO_2 distribution infrastructure). In certain cases, relevant infrastructure on the consumption side should be also developed or adjusted. Sometimes, a demand side should be created (e.g. hydrogen-powered transportation fleet). To do this, both specific values and the entire value chain must be appropriately identified, system integration alternatives should be defined, and the roles of different organisations should be specified. Therefore, district heating companies, which have so far operated under local monopoly conditions, should undertake innovative strategic planning activities, including engaging with the local socio-economic environment and creating new local energy business environments. The main opportunities for this lay in technological innovations and organisational, business and social measures. However, to take advantage of opportunities, the district heating companies should reach out to as many stakeholders as possible, to create networks and local collaboration platforms. The natural partners in this process should be local industrial companies as well as companies from the electricity and fuel sectors. In such local ecosystems, new roles for district heating companies can be defined. Examples of roles that can be assigned to a district heating company are an energy system integrator, provider of energy efficiency improvement services in the municipality, provider of decarbonisation services for the buildings sector and some actors in the industrial sector, provider of flexibility services for the energy system, operator of a municipal energy hub, operator of local energy storage facility, etc.

2.3 District heating and sector integration to Cooling

There is a significant cooling demand in many countries, and most of this is supplied by individual solutions, however, district heating systems can integrate with district cooling systems thereby providing energy efficient as economically attractive solutions. District cooling may even form a viable route for possible expansion of business focus in district heating companies as it shares many characteristics with the supply of district heating. Different archetypes – here called generations – of district cooling have different possibilities for integrating with district heating systems. These are outlined and deliberated here with a view to identifying opportunities for district heating systems and companies.

The first generation of district cooling systems introduced in the late 19th century in the USA, were pioneering pipeline refrigeration systems. Using pressurized ammonia or brine, these systems provided cost-effective and convenient refrigeration compared to ice-based alternatives. Such piped refrigeration offered space efficiency, dry air, and easy regulation, and such systems were established in various cities, delivering refrigeration services to concentrated market areas within the food supply chain. Second Generation District Cooling emerged in the 1960s-1970s, emphasizing scale with large compression chillers. Early systems showcased synergy by using absorption and compression chillers driven by district steam and later free cooling was integrated [40]. However, in such systems as well as in more modern systems based on individual air conditioners, there is little energy system integration apart from the situation that both large compression chillers and air-conditioning units are based on electricity. While providing cooling in a more fundamental understanding in fact means removing heat, there is no capturing of heat in such a system, as heat is merely discarded at the point of condensation in the refrigeration systems.

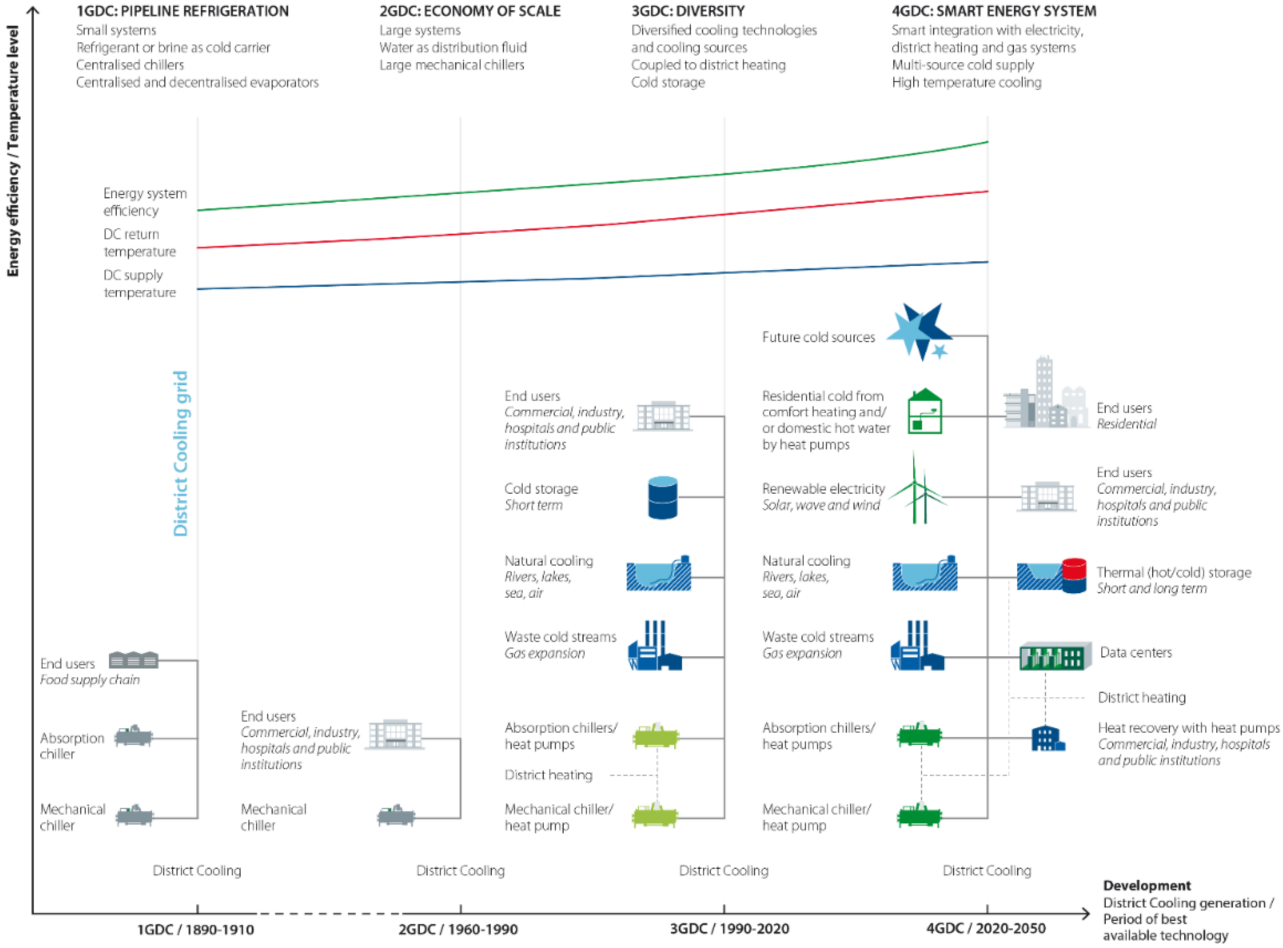


Figure 2-7: The four generations of district cooling [41].

Moving towards third and fourth-generation district cooling systems, the situation changes, with more integration across sectors. The 1995 district cooling system in Stockholm, for example, provided both comfort and process cooling while exploiting the extracted heat for district heating purposes. Another third-generation district cooling system is the Gothenburg system, exploiting waste heat sources and absorption chillers for cold generation, and in the Helsinki district cooling system, compression and absorption as well as cold storage is applied to provide cooling and system flexibility – while also providing district heating. These and other systems typically also integrate free cooling – i.e., cold lake or river water – and the extent to which one or the other technology is used varies with local conditions. For fourth-generation district cooling, there is even more focus on the synergy between the provision of heating and cooling, but also a diversification of technologies [40].

In general, where first and second generations only integrated with the electricity sector, third and fourth generations integrate with both heating and electricity systems. While the term generation may suggest an inevitable progression over time, this is an over-interpretation, but a higher generation number does indicate an increasing level of complexity and system integration. The most relevant district cooling generation is also highly case-dependent but taking the four SET_HEAT cases – Poland, Lithuania, Romania, and Croatia – all cases have heating demands and even district heating systems in operation which can potentially integrate with district cooling systems. This provides both technical opportunities for district heating to optimise the generation of and usage of heating – as well as a potential business opportunity. Whether this is feasible, depends also on local circumstances – i.e., whether local legislation permits district heating companies to venture beyond their core field, whether there are potential development projects, that can readily be connected to new systems, and of course whether local stakeholders requiring cooling are willing and motivated to consider district cooling as an option.

2.4 District heating and sector integration to transportation and power-2-x

The expected transition pathway in district heating is based on a shift from fossil fuel-fired systems to systems with a significant proportion of various forms of renewable energy and waste heat. This is however very challenging in many cases. First of all, energy transition and decarbonisation are usually not possible within the current physical limits of existing heating facilities (heating and cogeneration plants) and networks. Extensive modernisation measures (including building stock), territorial expansion, decomposition, reconfiguration, and dispersion of heat sources, whose contribution to heat generation will often be small and whose annual operating time will be relatively short, are required. For example, the identification and review of waste heat sources in selected district heating systems showed that the potential lies in many distributed sources with relatively low heating capacity (typically less than 1 MW). Moreover, many of these sources are uncertain in terms of availability and potential for continuous heat supply. In addition to this, in many systems, the available potential for renewable and waste heat sources is simply insufficient to meet the requirements of legal regulations. A solution to this may be an integration with the electricity and fuel sectors and seeking opportunities in the development of multi-energy municipal energy systems (district energy systems). Important elements of such systems will be the production of fuels for transportation and aviation sectors. In this area three key directions can be nowadays distinguished:

- Production of green synthetic fuels (e-fuels) for internal combustion engines;
- Production of green hydrogen for fuel cells and the development of hydrogen-fired engines;
- Production of green ammonia and the development of ammonia-fired engines.

All three pathways are nowadays emerging alternatives. The most advanced one is based on e-fuels, which are produced from hydrogen and carbon dioxide captured from power plants and carbon-intensive industries like cement and steel. There are dozens of ongoing demonstration projects in this area in Europe, mainly dedicated to aviation. The status of e-fuels is presented in the report recently published by the International Energy Agency: "The Role of E-fuels in Decarbonising Transport"[42].

Regarding the hydrogen pathway, the market is emerging in the countries participating in the SET_HEAT project. For example, in December 2023 there were 218 hydrogen-fuelled vehicles registered in Poland, including 54 busses. Currently, in Poland, there are 2 public hydrogen fuelling stations, in Warsaw and Rybnik. New are in the planning stage. In February 2024 Orlen SA announced the programme of building 17 public hydrogen fuelling stations in Gdańsk – North Port, Gdynia, Gliwice, Lublin, Płock, Zielona Góra, Wrocław (2 stations), Szczecin (2 stations), Częstochowa, Rzeszów, Kraków, Przeźmierowo, Koszwały, Łódź, Łąka, Poznań. The Polish hydrogen strategy estimates that by 2025, demand for hydrogen in the transport sector in Poland will amount to some 2933.5 tonnes, of which as much as 1764 tonnes for refuelling zero-emission buses. Servicing this demand assumes the construction of 32 hydrogen refuelling stations at pressures of 350 and 700 bar. In 10 years, hydrogen demand in the transport sector will increase to 22510.7 tonnes per year.

In Croatia, the Ministry of Economy and Sustainable Development has recently established a EUR 29.6 million subsidy programme for investments in fuel supply infrastructure. It is expected to install at least six hydrogen refuelling stations by 2026 between Zagreb and the cities of Split, Varaždin and Rijeka. In Lithuania, there are plans to encourage the installation of 4 public refuelling stations in Lithuania by 2026. As of now, there are no operational hydrogen refuelling stations in Romania. However, Romania has published a draft of its Hydrogen Strategy and Action Plan for 2023-2030, which includes significant investment in hydrogen infrastructure.

Using ammonia as fuel in internal combustion engines is a less developed concept. However, different companies, such as MAN, Wärtsilä, and Toyota have already announced the availability of technology solutions. Considerable developments in this field are further expected.

Due to the increase in power installed in intermittent RES like wind and solar, there is a growing demand for energy storage, grid stabilisation, and support services in the electricity sector. In the field of energy storage, an important and groundbreaking concept for electricity storage is the shift from the traditional Power-to-Power (P2P) pathway into the more flexible Power-to-X (P2X) pathway, which is based on the use of electricity for the production of other energy carriers (e.g. fuels or chemicals) for various sectors of the national economy. In the process, an additional, usually locally available, substance or energy carrier can also be used (e.g. biomass or wastes). Examples include Power-to-Gas (P2G) technology integrated with biomass gasification or systems using CO_2 from capture in conventional power plants. Key technologies that can be considered as P2X are:

- Water electrolysis
- Synthesis of the synthetic natural gas (SNG)
- Synthesis of methanol
- Synthesis of ethanol

- Synthesis of dimethyl ether (DME)
- Synthesis of ammonia
- Synthesis of urea
- Synthesis of formic acid
- Synthesis of e-fuels for the land and sea transport as well as the aviation
- Hydropyrolysis
- Biorefining

The products of the mentioned process can be regarded as a secondary man-made storable feedstock providing flexibility to the energy system. The most important secondary feedstock today is hydrogen, which is also an enabler for other energy conversion pathways. Significant developments can currently be seen in the area of the hydrogen economy. Most of the European countries have already announced their hydrogen strategies.

Figure 2-8 depicts a sample district heating system integrated with a P2X plant with a reversible electrolysis/fuel cell device. Overall, both systems can be integrated using:

- Waste heat stream;
- Electricity stream;
- Fuel stream.

Additionally, storage components can be placed both in the P2X plant and the DH plant. Such a solution enables waste heat from the technological process to be captured for district heating as well as increases flexibility in power and gas management.

Figure 2-8 and Figure 2-9 depict sample electrolysis systems with cooling devices where currently waste heat is dissipated into the atmosphere. This heat can be effectively injected into the district heating systems. The heat recovery potential of electrolysers depends on design and operating conditions such as voltage, electric current, and cell temperature. It is higher for Alkaline Electrolysers (around 30-40% of electric power input) and lower for Proton Exchange Membrane (PEM) Electrolysers (around 20-30% of electric power input).

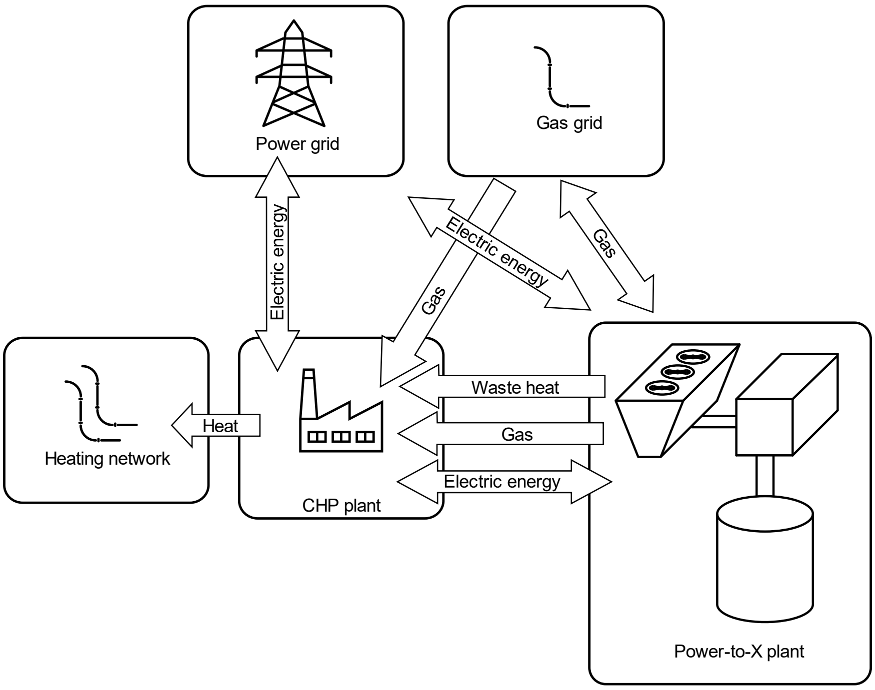


Figure 2-8: Schematic diagram of cogeneration plant integrated to Power-to-X plant

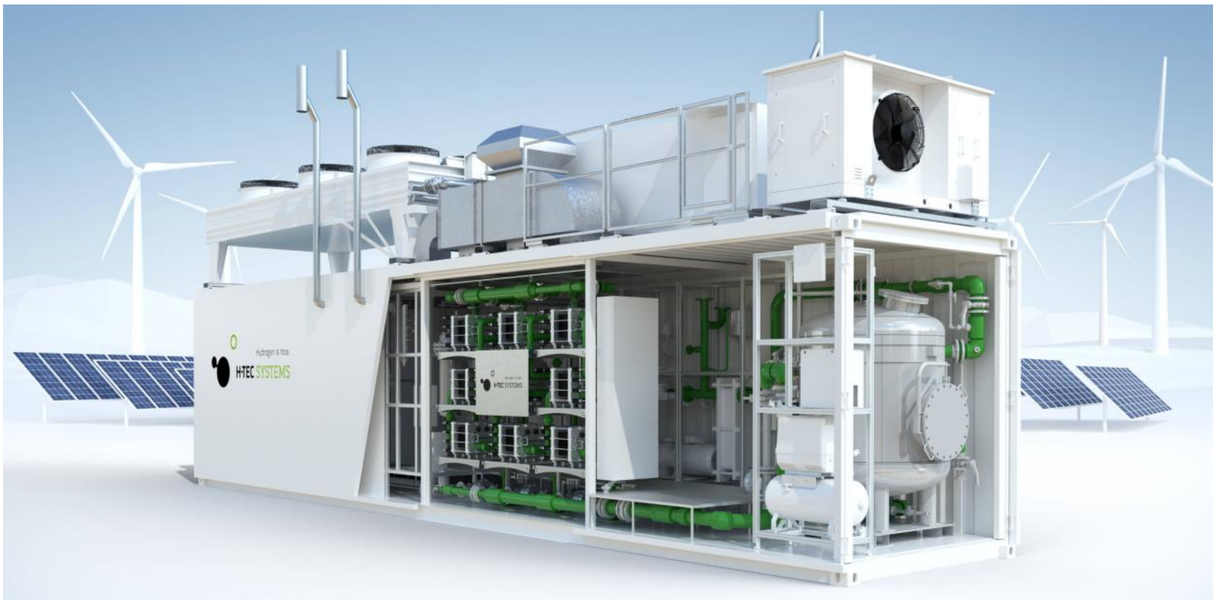


Figure 2-9: Sample electrolyser system with integrated cooling system (Source: [43]*)*

Figure 2-10: Sample electrolyser system with stand-alone cooling system (Source:[44])

Further heat recovery can take place in different process blocks when liquid fuel or chemical processes are used. Some ideas of technological processes that can take place in new local energy systems are depicted in Figure 2-11 to Figure 2-14.

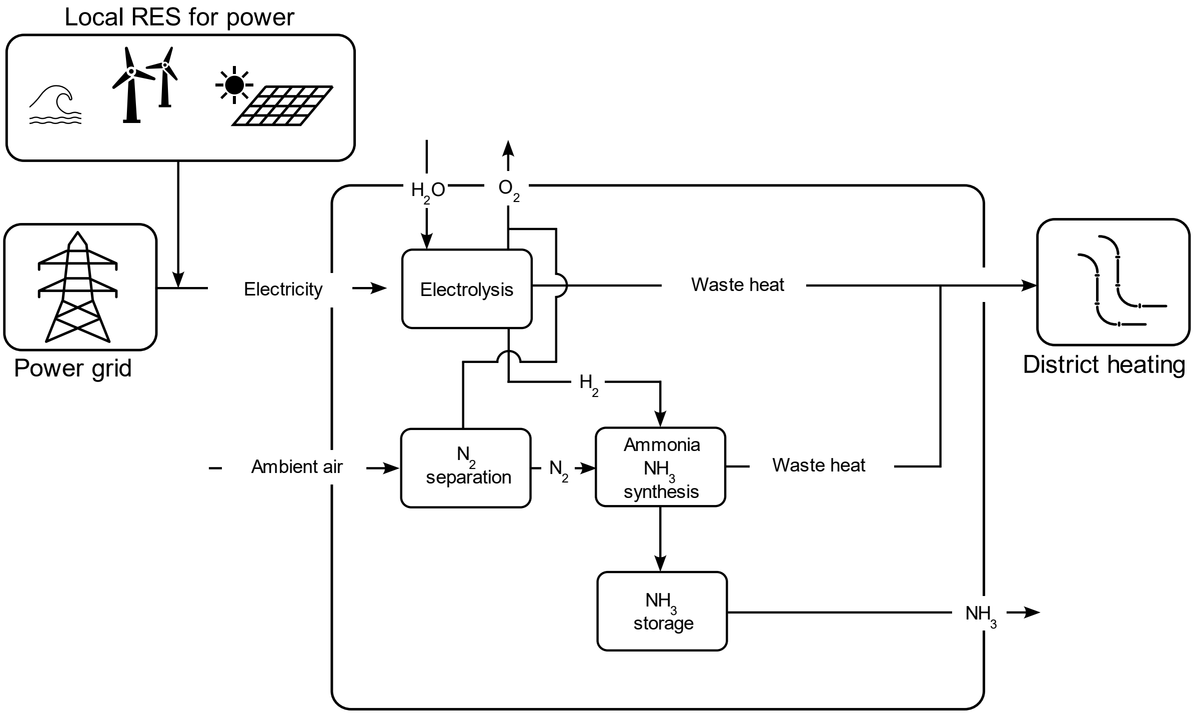


Figure 2-11: Schematic diagram of green ammonia synthesis process

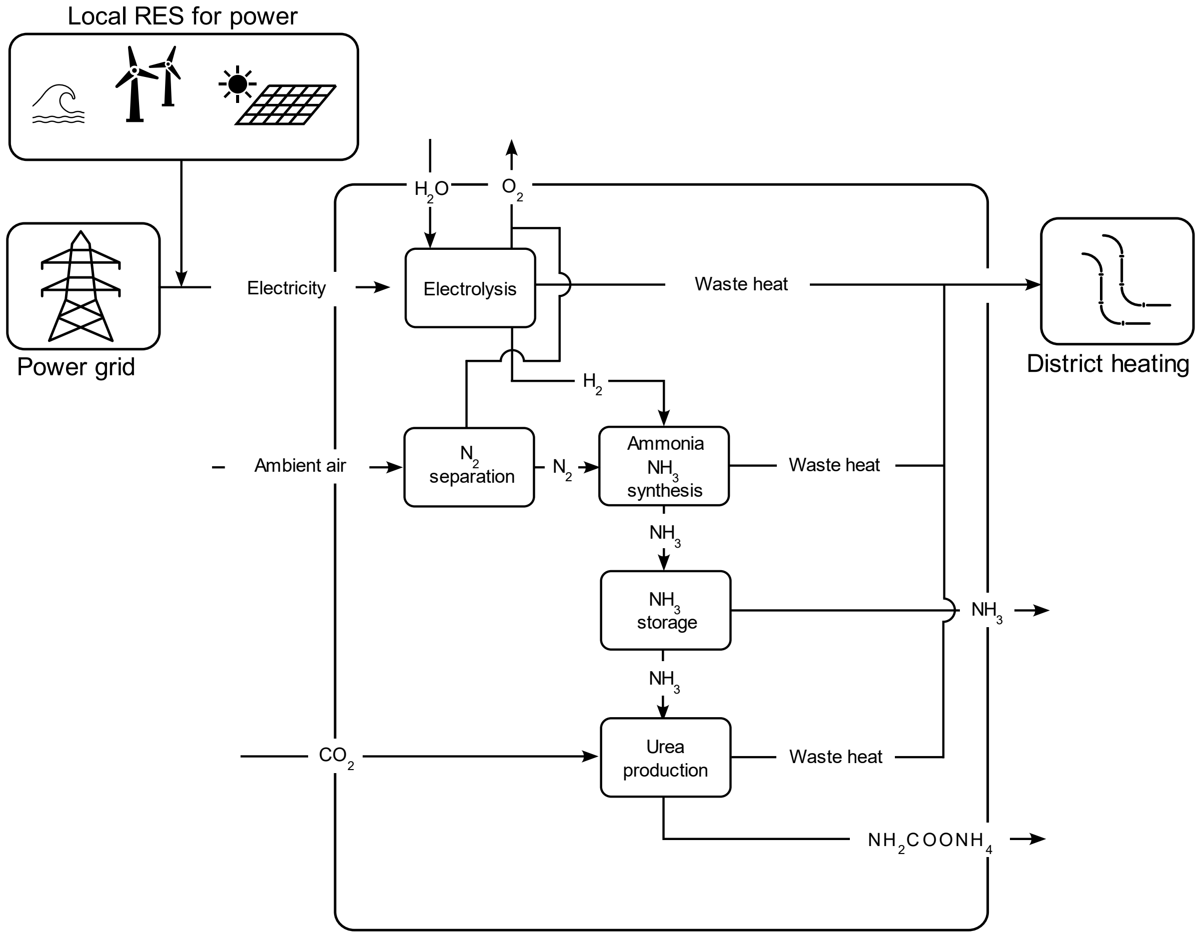


Figure 2-12: Schematic diagram of green ammonia synthesis and urea production process

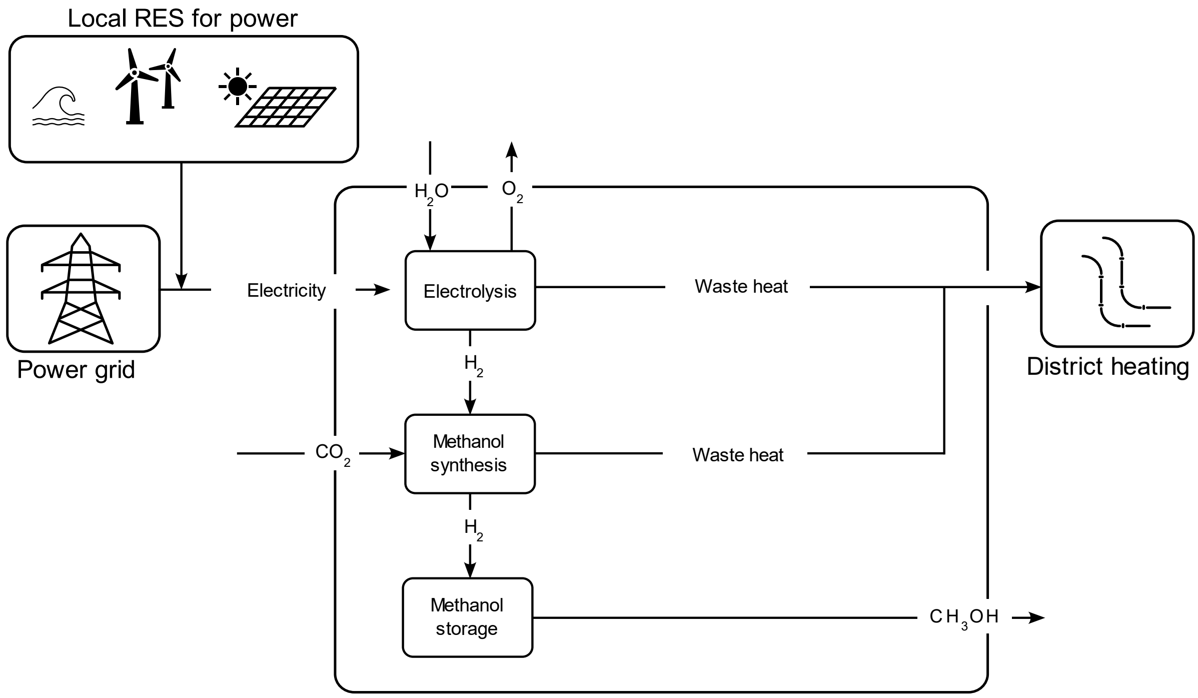


Figure 2-13: Schematic diagram of methanol synthesis

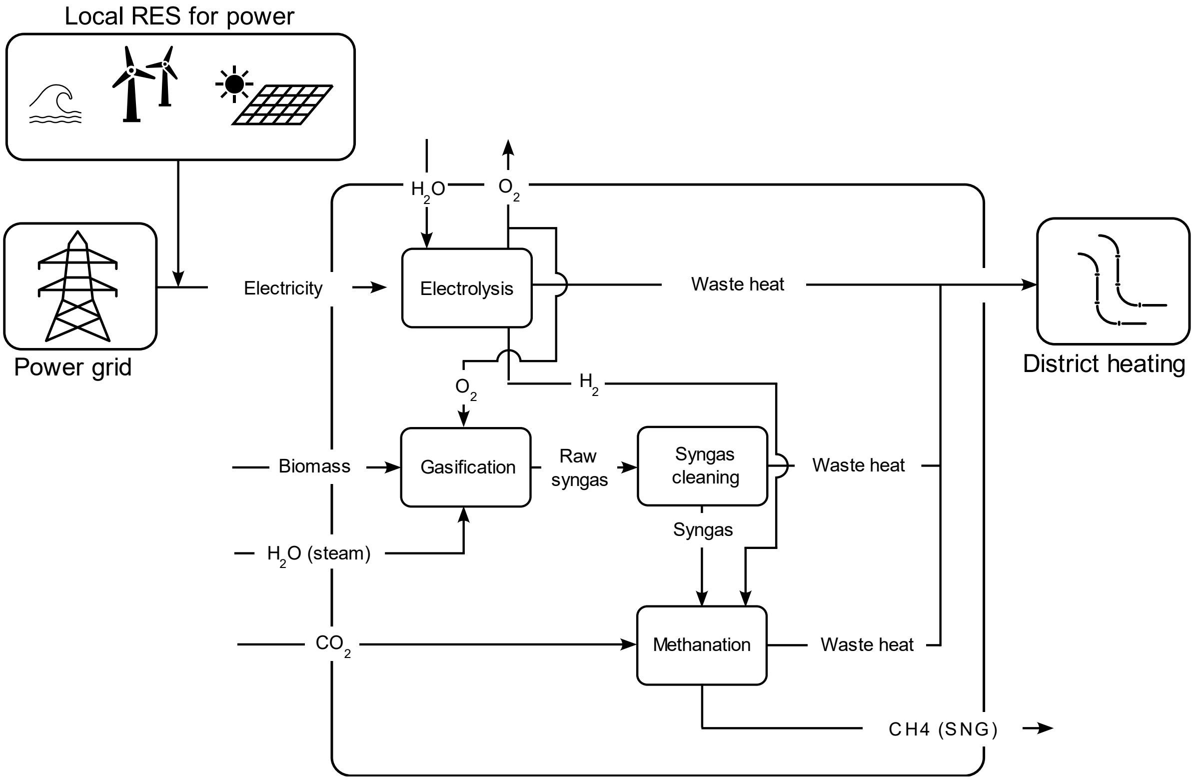


Figure 2-14: Schematic diagram of SNG production process

2.5 Danish experience in the phasing in of new technologies in DH supply

This last section of Chapter 2 showcases developments in the Danish DH sector, where the sector has been affected by legislation, incentives, and disincentives over decades, to shape the district heating sector as it is today. A three-tier tariff (triple tariff) with low feed-in tariffs during empirically low-load periods, high prices at the shoulders, and peak tariffs at peak hours shaped the sector for decades [45]. Basically, this caused DH CHP stations to be designed with surplus capacity as well as with heat storage to enable the stations to stop producing during low-price periods and only produce with high or peak prices, thus drawing on heat storage to supply heat when the CHP is not in operation.

While this was originally simply a measure designed to account for and compensate CHP for the reductions they supplied to the fossil fuel-based central power stations, where dispatch sequence gave a different value of any decentralised production depending on its temporal character. Subsequently, while designed after this thermal power station logic, the decentralised CHP DH stations were indeed equipped with extra capacity and storage which later facilitated the integration of wind power and even later PV.

Observing Figure 2-15 one can see how the number of steam turbines has remained stable with a small declining trend from the period 1994 to 2022, while gas turbines particularly in the latter year have declined. Gas engines grew significantly in number from 1994 and the next few years. Basically, the first DH systems were relatively large – calling for steam and gas turbines – in an evolution preceding the chart, while gas engines were introduced in small systems, which only peaked within the period shown.

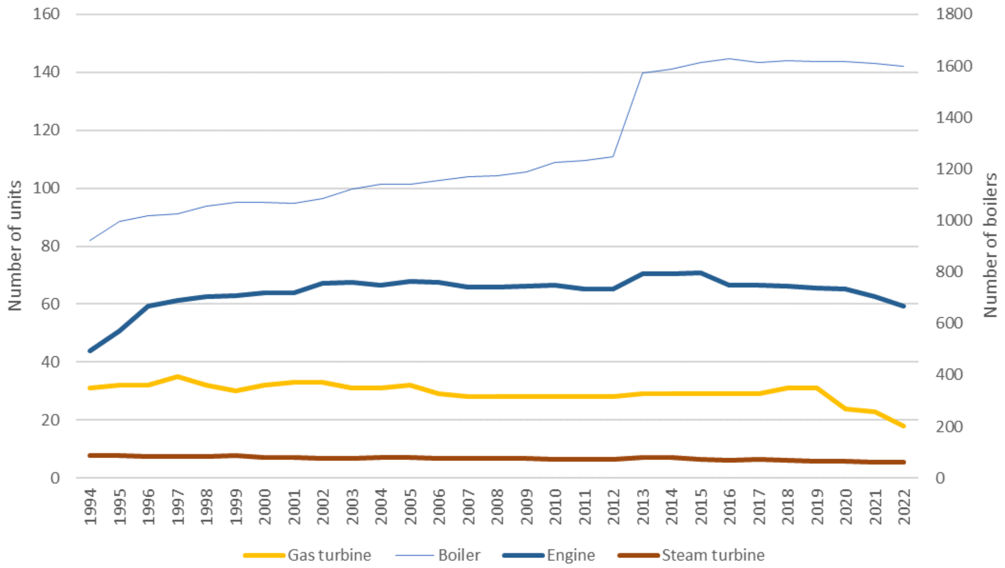


Figure 2-15: Conventional DH generating technologies in Danish DH stations - evolution from 1994 to 2022. Note that the number of boilers changes due to a difference in methodology.

Moving to other production units, Figure 2-16 shows the number of electric boilers, heat pumps, solar collectors, and waste heat utilisation. While the number of waste heat applications have risen over the last decade, the evolution has not been as significant as it has been for the other technologies, which pre-1994 were more or less non-existent. Solar heating was the first to start a significant increase, but the market has saturated as there are more economical options [24], while heat pumps and electric boilers keep growing.

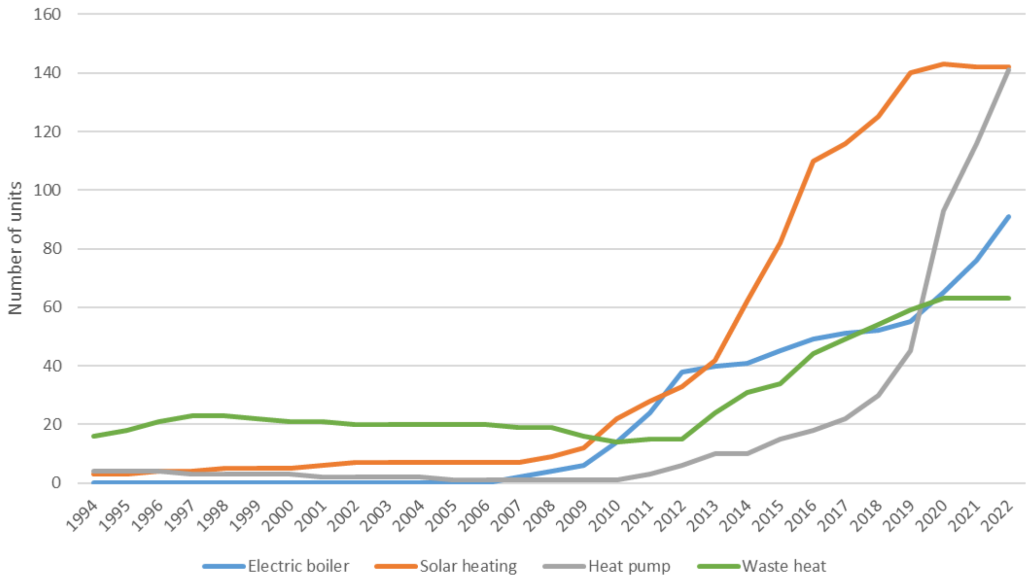


Figure 2-16: Unconventional heating technologies in Danish DH stations – evolution from 1994 to 2022.

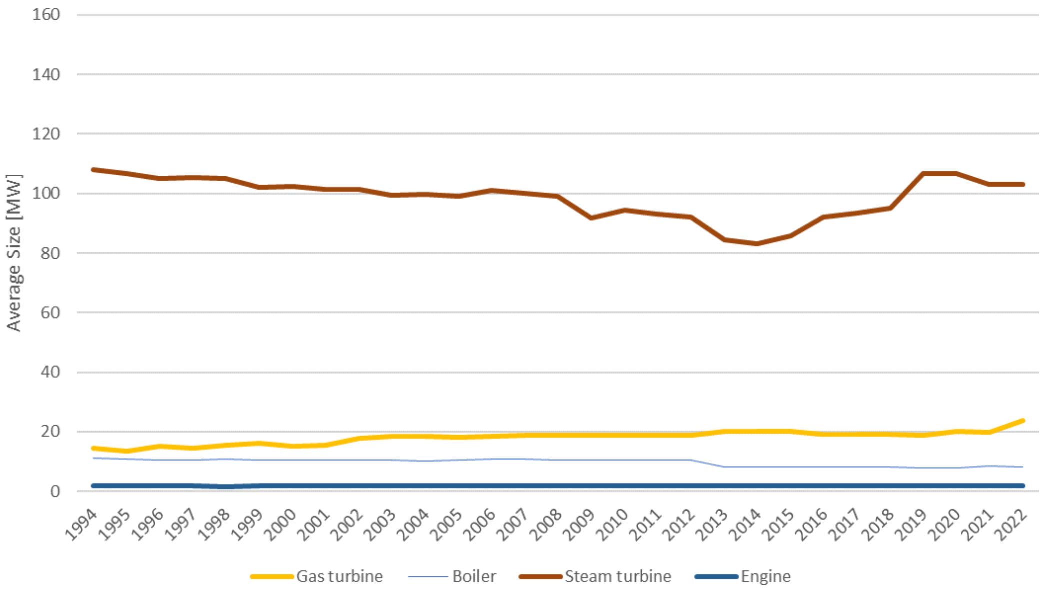


Figure 2-17: Average size of conventional heat production units in the Danish DH sector - Evolution from 1994 till 2022

Figure 2-17 and Figure 2-18 show the average size of installations. The reasons for the increasing trend in gas turbines lie in the phasing out of small units and not in the introduction of larger units. Solar thermal plants grew over the period, as the technology was incepted in smaller systems and were only later used in larger systems. The abrupt changes in the size of boilers derive from the very low number of units – with e.g. one single 16 MW unit in the first year of that graph.

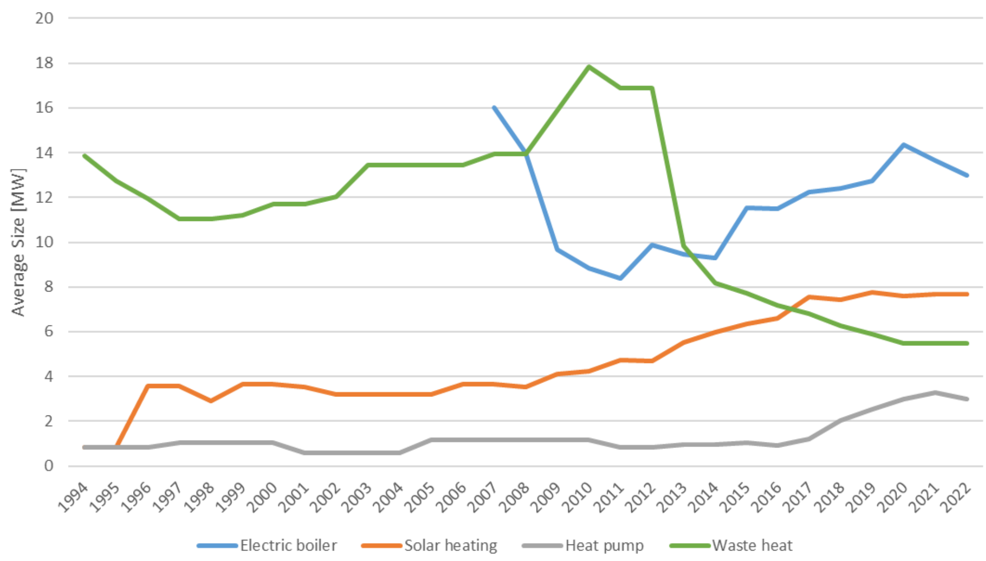


Figure 2-18: Average size of unconventional heat production units in the Danish DH sector - Evolution from 1994 till 2022

While Figure 2-15 to Figure 2-18 show the actual physical composition of the DH stations in Denmark, Figure 2-19 and Figure 2-20 show the actual usage of these. While the composition is conservative in the sense that even though technology may not be utilised, there is not necessarily an incentive to actively mothball or to directly decommission it. Observing Figure 2-19 it is clear that there has been a decreasing trend in the heat production from gas turbines and from gas engines, while steam turbines have managed to better retain a high market share. For the gas engines and gas turbines, this is the effect of decreasing electricity prices and increasing natural gas prices, and basically more economical alternatives. Figure 2-20 on the other hand shows a strong increase in the production from heat pumps and electric boilers – for exactly the same electricity price reason – along with increases from solar thermal and waste heat resources. The latter is clearly drawn by an increasing interest in exploiting such low-cost potentials where available.

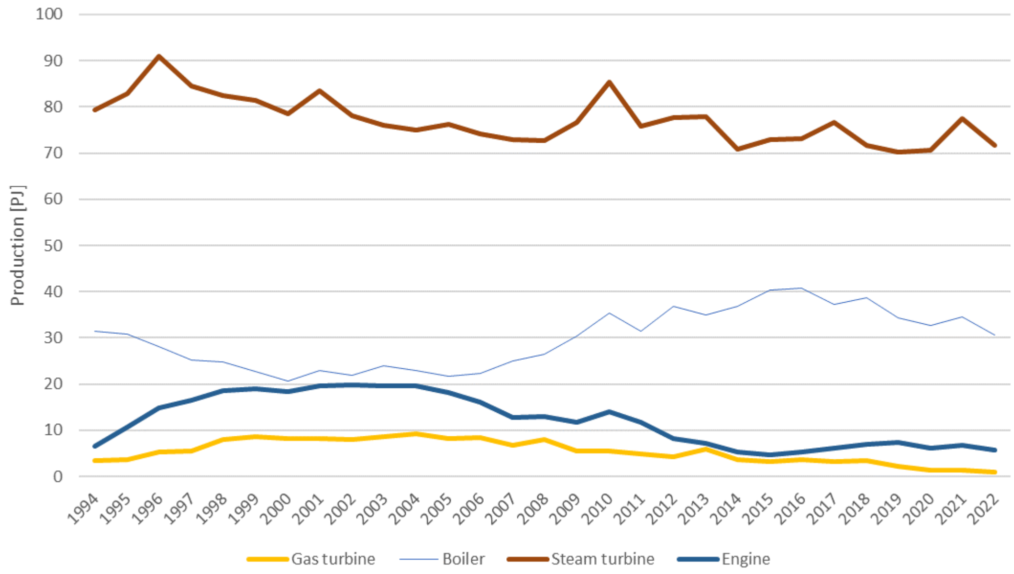


Figure 2-19: Annual production of conventional heat production units in the Danish DH sector - Evolution from 1994 till 2022

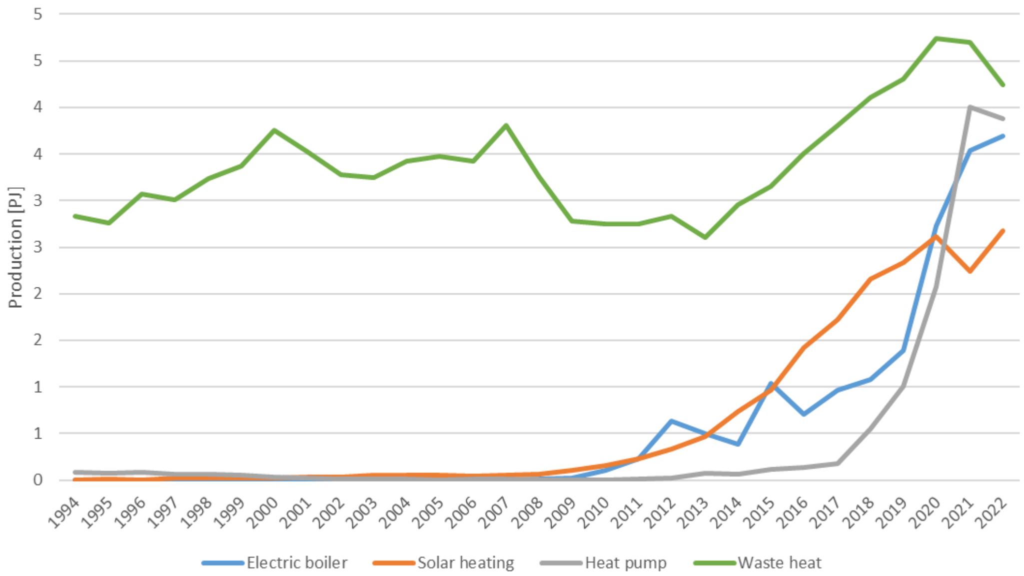


Figure 2-20: Annual production of unconventional heat production units in the Danish DH sector - Evolution from 1994 till 2022

One of the results of the DH sector development is the presence of storage throughout the DH systems. All Danish DH systems are equipped with storage, and Figure 2-21 shows the size of these (though a few newer and very large ones were not included in the database. However, even if focusing only on the shown, there is about 1 million m^3 of DH storage which is around 0.25 m^3 per capita within DH areas.

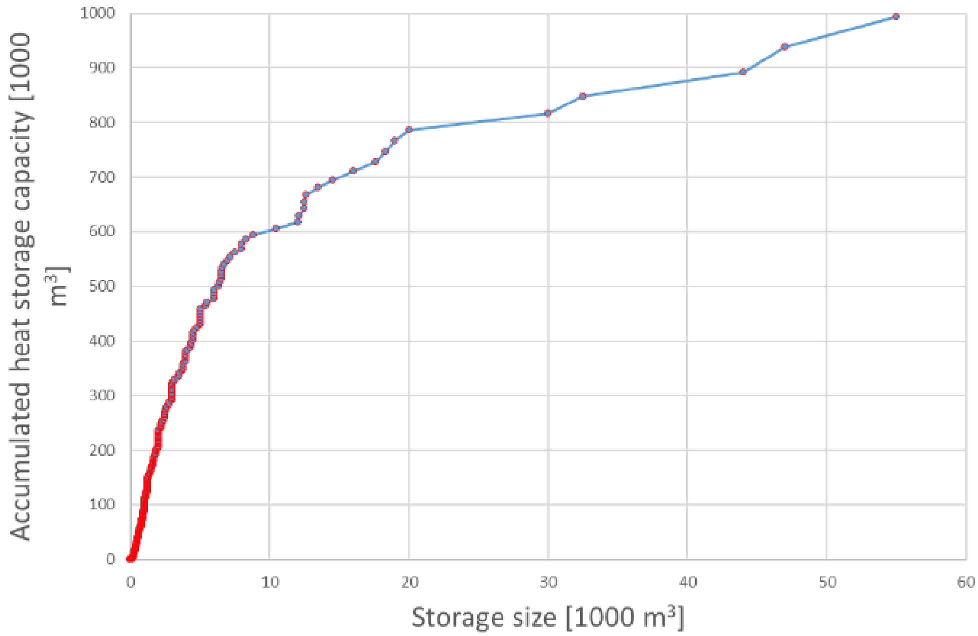


Figure 2-21: Distribution of the size of heat storage in the Danish DH sector. Status per 2022.

In general, an observation of the evolution of the technology stock and the technology usage in Danish DH plants show how they have evolved given the changing economic rationale over time to become a flexible sector, which not only can produce heating efficiently through the CHP synergy, but also tap into other heat streams including waste heat from various processes and today even performing import tasks in electricity system load balancing through the use of heat pumps and electric boiler.

2.6 Development prospects

To conclude, new opportunities for district heating emerge from the envisaged transition of technologies and infrastructure of the energy system, which nowadays considerably evolving in the fields of energy acquisition, conversion, distribution, and use. The global energy transition is noticeably accelerating. There is a visible shift from proposals of actions to actions, and there is ongoing unprecedented structural, technological, and organizational change. It can be concluded from the published literature that, with high probability, in the future systemic energy supply and energy-related services will be more important than today. This will mostly result from the deep integration of sectors, the development of prosumerism, and other social innovations, and the range of functionalities and services provided by system operators. The energy system will be deeply immersed in the global socio-economic system. The energy will be easily accessed thanks to the increased spatial coverage of energy systems as well as due to favourable prices resulting from new infrastructure, optimised business models, and the number of stakeholders involved in the production and conversion processes. The system itself, taking into consideration its current state, will be largely decomposed and the existing technical infrastructure, including production plants and grids, will be reconfigured. It will be much more complex than today and will integrate different sectors of national economies and harvest cross-sectoral synergies. It will be based on many dispersed resources, among which renewables will be the central pillar.

Fossil and nuclear fuels can transitionally be used in utility-scale power and cogeneration plants. The role of secondary resources (e.g. fuels from wastes) and waste energy will significantly increase, mainly in sectors such as district heating and cooling. Biomass will be mainly used for the production of biofuels for aviation, maritime transportation, and industrial process steam generation. The portfolio of technologies used in future energy systems will be large. Despite central utility power plants, the majority of energy conversion plants will take the form of multi-energy multi-service systems (i.e. Multiple Input Multiple Outputs) to provide not only various products by also flexibility to the system. The number of decentralised microgrids with multi-energy nodes will be considerable. They will be managed under different business models using advanced digital tools. Energy will be used in a much more effective way, and production and consumption profiles will be optimised by using digital communication tools and large data. A significant contribution to energy efficiency will be from new end-use technologies, mainly in industry. Energy storage will become a standard and central component of the technical infrastructure. It will take different forms, including Power-to-X and thermal storage for district heating and cooling. The main energy carrier will be electricity as sectors such as buildings, transport, district heating and cooling, and industry will be largely electrified either directly or through e-fuels and synthetic fuels (e.g. SNG). Green hydrogen and green ammonia will be key products from surplus electricity. Although the system will be largely decarbonised, there will be an important role to play by CO_2, which will be required for the synthesis of e-fuels and chemicals. The CO_2 will be mainly from capture from fossil-fuel and biomass-fired thermal plants. Some will be directly captured from the air. The CO_2 infrastructure, including major transportation pipelines and storage, will become an integral component of the energy system. Eventually, the national energy systems will be optimally designed thanks to powerful hardware and advanced software tools. In some areas digital twins of systems will be developed. Future, more effective modelling tools will even further accelerate the energy transition and will enable well-informed decisions to be taken. The optimal design and virtual tests will make the system flexible and resilient.

3. District heating and electricity costs

3.1 Variability of electricity prices

In all countries represented in the SET_HEAT project consortium, electricity prices considerably decreased after the price shocks in 2022. Currently, the prices are at the level observed in 2021. For example, the average price of electricity in Lithuania in 2023 almost halved to the level of 90 EUR/MWh and in April 2024, the average wholesale electricity price in Lithuania further dropped to approximately 60.2 EUR/MWh. This was mainly influenced by the global stabilization of the energy resources market and the rapid development of renewable energy in Lithuania.

Different national electric energy systems vary in terms of energy mix. However, technologies of power generation differ in those countries and therefore the market price profiles are different as well. Croatia, Denmark, and Lithuania have a relatively high share of renewable energy in the primary energy mix for power generation. In Croatia, the primary source of energy for power generation is hydro energy. A significant share of the national energy mix has also fossil fuels such as coal and natural gas. The Danish energy system is dominated by renewables such as wind, solar energy, and bioenergy (biomass and biogas). There are also used fossil fuels such as coal and gas. A primary source of electricity in Lithuania was nuclear until 2010, while in 2022 wind and bioenergy were dominating with a combined 56% of domestic production. Additionally, 55% of the entire electricity demand is covered by imports mainly from Sweden and Latvia.

The Polish energy system is heavily based on coal. Although a significant increase in wind and solar power has been observed in recent years, the share of renewables is still the lowest among the countries represented in the SET_HEAT project. Therefore, the energy transition in the district heating sector is very challenging in Poland and investment decisions must be made under high uncertainty regarding the entire energy system.

In Romania, the primary energy sources in the energy mix for power generation are hydroelectric power, coal, and nuclear energy. All the countries are active participants in the integrated EU electricity market and take part in the cross-border electricity trade

The variability of electricity market prices is depicted in Figure 3-1 to Figure 3-6.

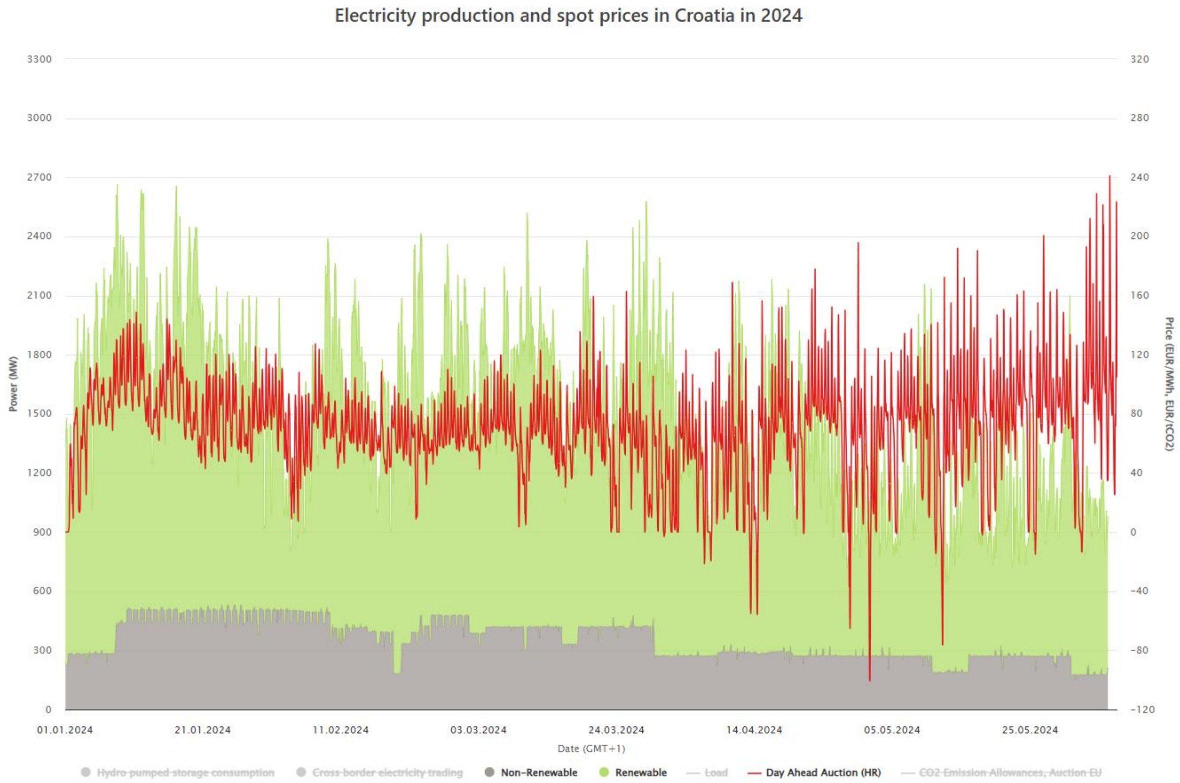


Figure 3-1: Electricity production and market prices in Croatia in 2024. Source: [32]

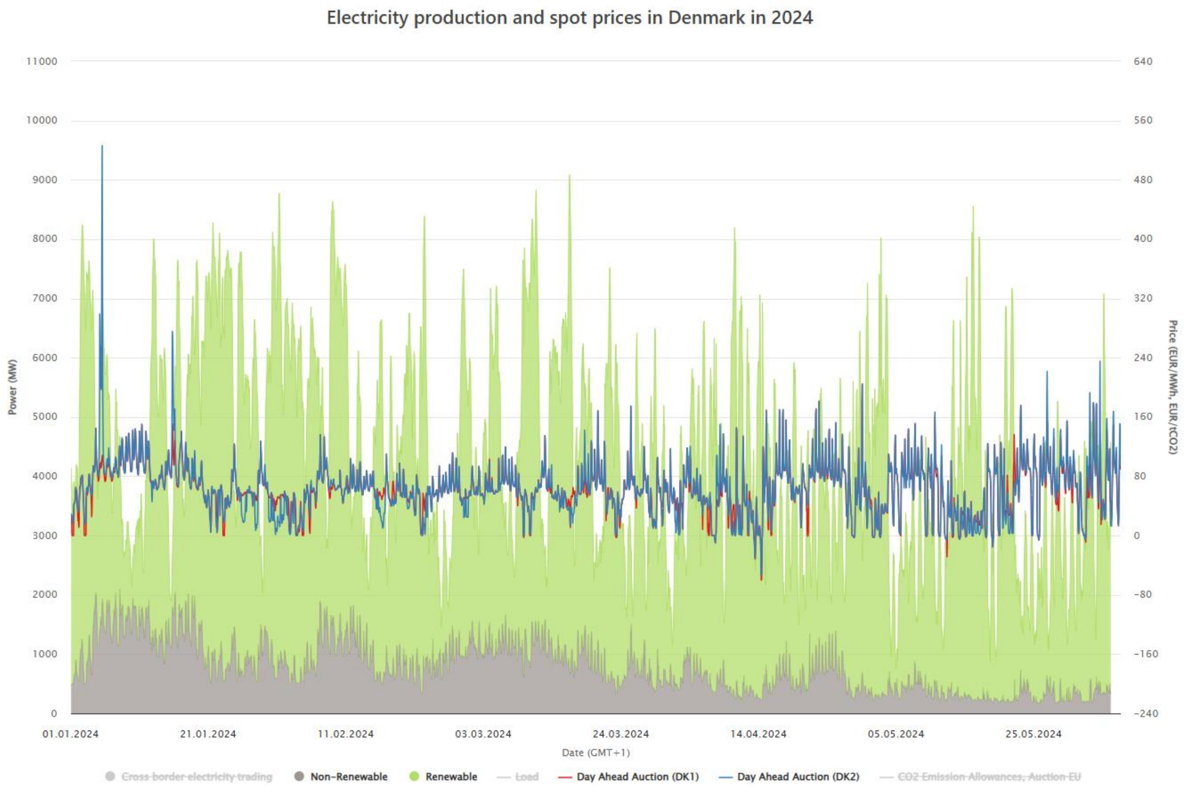


Figure 3-2: Electricity production and market prices in Denmark in 2024. Source: [32]

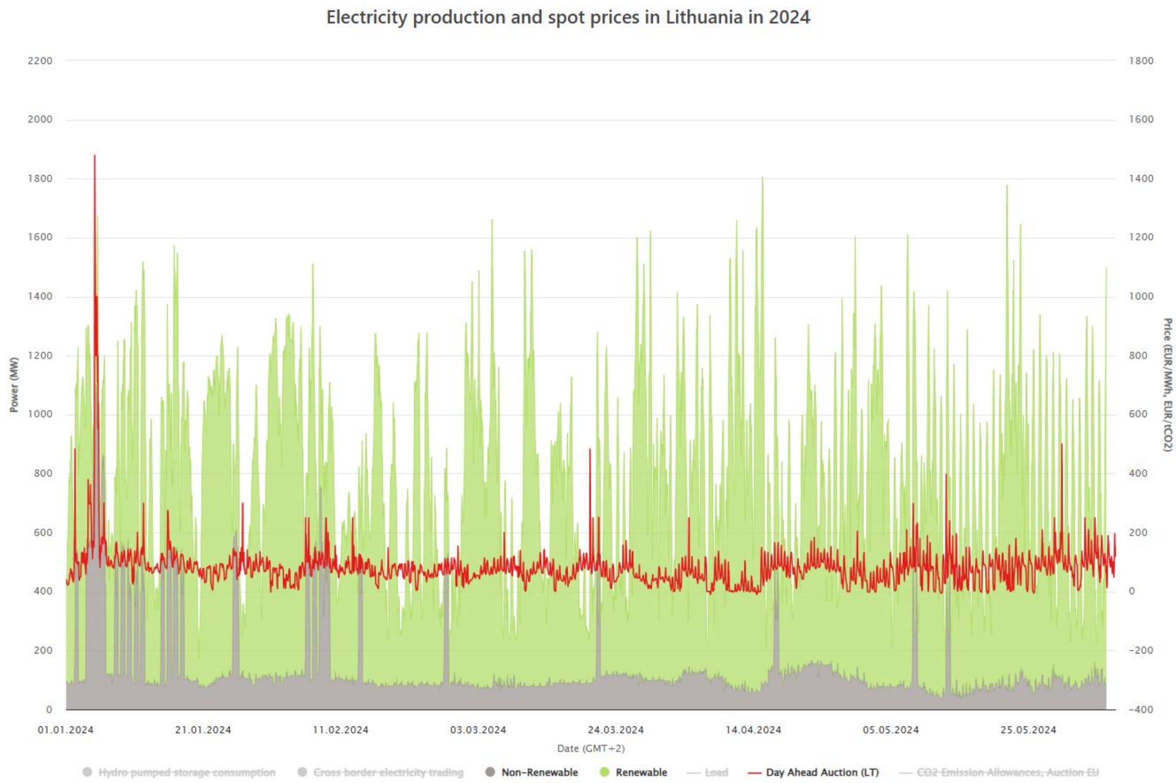


Figure 3-3: E Electricity production and market prices in Lithuania in 2024 Source: [32]

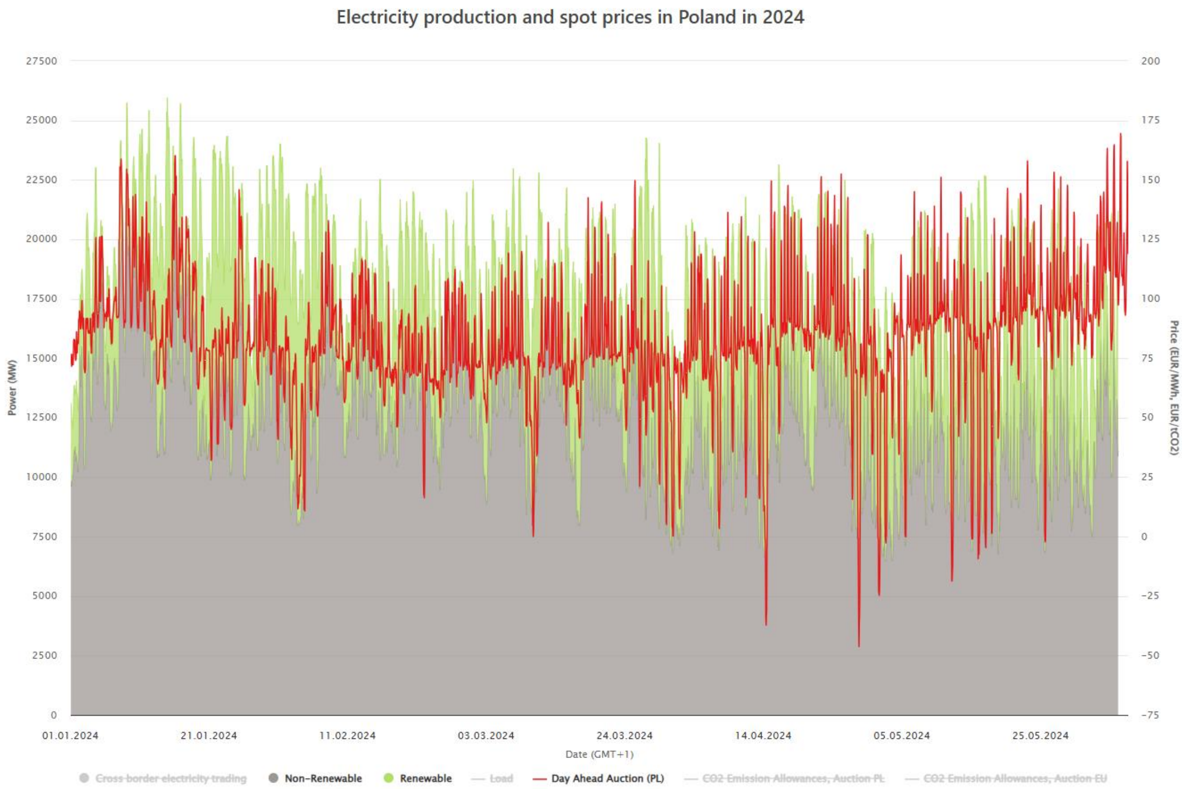


Figure 3-4: Electricity production and market prices in Poland in 2024. Source: [46]

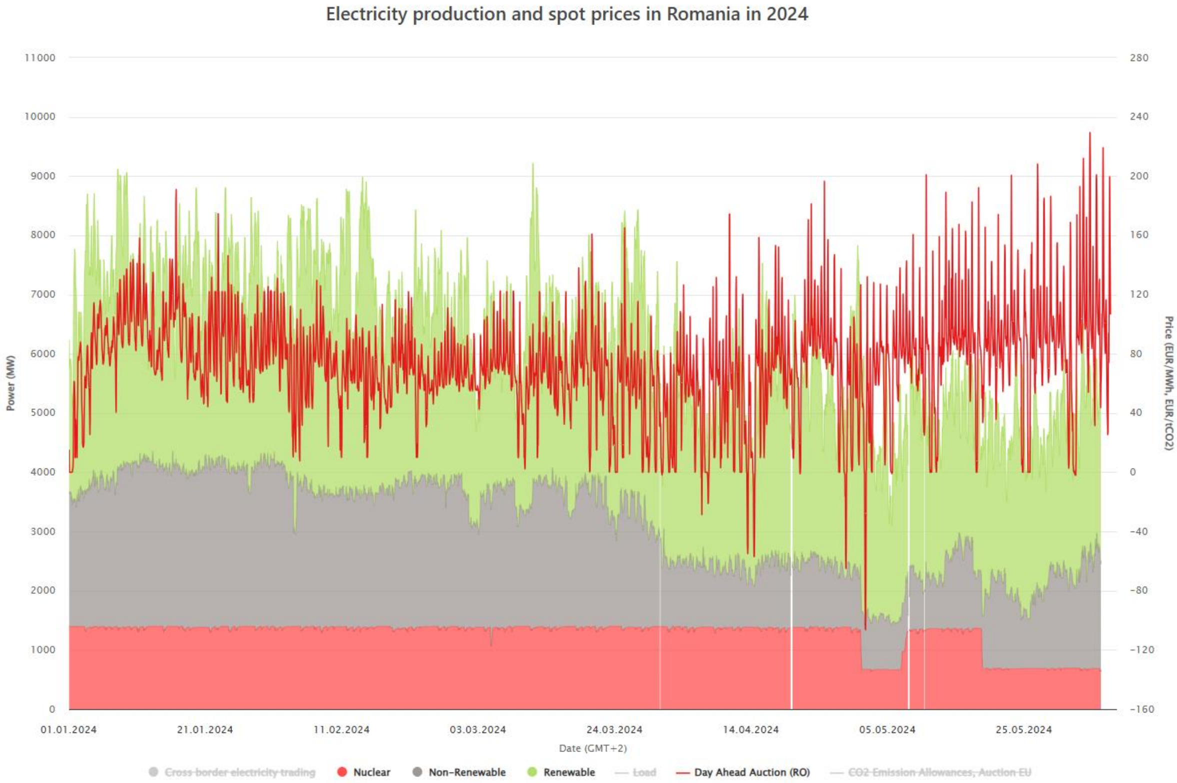


Figure 3-5: Electricity production and market prices in Romania in 2024. Source: [46]

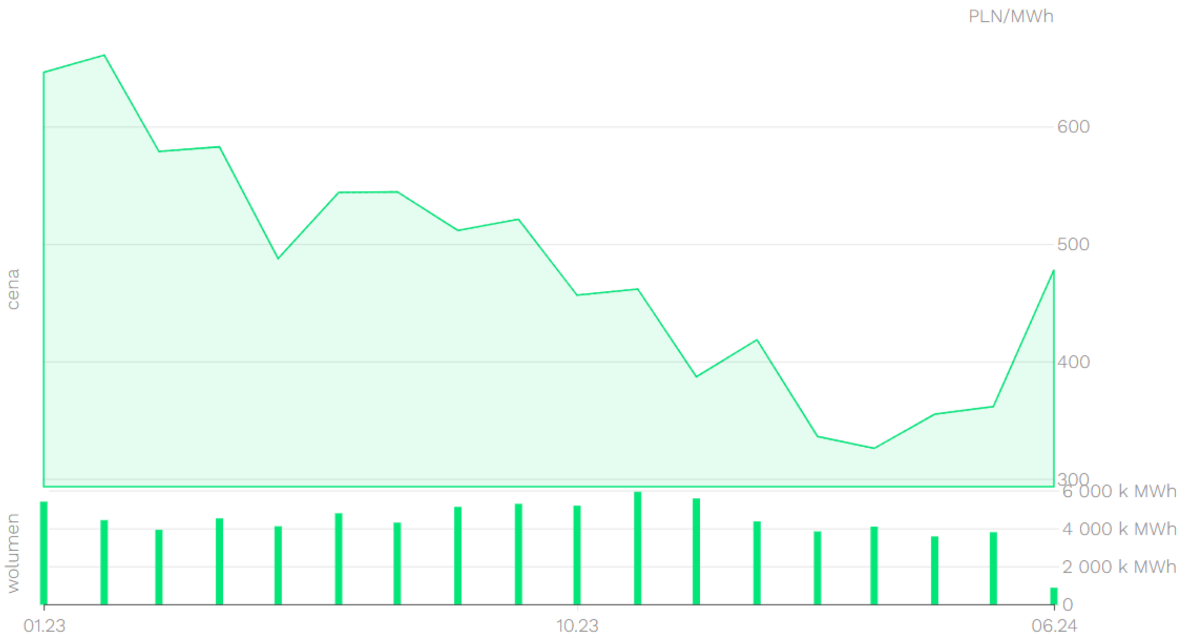


Figure 3-6: Electricity market prices in Poland in 2023 and 2024. Source: [47]

Overall, in all markets, there are every year relatively short periods of high and low prices and long periods of medium prices. The variability of energy prices in Croatia, Lithuania, Poland, and Romania is similar to that in Denmark, which is mainly the result of cross-border trade. This means the future district heat solutions in those countries can also be similar when regarding solutions with power system integration.

The fate of electricity market prices is difficult to predict as the future of the European and national energy systems is not fully defined yet. For example, in Lithuania the average wholesale electricity price in some forecasts is expected to drop to around 68 EUR/MWh in 2027 and then increase to 77 EUR/MWh in 2030. There are also forecasts showing a stabilisation of prices in the range of 100 EUR/MWh to 110 EUR/MWh from 2026 to 2035. The Lithuanian Energy Agency together with NREL (US) have recently published a study [48], in which they expect the average electricity price in 2030 at the level of 55 EUR/MWh. In Poland, an increase in prices has been observed since May 2024. The trajectory of prices until 2040 is uncertain. There are scenarios showing declines as well as increases. The future prices will be mostly influenced by the expected phase-out of coal production assets.

3.2 Electricity prices

A key factor influencing the progress of decarbonisation of district heating is the volatility of market electricity prices. It is influenced by a number of factors in addition to supply (generation from domestic sources and imports) and demand. Among the most important of these are:

- Legal mechanisms that stimulate the implementation of the energy policy of the European Union and, e.g., the Polish Government.
- State of generation, transmission, and distribution infrastructure and fuel-technology mix.
- Achievable capacity of generation sources, including controllable sources.
- Presence of energy storage in the system, and storage capacity.
- Share of RES in the power injected into the system.
- The degree of intrastate system imbalance and the instantaneous volume of energy exports and imports.
- The possibility to regulate supply through generation outage calls.
- Possibility to regulate offtake by calls for outages of customers providing system services;
- the amount of energy sold by generators under forward contracts.
- Presence of support mechanisms for selected energy technologies (e.g. RES, high-efficiency CHP).
- Shape and operation of the system services market, including the market for flexibility services.
- Shape and rules of functioning of the balancing market.
- Shape and principles of functioning of the power market.

- Global market price levels and geopolitical situation.
- Supply path disruptions.

The key risks of the energy transition and decarbonisation of the district heating sector include the insufficient level of total installed generation capacity in the electricity sector, including above all generation capacity in dispatchable sources and so-called spinning capacity. Analyses carried out by PSE SA [49] show the possibility of a significant reduction in the generating capacity of conventional coal- and lignite-fired electricity sources, which is mainly due to the expected lack of profitability and a subsequent phase-out. The expected achievable capacity of these sources in 2040 is 5.4 GW compared to the current approximately 24 GW in Poland. At the same time, about 77 initiatives are currently underway to connect electricity storage facilities with a total installed power of about 11 GW to the transmission grid. In addition, the document indicates that photovoltaic power plants and wind power plants may develop faster than indicated in the strategic documents over the next 10 years. However, the net effect of structural change leads to an increase in generation capacity deficits in the system expressed by the Loss of Load Expectation (LOLE) indicator, whose value varies from 30.29 hours per year in 2025 to 1589 in 2040. It is estimated that to maintain the LOLE indicator at 3 hours per year, an additional 13.6 GW of available capacity is required in the national power system in 2040. Therefore, it can be concluded that to assume a declining trend in electricity prices with an acceptable degree of certainty, relevant large-scale investments in the electric power sector should be publicly announced.

3.2.1 Poland

In the Polish electric energy system a shift from fossil fuels to RES is gradually taking place. The share of solar and wind plants in total electricity generation increased from 8.5% in January 2021 to more than 24% in May and July 2023 [50]. The dominating technology is photovoltaics, which is the result of recent unfavourable legal regulations for wind farms. For the first time in Polish history, negative electricity prices occurred in June and December 2023. Key energy system data is depicted in Figure 3-7 to Figure 3-10.

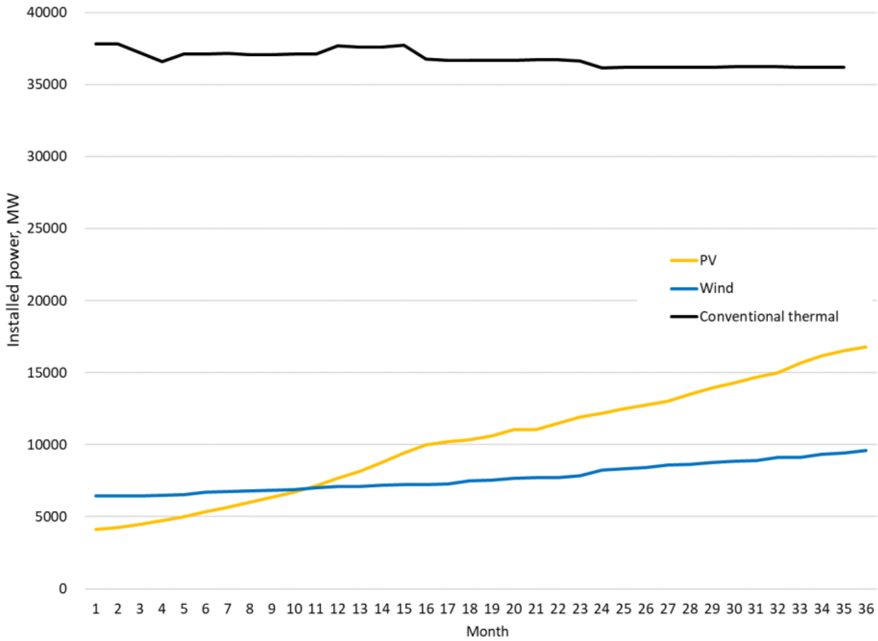


Figure 3-7: Polish energy system – installed electric power (monthly data from January 2021 to December 2023) [51]

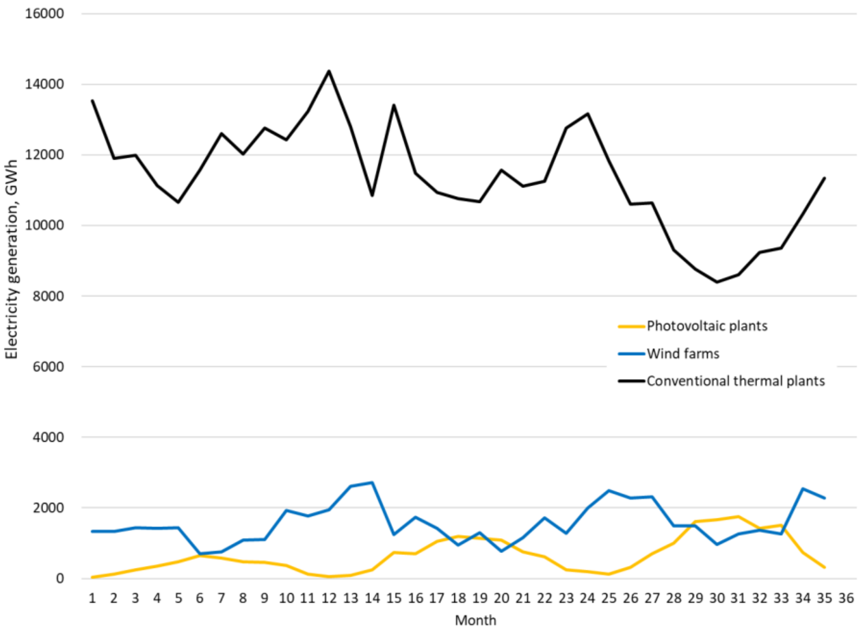


Figure 3-8: Electricity generation in Poland (monthly data from January 2021 to December 2023) [51]

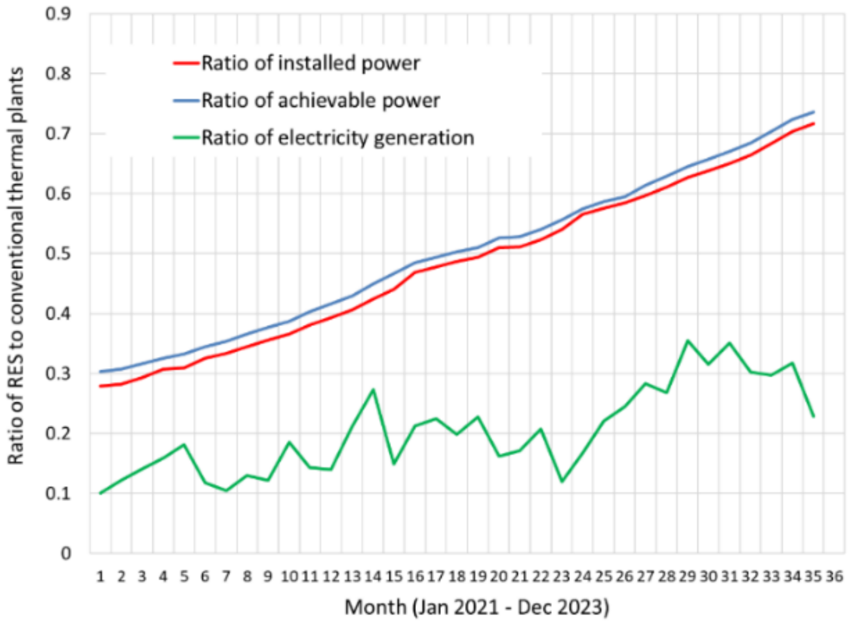


Figure 3-9: Polish energy system – key ratios of RES plants to conventional thermal plants [51]

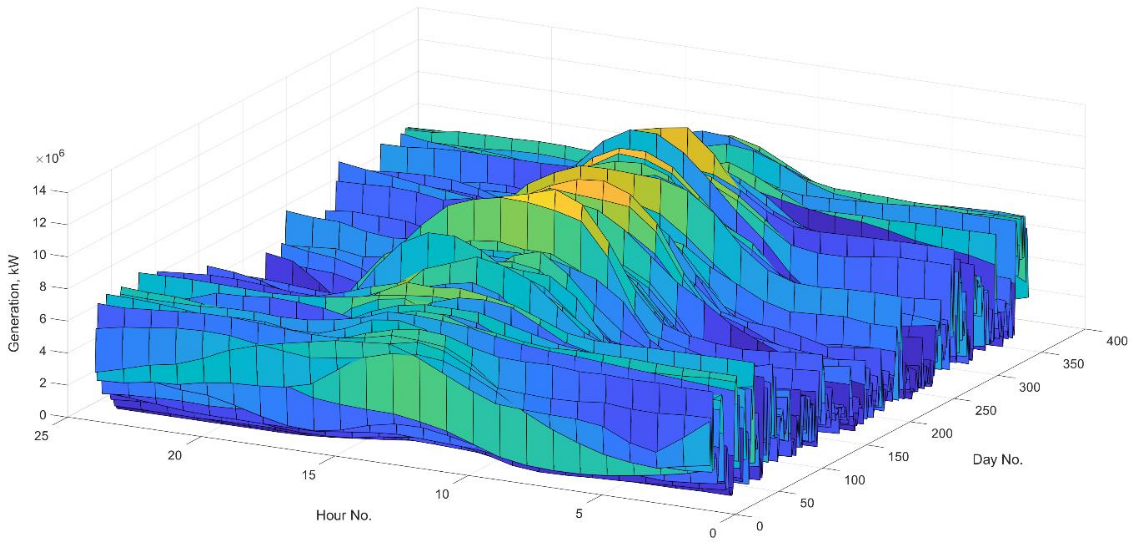


Figure 3-10: Hourly electricity generation by wind and solar plants in Poland (Polish Energy System 2023 data) [52]

As a result of the developments in the RES sector, the decrease in the market electricity price became noticeable [53]. After the 2022 market turmoil, in 2023 fuel and energy prices returned to the level from the beginning of 2021. In the electricity sector further decreases have been observed, including negative prices in June and December 2023. Figure 3-11 depicts the hourly electricity market price variation in 2023. After analysis of those data against the demand for power in the energy system and RES generation, it was found that a correlation can be established (see Figure 3-12).

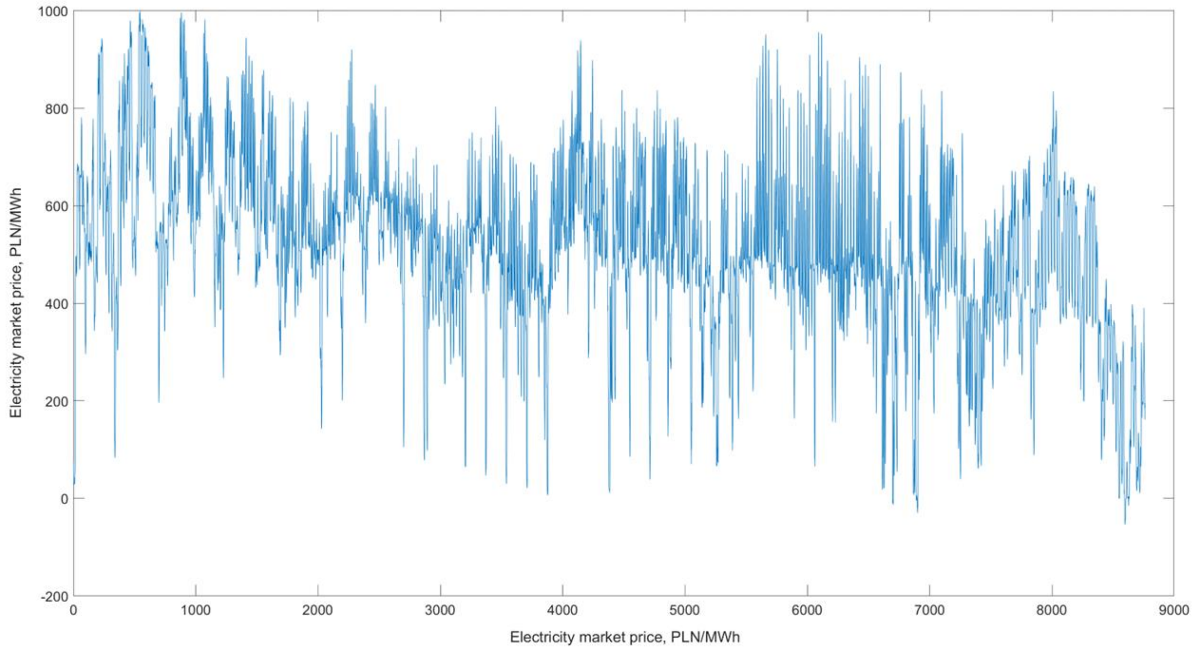


Figure 3-11: Hourly electricity market price in 2023 [52]

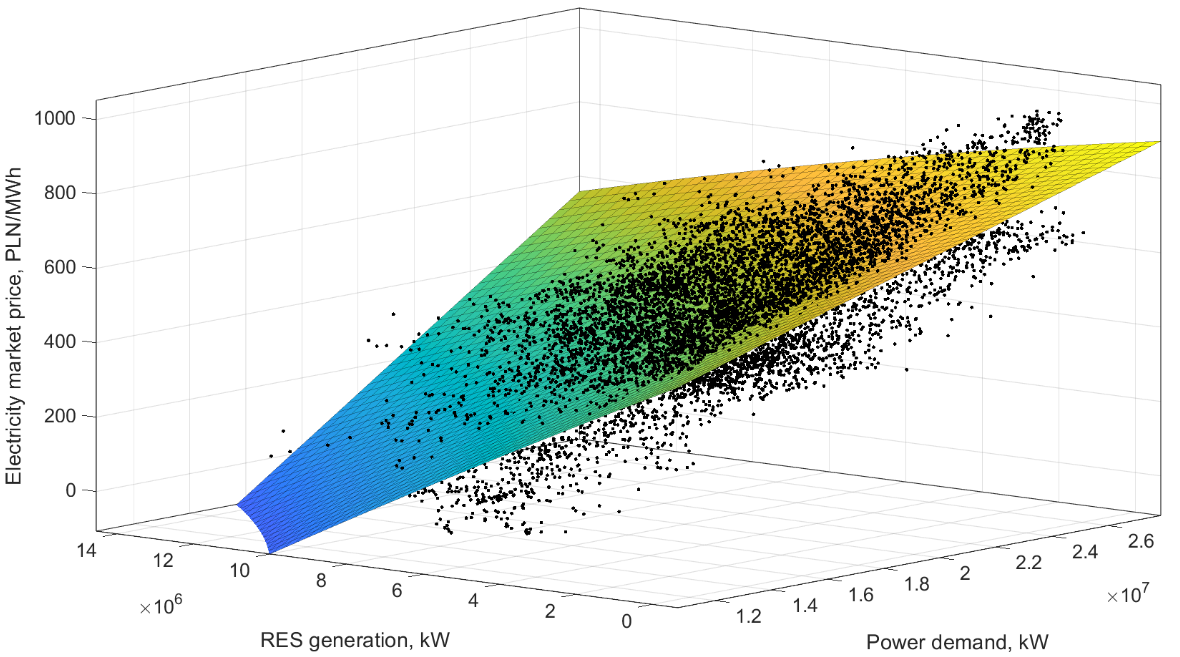


Figure 3-12: Electricity market price vs. power demand and RES generation (Polish Energy System 2023 data)

Further significant developments are expected as key companies, such as Orlen, Tauron, PGE, Enea and Energa have committed to further significant growth in the solar and wind sectors, including onshore and offshore installations. Their ambitious strategies show in total the addition of 24.11 GW of RES power capacity by 2030. According to available governmental documents, the total installed capacity of RES plants is expected at the level of 88 GW in

2040 [54]. In addition, 7.8 GW of installed capacity of nuclear power plants is expected. According to projections, the first nuclear unit with a capacity of 1-1.6 GW will be commissioned in 2033. A further five units with a total capacity of 5 to 8 GW will be commissioned every 2-3 years. On the other hand, key decisions on triggering the first investment project have been recently postponed.

The total production level of RES and nuclear plants will reach 124 TWh in 2024 (out of a total 244 TWh). On the other hand, it is expected that around 26.5 GW of coal-fired generating capacity will be permanently decommissioned by 2040 [54]. In the same period, the share of renewables in European electricity generation in 2040 could be between 63% and 86% in 2040 and between 75% and 95% in 2050 [55]. This will reduce the possibility of cross-border provision of system flexibility services.

Regarding the demand for electric energy, forecasts show that electricity consumption in Poland will increase, with a significant decrease in coal consumption and slight changes in the consumption of other fuels (especially natural gas) [56]. According to [57] the electricity demand will increase from the current 175 TWh/a to 225 TWh/a without the electrification of transport and DH, and under the current model of the national economy. Electrification of transport and district heating will significantly increase the demand.

Besides the developments in the electricity sector, new organisational, research, development, and investment activities are observed in other sectors. Many companies seek opportunities for decarbonisation and lowering the carbon footprint of their products. There have been observed increasing investment activities in energy storage, hydrogen, and alternative fuels sectors (e.g. ammonia), which may result in increased availability of waste heat. Several so-called “hydrogen valleys” were established in the country due to the availability of governmental funding opportunities. Several cities, including Opole, consider municipal energy clusters to effectively manage energy and emissions. Some of them introduce programmes for the decarbonisation of public transport. First hydrogen charging stations for busses have been already commissioned in the country. New funding opportunities appear, which result from the determination of the EU member states to meet the policy targets set in the Fit for 55 and REPowerEU legislative packages. The recent reform of the European Carbon Trading System (ETS) and implementation of the ETS 2 system for buildings, road transport, and additional sectors will certainly strengthen the investment trends. Connections of new consumers may result from replacing individual heat sources with district heating due to limited possibilities of meeting the requirements of new legal regulations. In addition, new planning obligations have been imposed on municipalities with the EU directives EED and RED III. There has been also observed increasing public awareness of climate and energy issues, which is mainly due to intensified communication activities of different organisations.

Taking into account the assumptions set out in the development strategies of the main energy market players (PKN Orlen, Tauron, Energa, Enea, Polska Grupa Energetyczna, PSE), it can be assumed that:

- There will be a significant increase in the electrical capacity installed in RES, mainly wind and photovoltaic.
- There will be a start-up of nuclear power plants and an increase in installed capacity in this sector.
- There will be a gradual withdrawal of coal-fired generation assets from the system.
- Biomass will be used mainly for district heating and the production of liquid biofuels.
- There will be a significant demand for hydrogen for fuel production and energy storage.
- There will be significant integration of sectors and significant electrification of transport and heating.
- There will be a significant dispersion of production assets in the electricity sector.
- There will be a reduction in the energy intensity of the economy and a reduction in primary energy demand due to increased energy efficiency in industry and the buildings sector.
- There will be a significant increase in electricity demand due to the electrification of key sectors including industry, transport, and heating.

To assess the potential evolution of electricity prices, a simplified model of the Polish energy system and the electricity market was developed, which enabled the variability of electricity prices at hourly resolution under different scenarios to be estimated. The model has a simplified black-box character (it does not take into account the physical conditions of the system) and is based on a limited number of parameters. Its main element is the relationship between electricity price, renewable generation (solar and wind) and system power demand. The level of imbalance expressed by the balance of parallel and non-parallel interchange is also included as a parameter of the model. Based on 2023 market data [52] a neural network was built using Matlab Neural Networks Fitting tool (nftool) from the Deep Learning Toolbox 14.6. The developed two-layer feed-forward network with sigmoid hidden neurons and linear output neurons is able to predict electricity prices with an hourly resolution. The coefficient of determination for the network fit is $R^2 = 0.77$.

In the next step, the evolution of the demand for power and electricity generation by RES was assumed based on available data. The hourly demand for power was multiplied by the forecasted increase factor, which was determined based on current governmental estimations [54,56]. The 2023 RES generation data was normalised by dividing hourly generation data by the installed capacity. According to the current governmental estimations the installed RES generation capacity in Poland in 2030 will be 50 GW, and in 2040 88 GW. Linear extrapolation of trends depicted in Figure 3-7 gives similar values of 47.6 GW and 91.8 GW. In the first scenario the governmental data were adopted, and in the second one 50% of the expected increase was assumed. The installed capacity was then divided between solar and wind using information collected from the announced strategies of major energy companies. Future generation profiles were created by multiplying the normalised generation profiles for solar and wind plants by the newly installed generation capacity. Additionally, it was assumed that the electrification of district heating would take place in the forthcoming years. This is justified by the fact that many DH companies in Poland triggered heat pump projects and considered phasing in electric boilers. According to the DH statistics of the Polish Energy Regulatory Office the total contracted heating capacity of the 405 licensed DH companies is 34.9 GW. The hourly profile of the system was created using the normalised heat production profile of Opole, which was then multiplied by the total heating capacity of the system. In the next step, different electrification factors were assumed for years from 2030 to 2050. In this way, an additional electric load was created.

The values of different model parameters are given in Table 3-1. The values of parameters for the years other than specified in the table were linearly interpolated. The developed model of the electric energy system is rough as it does not take into consideration the development of the electric energy storage and power-to-X facilities. It has been also assumed that the addition of nuclear power blocks will be compensated by the decommissioning of the existing coal-fired power plants, and the current level of generation will be maintained by additional revitalisation programmes of the remaining existing plants. Nevertheless, it results in acceptable and justifiable predictions of trends.

Table 3-1. Key parameters of the anticipated future Polish energy market model

Model parameters	Value in year			
	2024	2030	2040	2050
Scenario 1				
Coal market price, EUR/GJ	5.99	2.48	2.18	1.87
Gas market price, EUR/MWh	36.18	14.67	14.33	13.99
EUA market price, EUR/ton	65.00	140.00	205.00	250.00
Installed RES generation capacity, MW	26400	50000	88000	127742
Share of wind installed capacity	0.363	0.458	0.505	0.523
Electric power demand increase factor	1.0	1.127	1.311	1.496
District heating load electrification factor	0.0	0.3	0.5	0.7
Scenario 2				
Coal market price, EUR/GJ	5.99	2.91	2.96	3.00
Gas market price, EUR/MWh	36.17	23.54	23.89	24.23
EUA market price, EUR/ton	65	135	175	200
Installed RES generation capacity, MW	26400	38200	57200	77071
Share of wind installed capacity	0.363	0.411	0.434	0.443
Electric power demand increase factor	1.0	1.064	1.156	1.248
District heating load electrification factor	0.0	0.15	0.30	0.50

Sample results are presented in Figure 3-13 to Figure 3-19. The results reveal, that in forthcoming years overproduction of electricity can take place in a considerable number of hours, mainly in summer, and negative market prices of electricity will occur more frequently. It is also interesting that the difference between maximum and minimum electricity prices will considerably increase, both on an annual and daily basis. According to Scenario 1 of the model, in 2035 the number of hours with negative energy prices is 575, in 2040 875, and 1125 in 2050. In Scenario 2 the numbers are 49, 57, and 105 respectively.

Another important conclusion is that compared to the current situation, there may be a shift in the positions of the daily peaks and valleys of the energy price in the competitive market. High prices may occur at night, while low prices may occur during the day. This is related to the significant supply of energy from solar and wind sources. In addition, in Scenario 2, compared to the widespread expectation of a reduction in the price of electricity, the results obtained show an increase in the weighted average annual price. This is mainly due to insufficient growth in installed capacity in relation to demand, which also includes the electrification of district heating. The results reveal that the DH sector may have a significant impact on the entire energy system and the national economy.

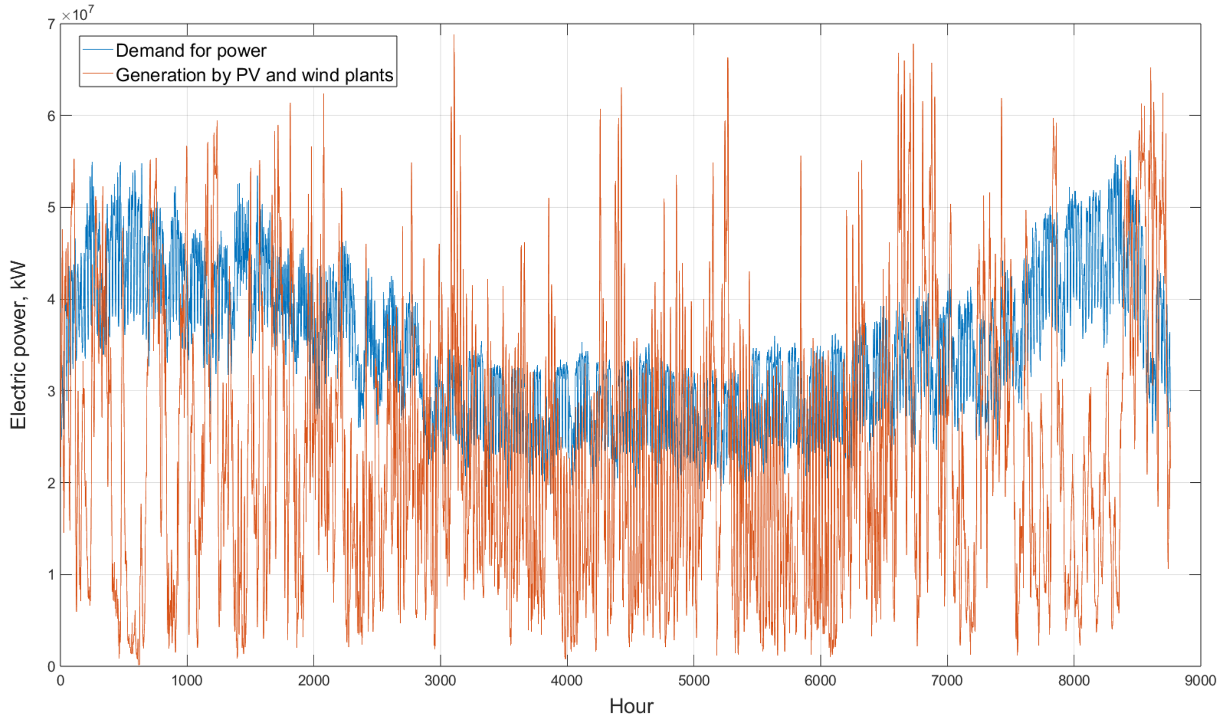


Figure 3-13: Anticipated demand for power and RES generation in 2050 in Scenario 1

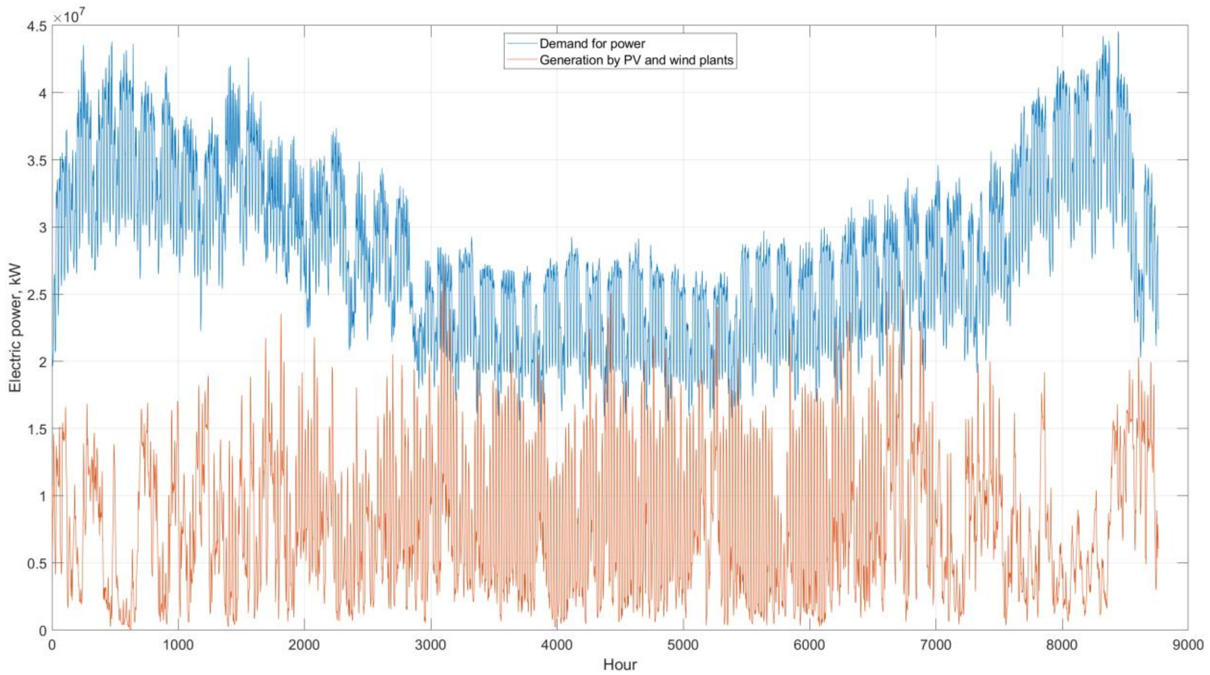


Figure 3-14: Anticipated demand for power and RES generation in 2050 in Scenario 2

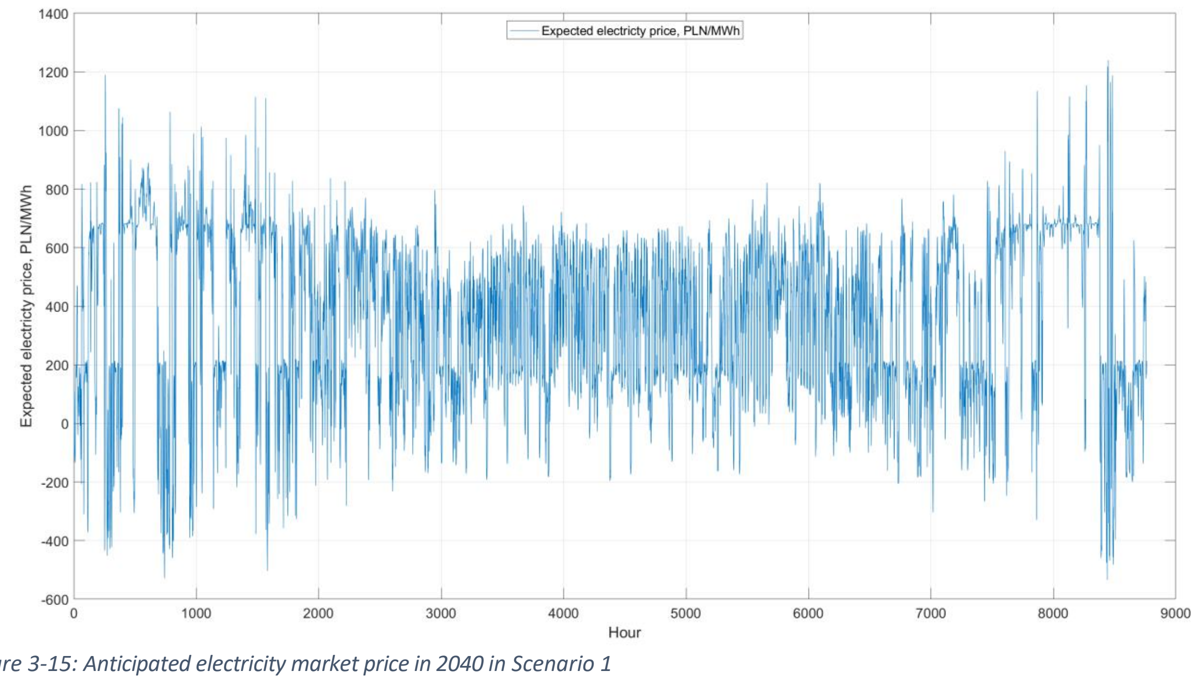


Figure 3-15: Anticipated electricity market price in 2040 in Scenario 1

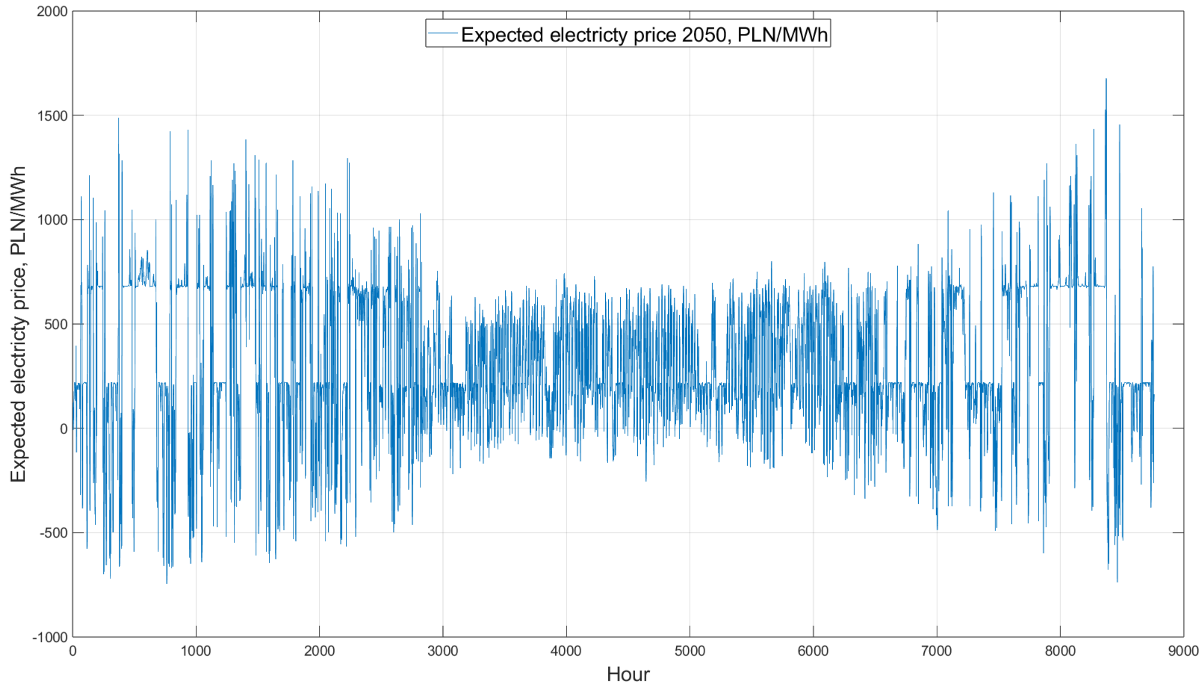


Figure 3-16: Figure. 10. Anticipated electricity market price in 2050 in Scenario 1

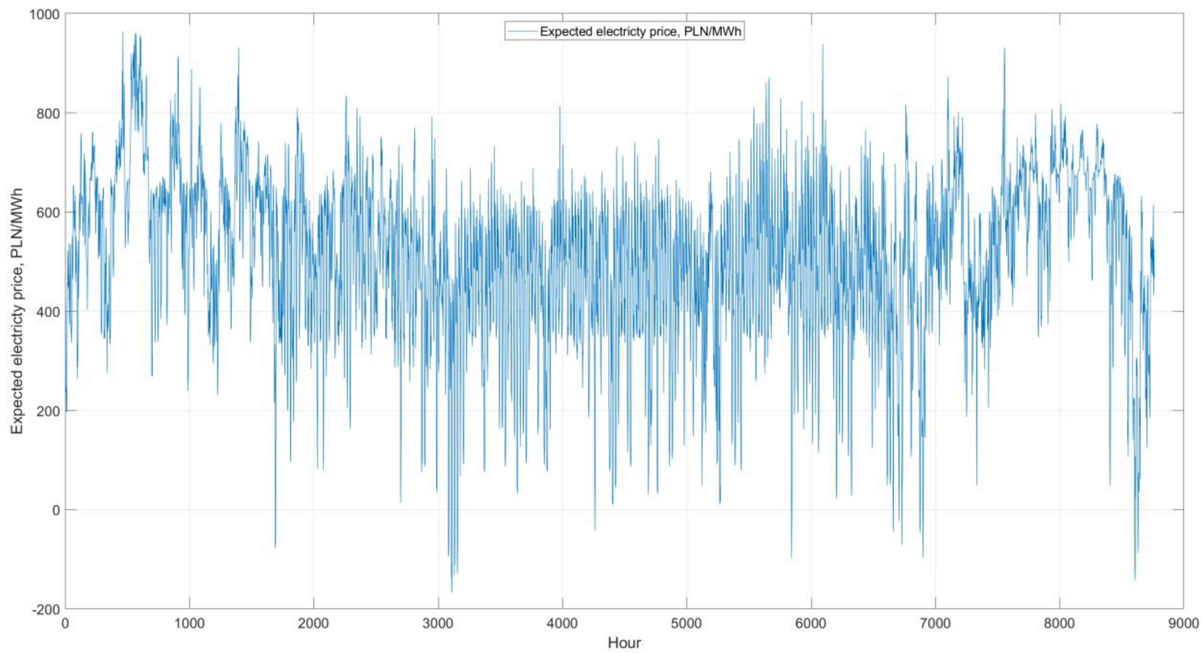


Figure 3-17: Anticipated electricity market price in 2040 in Scenario 2

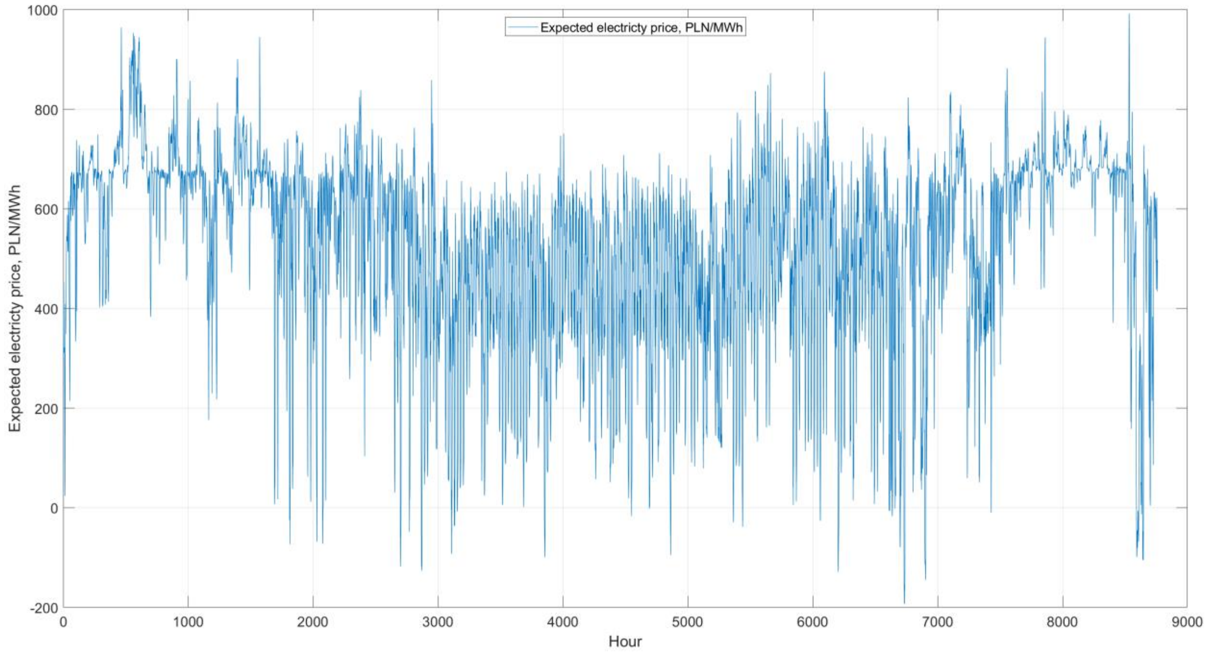


Figure 3-18: Anticipated electricity market price in 2050 in Scenario 2

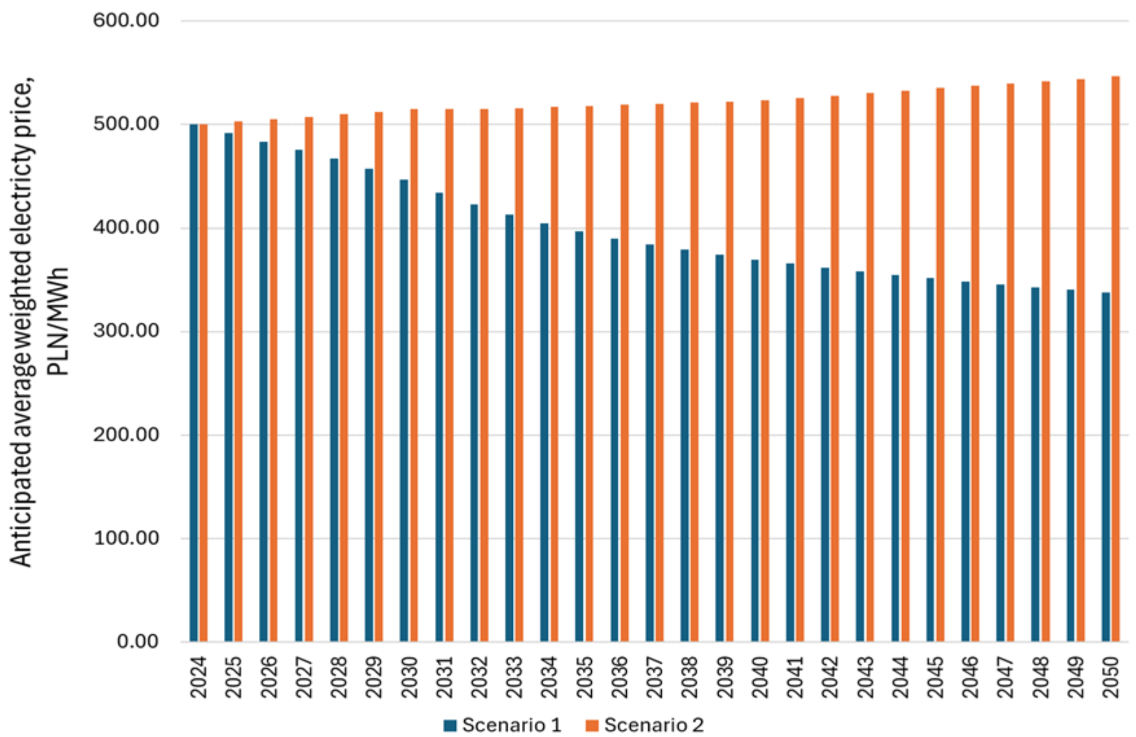


Figure 3-19: Anticipated annual average weighted electricity price by years

3.2.2 Romania

In Romania, The Energy Strategy shows that Romania has a diversified energy mix. At the level of 2022, coal, in the proportion of 80% extracted locally, provides 14% of the primary energy mix; oil, and petroleum products (approx. 65% imported, 35% domestically produced) approx. 36%; natural gas (approx. 84% of domestic production, 16% imported) approx. 30% of the mix; renewable energy and biofuels approx. 12%, and nuclear energy approx. 9%.

Total electricity consumption fell substantially from 60 TWh in 1990 to 39 TWh in 1999, mainly on the back of contracting industrial activity, after which it increased to 48 TWh in 2008. The economic crisis of 2008-2009 caused a further decrease in consumption to 43 TWh. It gradually recovered to 47 TWh in 2012, remaining constant until 2016. In the same period 2012-2016, GDP increased by 25.8%. From 2014, the trend of final energy consumption was upward until 2021, followed by a sharp decline of 8.5% in 2022 when consumption fell to the 2014 level.

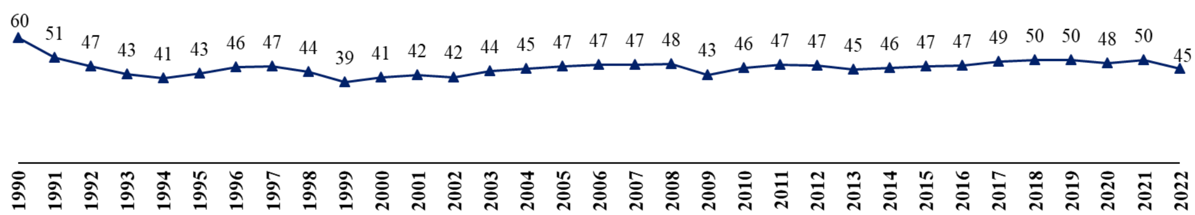


Figure 3-20: Romania's total electricity consumption [TWh] Source. Eurostat

In the period 22.09.2017 – 01.06.2023, at the Romanian level, capacities totaling an installed power of 5,508 MW were withdrawn from the operation. Thus, in 2023, the installed capacity in the power system reached a historic low of 18,254 MW (see Figure 3-21).

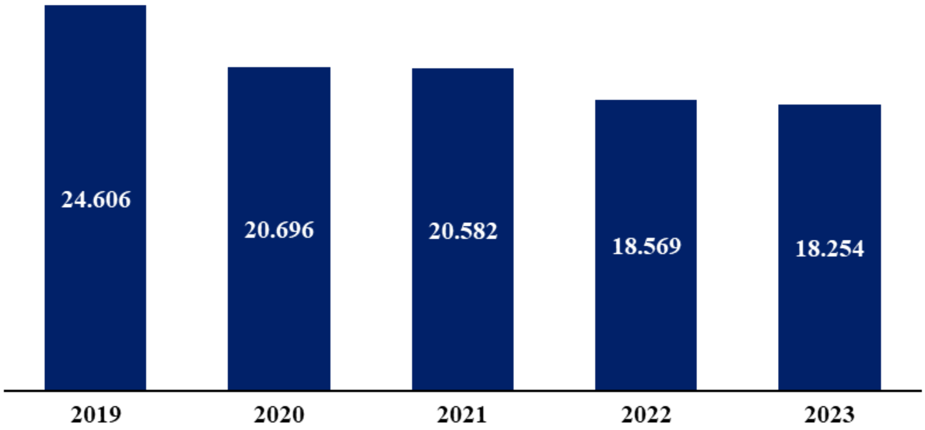


Figure 3-21: Evolution of installed capacity in the power system [MW]

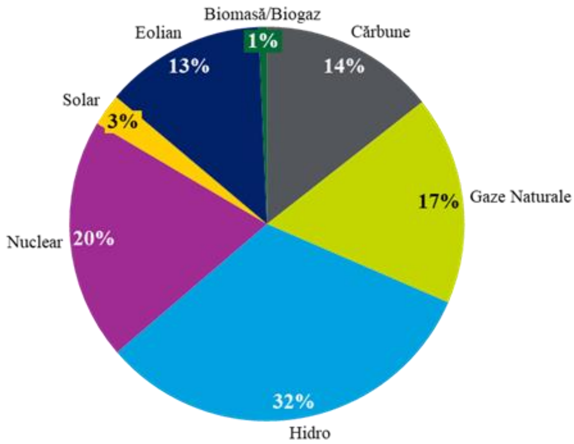


Figure 3-22: Electricity production in Romania, by types of producers, 2023. Source: Transelectrica

Regarding the development potential of energy sources at the national level, the situation is as follows:

The hydropower potential that could still be developed in Romania is estimated at approx. 10.30 TWh/year.

According to Transelectrica data, there are connection contracts for wind power plants totaling an installed power of about 1,895.95 MW that will be connected. Traselectrica also highlights a power installed in photovoltaic panels of 1,019.99 MW.

In 2023, only 0.69% of the electricity produced in the country came from biomass, bioliquids, biogas, waste and waste and sludge fermentation gases, in plants totaling 118 MW of installed power.

The gross final consumption of energy from RES in the period 2004-2022 was continuously increasing reaching a global share of RES of 24.1%. At the level of 2022, the share of SRE in the electricity sector (RES-E) was 43.7%, a significant increase compared to 2004. Due to the increased use of biofuels in transport, the share of RES in this sector (RES-T) increased from 1.4% in 2010 to 8.2% in 2020. The RES share in the heating and cooling sector (SRE-H&C) has remained almost constant over the past 10 years [58].

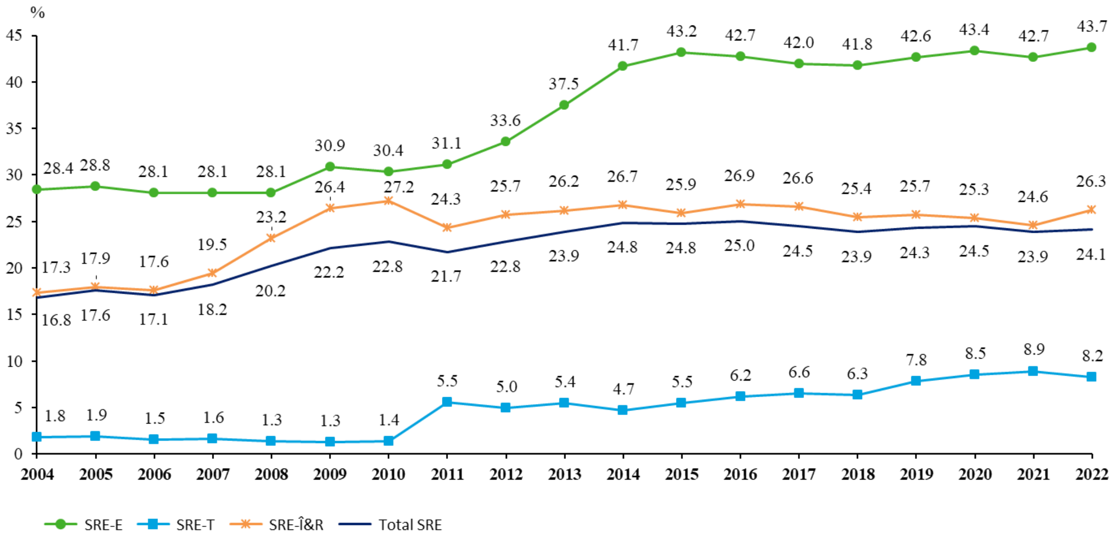


Figure 3-23: Evolution of the global RES share and sectoral RES shares

In the second half of 2022, the price of electricity for households in Romania was approximately 20% higher than the EU average. In addition, electricity prices for non-household consumers in 2022 also exceeded the EU average. Figure 3-24 shows the complete price structure of electricity supplied to domestic and non-domestic consumers.

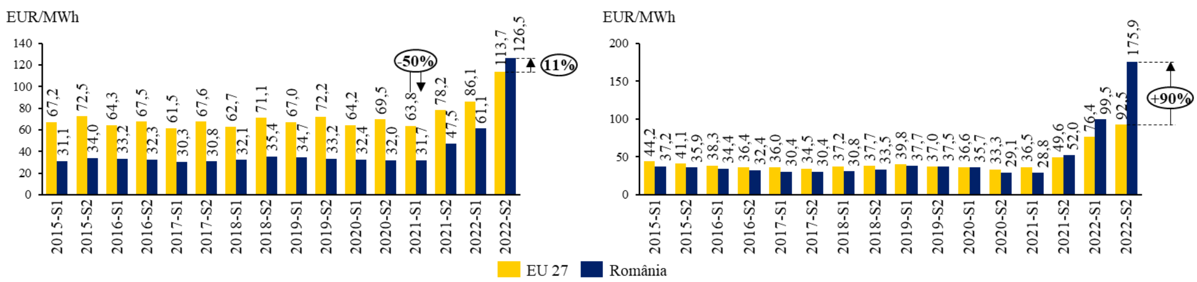


Figure 3-24: (Left) Variation of electricity prices for household consumers - biannual data. Consumption from 2,500 kWh to 4,999 kWh - DC band (Right) The variation of electricity prices for non-household consumers - half-yearly data. Consumption from 2,000 MWh to 19,999 MWh – ID band

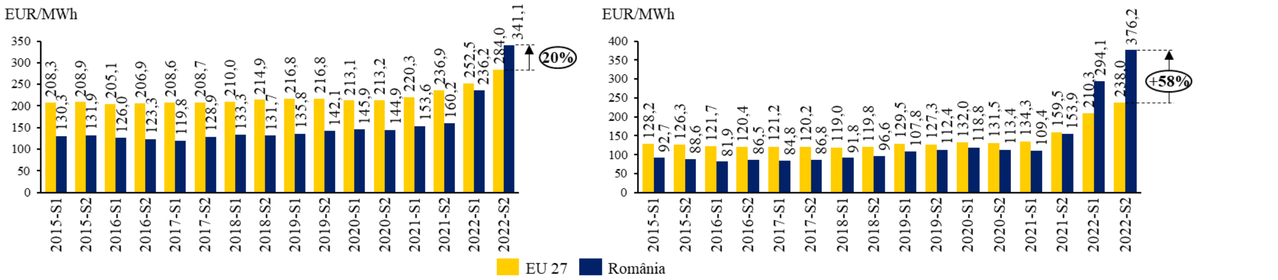


Figure 3-25: (Left) Variation in natural gas prices for domestic consumers - biannual data. Consumption from 20 GJ to 199 GJ - band D2 (Right) The variation of natural gas prices for non-household consumers - half-yearly data. Consumption from 10,000 GJ to 99,999 GJ - band I3

The evolution of electricity prices is similar to that of natural gas prices as shown in Figure 3-25.

The state practices a policy of supporting vulnerable people through energy subsidy policies. In total, energy subsidies in Romania have increased in recent years, reaching approximately 1.2% of GDP in 2022.

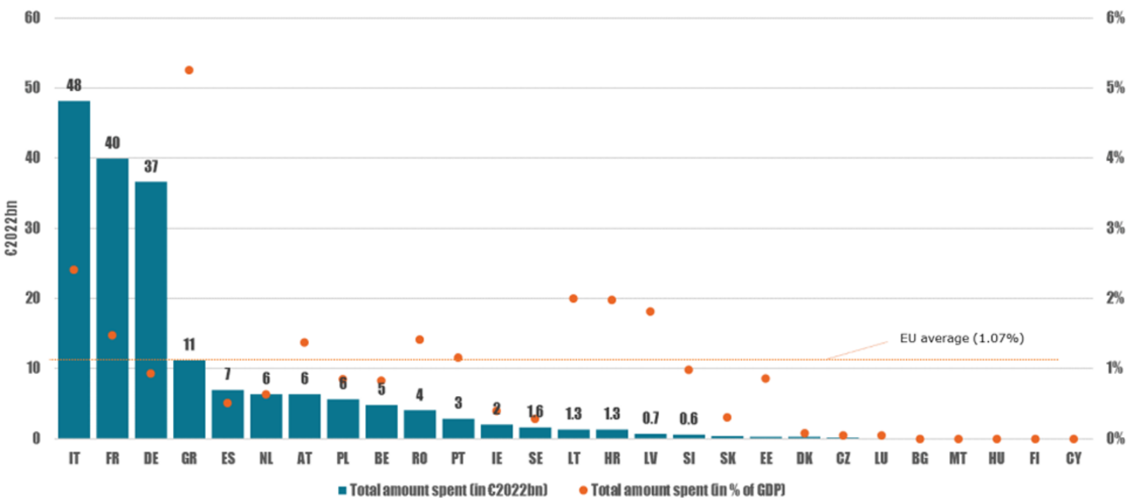


Figure 3-26: Subsidies to counter rising energy prices, as a percentage of GDP and nominal value in billion EUR. Source:

In 2023-2024, Romania faces high volatility of electricity prices on the spot markets (Day-Ahead Market and Intra-Day Market), partly due to the variability of RES. Thus, prices vary from values of around 200 EUR/MWh, to negative values of around -20 EUR/MWh. Also, in the Balancing Market, a large volume of power reduction selections is registered, which led to the registration of negative prices in the Balancing Market of up to -9,000 lei/MWh (20 – 21.05.2023), respectively of -10,000 lei/MWh (28.05.2023), in several settlement intervals [58].

3.3 District heating prices

3.3.1 Croatia

Heat production and distribution in Croatia require relevant licenses. The legal framework is set in the Energy Act, the Act on the Regulation of Energy Activities, and the Thermal Energy Market Act. In general, the legal framework is constructed in a way that customers are protected.

Heat prices in Croatia are regulated according to the legal regulations: Methodology for setting tariffs for thermal energy production (Official Gazette no. 56/14), and Methodology for setting tariffs for thermal energy distribution (Official Gazette no. 56/14). The supervisory organisation is the Croatian Energy Regulatory Agency. There are four main components of the final heat prices, namely:

- Energy
- Capacity
- Thermal energy buyer charge
- Thermal energy supply charge.

On average, the cost of energy contributed to the final price by around 50%.

Most district heating companies in Croatia are capable of covering their cash operating expenses, which include fuel, materials, and salaries. However, current tariffs often fail to account for depreciation, thereby constraining the companies' capacity to invest in upgrading the DH network. Moreover, approximately 75-80% of the cash operating expenses for a DH company are attributed to fuel costs, rendering the company's profitability highly sensitive to international gas and oil prices.

Table 3-2. Amounts of tariff items on 31 December 2022 in Zagreb [123]

	TARIFF MODEL		
PRICE COMPONENT	TM1	TM2	*TM3*
Heat production – energy, [HRK/kWh] [*HRK/t*]	0.1525	0.3050	*232.5521*
Heat production – power, [HRK/kW] [*k/t/h*]	2.30	5.86	*3,980.57*
Heat distribution – energy, [HRK/kWh] [*HRK/t*]	0.0175	0.0350	*55.7079*
Heat distribution – power[HRK/kW] [*k/t/h*]	3.45	6.17	*4,194.64*
Heat production and distribution – energy[HRK/kWh] [*HRK/t*]	0.1700	0.3400	*288.2600*
Heat production and distribution - power[HRK/kW] [*k/t/h*]	5.75	12.03	*8,175.21*

3.3.2 Lithuania

Heat supply activities are licensed. The licensing procedure and rules shall be approved by the Government. Licenses shall be issued, suspended, and revoked and the licensed activity shall be controlled by the National Energy Regulatory Council (NERC), taking into account the recommendations of the municipal authority, for heat suppliers supplying at least 10 GWh of heat per year. Licenses for suppliers supplying less heat shall be issued, suspended, revoked and the licensed activity shall be subject to control by the municipal authority [61,62]. In May 2024, there were 56 licensees in Lithuania [63].

Heat prices for heat supply companies are set by the National Energy Regulatory Council in accordance with the "Methodology for Setting Heat Prices" („[Šilumos kainų nustatymo metodika“](Šilumos kainų nustatymo metodika)) [64] and are recalculated every month, taking into account the change in the price of fuels and the price of the purchased heat (see www.regula.lt). Heat prices are mainly determined by the cost of the fuel used to produce heat [65]. The composition of the DH price and the fuel used is shown in Figure 3-27.

The district heating prices from the 1st of August 2022 (including VAT)

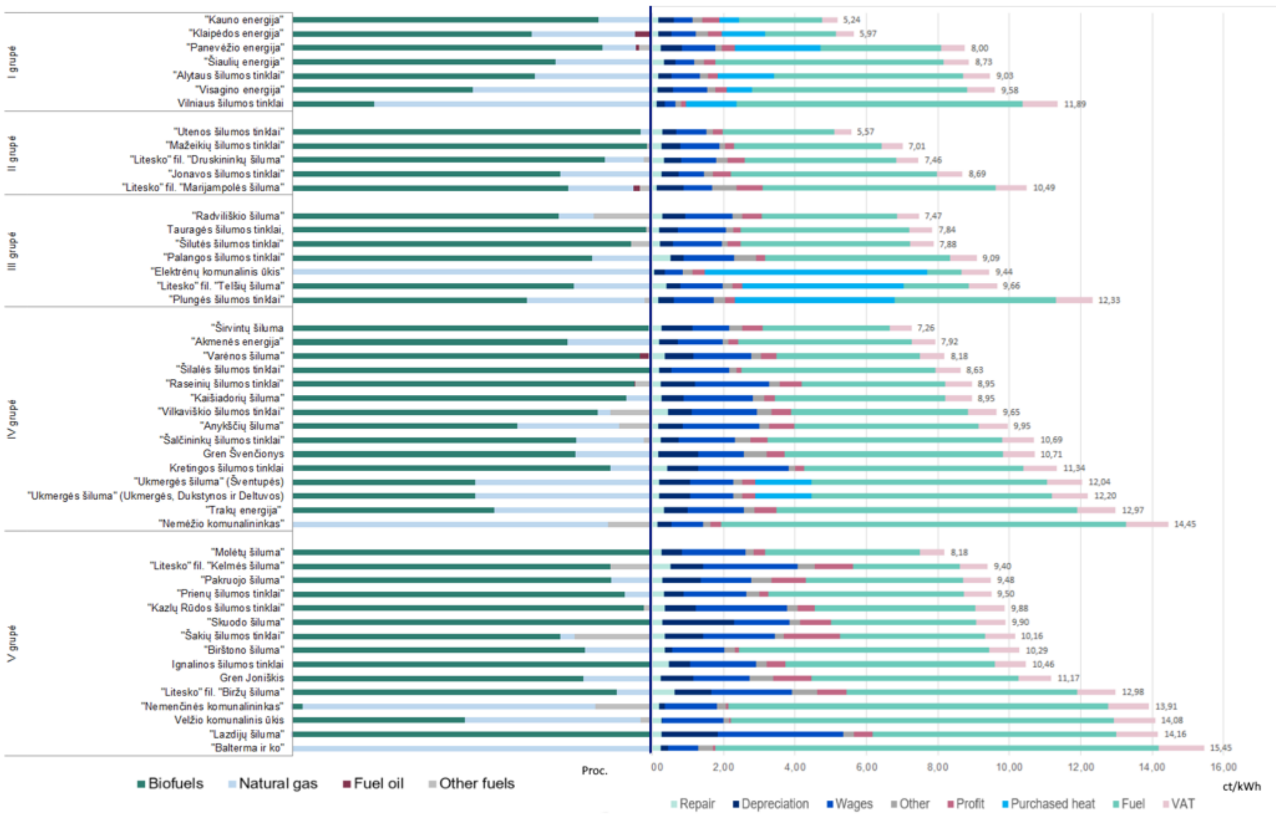


*Figure 3-27: DH prices 2022, August including VAT (*Heat supply companies grouped according to the annual sales of heat*)* [66]

Final heat prices are changed no more frequently than monthly, but the heat supplier may decide to recalculate the heat price less frequently. When calculating the final heat price for each month, the heat supplier shall take into account the established Income Base Level or Adjusted Income Level, changes in the fuel used, the cost of purchased heat and electricity, the results of the capacity auction, and any other factors affecting the final heat price. In this way, the heat price for consumers is recalculated every month, taking into account current fuel prices [67].

Heat end prices charged to consumers are either unitary/single or dual-priced. They are calculated as the sum of the prices for heat production (including purchased heat), heat transmission, retail servicing, and the additional component [68]:

- The unitary heat price consists of variable, fixed and additional components expressed in ct/kWh;
- The dual heat price consists of a fixed part, expressed in Eur/month/kW, and variable and additional components, expressed in ct/kWh.

The fixed part of the price is made up of personnel, depreciation, repairs, and other costs necessary for the operation of the company. Fixed costs incur irrespective of the amount of heat produced and supplied to consumers. The variable part of the price consists of biofuels and gas used for heat production, purchased heat and losses in the network. These costs vary depending on the amount of heat required to be produced and delivered to the heat transmission network and the price of fuel. During the cold season, fuel is more expensive to buy, as the price on the exchange increases with increasing demand. This component represents the largest part of the heat price [67].

The average district heating price in February 2024 was 7.47 ct/kWh, 13.64% lower than in February 2023 (8.65 ct/kWh). The bulk of the heat price to consumers is made up of the cost of fuel and purchased heat, which depends on fuel prices on the market, while the remainder is made up of depreciation (amortisation), repairs, labour costs, return on investment etc.

The average heat price in Lithuania without VAT is shown in Figure 3-28.

Figure 3-28 Average heat price in Lithuania from 2013 January till 2024 June, ct/kWh without VAT [69]

The National Energy Regulatory Council announces that the average price of district heating in Lithuania in June is 6.02 ct/kWh (excluding VAT). Compared to May, the price per kilowatt-hour decreases by 2.11% [67].

Lithuanian heat suppliers' prices for June are shown below, with the fixed and variable parts and the total single-month price including VAT shown separately.

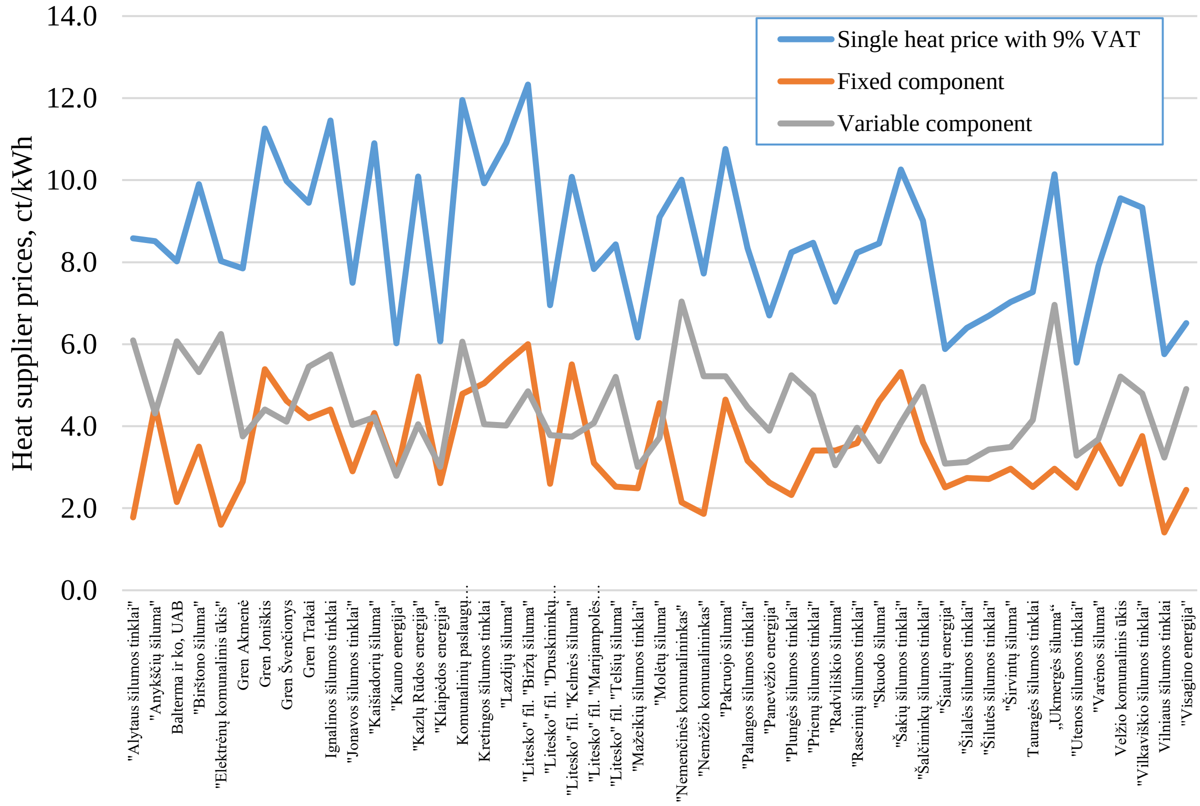


Figure 3-29 Heat suppliers' prices for June 2024 [9]

For example, in the case of the "Vilniaus šilumos tinklai" (VST), the price of DH in June 2024 is 5.28 ct/kWh (without VAT) or 5.76 ct/kWh (with 9% VAT). The fixed price component for June 2024 is 1.41 ct/kWh and represents 24.5 % of the total price. Of this amount, 0.51 ct/kWh are personnel costs, 0.27 ct/kWh are depreciation/amortisation costs, 0.26 ct/kWh are return on investment, 0.20 ct/kWh are routine repair costs and 0.17 ct/kWh are other costs. The variable price component for June 2024 is 3.24 ct/kWh, representing 56.3 % of the total price, taking into account fuel and purchased heat prices for the relevant period. The additional component is 0.63 ct/kWh and represents 10.9 % of the total heat price. The VAT (9%) is 0,48 ct/kWh and represents 8.3% of the total price [70].

Since 1 October 2023, following the amendments to the Law on Heat Sector, NERC regulates the competitive heat production activities of those independent heat producers and heat suppliers who [67]:

- have received EU financial, municipal or other support which exceeds 10 per cent of the purchase price of the fixed tangible assets owned by the owner or other legal agrarian rights attributable to the heat production activity (regulation period - 5 years);
- receives an eligible electricity tariff, i.e. using public service obligations funds or fixed tariff measures to promote the use of RES;
- the heat produced represents more than 1/3 of the DH system demand and has exceeded the benchmark level of heat income calculated and made public by VERT in the previous calendar year (regulatory period 5 years).

The amendments to the Law on Heat Sector also regulated the mechanism for purchasing waste heat. At the beginning of 2023, there were 42 independent heat producers (20 regulated and 22 unregulated) and at the end of 2023, there were 38 (12 regulated and 26 unregulated) and 3 waste heat generators (WHPs).

3.3.3 Poland

In Poland the business of generating heat in sources with a capacity greater than 5 MW as well as the transmission or distribution in networks of the ordered capacity greater than 5 MW requires a licence [59]. According to data from the Energy Regulatory Office [60], the number of licensed enterprises (with a capacity greater than 5 MW) was 392 in 2022, of which 52.4% were enterprises with an installed capacity of up to 50 MW. According to data from the Energy Market Agency SA [51], the district heating industry in Poland is made up of 682 companies in total, of which 389 are professional electric power and production-distribution enterprises and professional heating plants, and 293 are heat and power plants and non-professional heating plants.

The licenced energy enterprises shall set heat tariffs and propose their duration. Heating companies (excluding CHP plants) shall set their tariffs on the basis of the justified costs and a regulated (allowed) return on capital employed. The rules of calculations are defined in regulations by The Minister For Climate And Environment of 23 November 2022 amending the Ordinance on the detailed rules for shaping and calculating tariffs and calculation of tariffs and heat supply billing (Journal of Law 2022, item 2437). The tariffs are subject to the approval by the President of the Energy Regulatory Office (ERO). Energy enterprises with the licences shall submit tariffs and their amendments to the President of the ERO on their own initiative no later than two months before the expiry of the previous tariff or at the request of the President of the ERO.

In 2022, the volume of total heat sales by licensed district heating companies (including resale to other companies) amounted to 357.7 PJ. Purchased heat sales (pure trading), which form part of the above total, stood at 653 TJ. Regarding the energy mix for heat production, 66.22% of heat was generated from coal or lignite and 9.25% from natural gas. Overall, 82% of heat was generated from fossil fuels. Diversification of primary energy sources used for heat production is progressing very slowly. Regarding RES in district heating, the main one is biomass, with a 12.26% share in energy input for heat generation. In addition to this, in cities, high-temperature district heating grids prevail. The average heat generation efficiency is 82.84% and the distribution is 87.03% [60]. The main transition trend since around 2002 has been a shift from coal to natural gas and biomass, and from heat-only boilers to natural gas-fired cogeneration, which was strongly promoted by various incentives. Although many DH companies have recently triggered investment projects focused on renewables, the dominating investment trend is biomass-fired cogeneration.

In 2022, the average net price of heat sold from all licensed heat sources was 64.03 PLN/GJ (around 13.92 EUR). The average price from cogeneration only was 55.15 PLN/GJ (around 11.99 EUR) while the plants without cogeneration sold heat at the average price of 76.39 PLN/GJ (around 16.61 EUR). The average transmission and distribution service charge rate was in 2022 22.47 PLN/GJ. A typical tariff of a district heating company is presented in Table 3-3.

Table 3-3 Example of DH tariffs in Poland

Component No.	Tariff component	Unit	User group	
			A	B
1	Price for ordered heating capacity	PLN/MW/year	212 379.11	212 379.11
1.1	Monthly rate for ordered heating capacity	PLN/MW/month	17 698.26	17 698.26
2	Heat price	PLN/GJ	95.85	95.85
3	Heat carrier price	PLN/m^3	31.98	31.98
4	Fixed heat distribution rate	PLN/MW/year	81 815.01	65 186.84
4.1	Monthly heat distribution rate	PLN/MW/month	6 817.92	5 432.24
5	Variable heat distribution rate	PLN/GJ	27.39	18.73

The common practice is that tariffs for heat are modified once, sometimes two times, a year. It may happen that heat prices are under a political push and are regulated using special Ministerial orders. For example, from 1 March 2023 to 31 December 2023, heating companies were required to calculate, for each district heating system and each tariff group, a maximum heat supply price, which could not be higher than the calculated heat supply price as of 30 September 2022. In this way, the increase in the price of supplying heat to residential and public utility customers has been limited to a fixed level to prevent price shocks resulting from the war in Ukraine. Heating companies applying the maximum heat supply price to eligible customers were entitled to compensation in this respect in the amount representing the product of the difference between the heat supply price resulting from the applied tariff of that company and the price resulting from the application of prices and tariffs to these customers and the quantity of heat sold to these customers, in a given monthly billing period, increased by the tax on goods and services. The entities paying compensation on this account to energy enterprises was Zarządca Rozliczeń S.A. - for licensed companies, or the head of the municipality, mayor or city president, competent for the location of the authorised entity conducting an unlicensed activity. In the case of certain heat production units, the inability to dynamically change the price of heat following a change in the cost of fuel or carbon allowances often resulted in the shutdown of such units.

The average selling prices of heat generated by licensed heating companies in non-CHP heat generation units are depicted in Figure 3-30. It can be observed that a significant increase of prices from all types of input energy, including RES (mainly biomass), was encountered in

2022 and 2023. In addition, the inability to dynamically change the fuel price according to the situation in the fuel market caused financial losses for many Polish district heating companies.

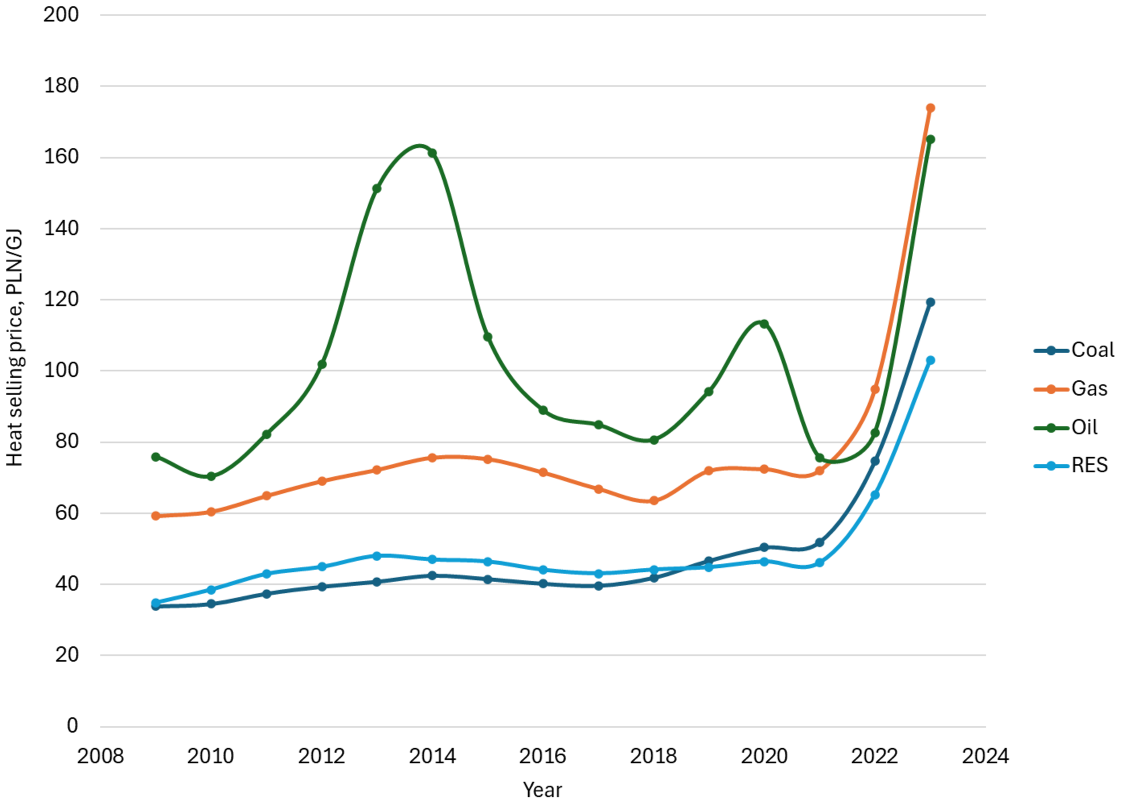


Figure 3-30: Average selling prices of heat generated in non-CHP heating units

CHP plants can choose between calculating the price for heat on the basis of justified costs, income from electricity sales, and return on capital (cost method) or a simplified benchmark method based on so-called reference heat prices (C_r). The common practice is that CHP units calculate heat prices using a simplified method, which allows the companies to assume the costs of heat equal to the cost of heat from non-CHP generation units using the same fuel (C_{CSn}) multiplied by a reference factor (X_c) published by the ERO according to the equation:

$$C_r = C_{CSn} * X_c$$

In this way they are allowed to increase profits from electricity generation.

Current (2024) values of the reference factors Xc are: 0.77 for coal, 0.78 for gas, 0.54 for oil, and 0.86 for renewable energy sources. It is worth mentioning that until 2021 the X_c values were constantly equal to 1.0 for all fuels. In 2022 the values of X_c for coal and gas were increased to 1.25 and 1.31 respectively. In 2023 the values were 1.24 for coal, 1.44 for gas 1.09 for oi 1.14 for RES.

The current high level of economic regulation of the district heating market is regarded as one of the key barriers to effective energy transition and decarbonisation of district heating systems. There is being identified need to adapt the legal framework to the current decarbonisation tasks, including the introduction of regulations to increase the investment and operational flexibility of district heating companies. There is also the need for the development of new rules for creating and approving heat tariffs, increasing the flexibility of heat companies to create changes in the behaviour of heat consumers, introducing seasonality into tariffs and taking into account the marginal cost of heat generation.

3.3.4 Romania

In Romania, in terms of thermal energy, district heating, especially in large cities, will continue to be necessary. There is a need to support the implementation of efficient cooling and low-temperature district heating systems for new housing developments. However, there is a major potential for the installation of new high-efficiency cogeneration sources, both for heating the population and in industry. The diversification of energy sources, with an emphasis on RES, is an option taken into account by all those active in the energy sector for centralized systems.

Outside the cities, dedicated measures are needed to address the pressing issue of heating using low-efficiency biomass in rural areas, in homes with low energy performance. Considering the prohibition of condensing plants and natural gas boilers from 2040, technologies that use electricity, the realization of efficient collective/centralized heating-cooling systems, or the more efficient use of sustainable biomass sources should be considered in particular, in accordance with the latest provisions of the Renewable Energy Directive.

It is estimated that the use of heat pumps and solar thermal energy will increase significantly by 2035, making a substantial contribution to meeting the demand for district heating energy. Also, the share of central heating systems based on biofuels will experience limited growth. These trends reflect the shift towards more sustainable renewable sources of heat energy production in the centralized system (See Figure 3-31).

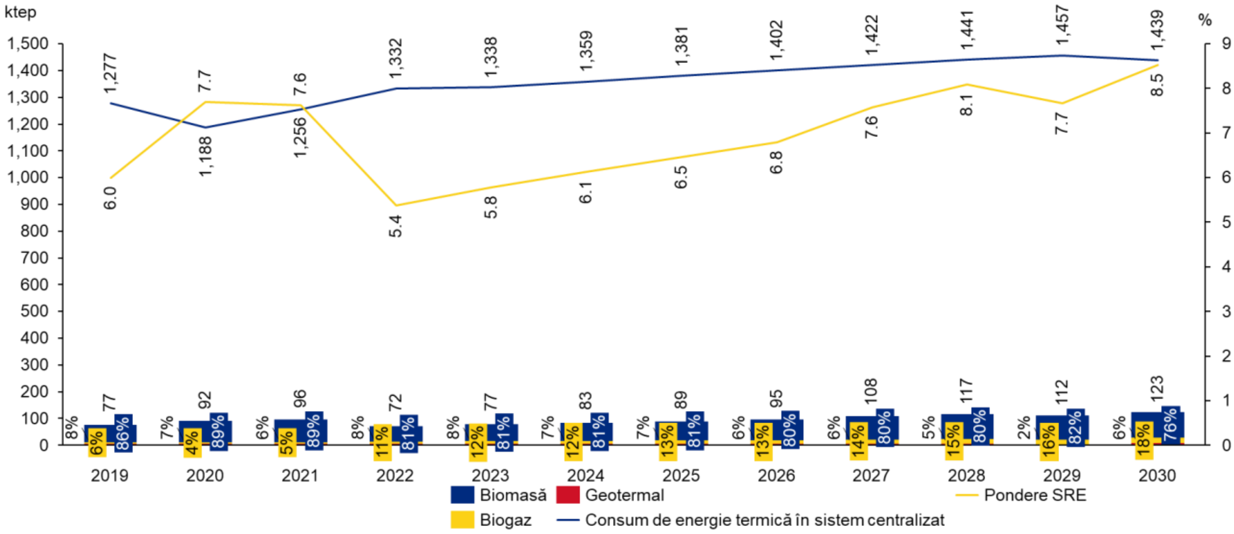


Figure 3-31: Estimated trajectory of RES share in district heating systems

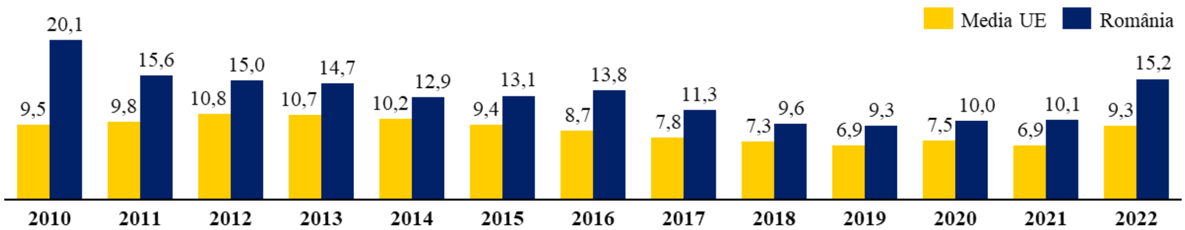


Figure 3-32: Inability to heat the household at an adequate level, % of households, 2010-2022. Source [71]

Heating subsidies for vulnerable consumers are for four types of heating systems (thermal energy in a centralized system; natural gas; electricity; solid and/or oil fuels). After a constant reduction until 2020 in the number of beneficiaries and the volume of funds, the trend reversed in 2021, mainly due to the fact that Law no. 226/2021 applied from November 1, 2021, the date from which GEO no. 70/ 2011 on social protection measures in the cold season was repealed.

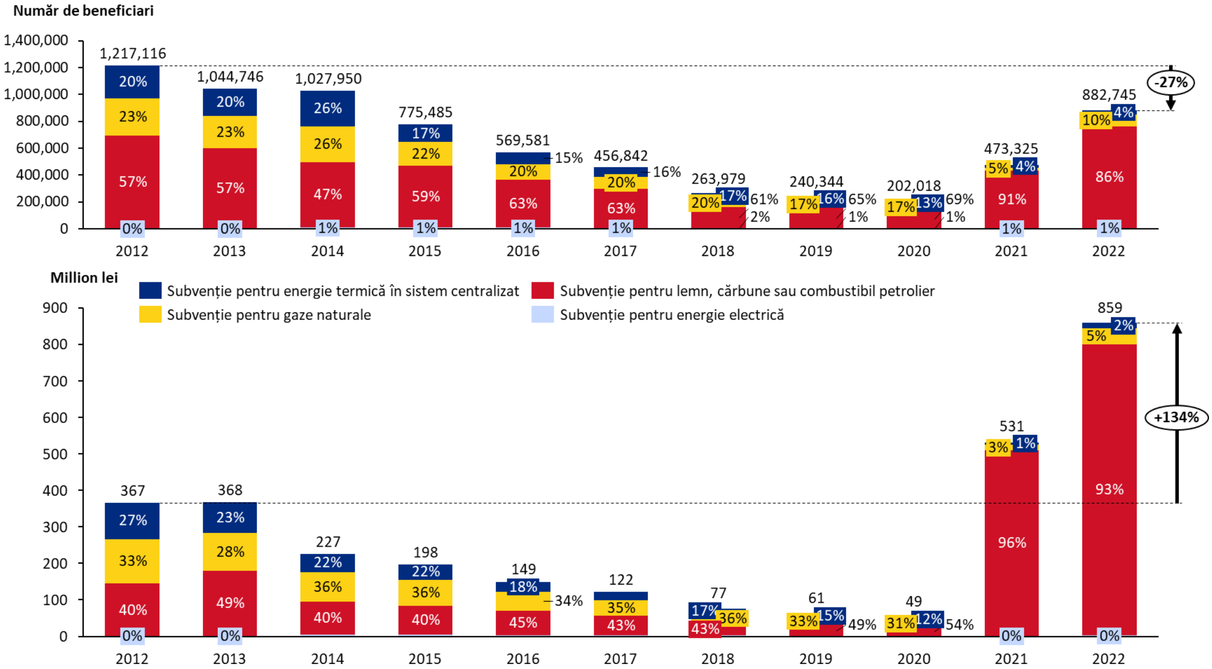


Figure 3-33: The number of beneficiaries and the funds received as aid for home heating

The price of thermal energy is regulated at national level. According to the data provided by CMTEB, the prices applied in 2024 are shown in Table 3-4

Table 3-4 Prices for thermal energy

	Prețuri / tarife până la 31.01.2024 [lei/MWh] fără TVA	Prețuri / tarife aprobate cu 01.02.2024 [lei/MWh] fără TVA
Tarif transport	256,86	216,68
Tarif distribuție și furnizare	178,67	213,81
TOTAL termoficare	435,53	430,49
Preț de producere și distribuție CT de cvartal	511,90	756,60
Preț de producere și distribuție CT de cvartal consumatori casnici 01.02.2024 – 31.03.2024	511,90	635,51
Preț de producere CTZ Casa Presei	331,70	472,71
Preț de producere CTZ Casa Presei consumatori casnici 01.02.2024 – 31.03.2024	331,70	374,33
Prețul pentru activitatea de producere, în capacitățile modulare închiriate, instalate în incinta CET TITAN	535,31	410,98
Prețul pentru activitatea de producere, în capacitățile modulare închiriate, instalate în incinta CET TITAN consumatori casnici 01.02.2024 – 31.03.2024	535,31	364,26
Preț consumatori non-casnici alimentați din PT urbane și Centrale Termice	916,79	898,89
Preț consumatori non-casnici alimentați din PT proprii	787,27	698,08
Preț populație	283,75	283,75

4. System development opportunities in SET_HEAT countries

This section explores opportunities for district heating expansion in the four SET_HEAT countries based on potentials developed in the Seenergies project. The potentials are preceded by a country overview made with a focus on overall energy demands and heating sector usage.

The Seenergies project take a starting point in energy efficiency. *"Efficiency First is the fundamental principle around which the EU's energy system should be designed. It means considering the potential value of investing in efficiency (including energy savings and demand response) in all decisions about energy system development – be that in homes, offices, industry or mobility."*[25] These are the words from European Climate Foundation, which describes the overall idea for making the sEEnergies project. The primary goal of sEEnergies is to identify and implement the potential for energy efficiency in buildings, transport, and industry. This is achieved by combining detailed, sector-specific data with temporal and spatial analyses to create an innovative and comprehensive energy efficiency modelling approach. Since changes in one energy sector can affect others, a thorough evaluation of energy efficiency policy impacts requires a holistic view that considers the interactions between different sectors. The sectors looked at in sEEnergies, were buildings, transport, industry & Energy grids. [25]

This new modelling approach integrates detailed sector analysis, grid assessment, energy system modelling, and spatial analytics. The energy efficiency approaches have been made for EU, it was found out that there were possibilities effectives and therefore lower the demands in the building, transport, industry & Energy grid sectors. [25]

For the context of the SET_HEAT project, the Seenergies project provides a good basis for comparing energy systems across the European Union on a consistent basis, as the approach applied in the different places was the same, the identifications of resources and possibilities were similar and since the same modelling approach was used.

For all countries, scenarios were developed using the EnergyPLAN model [72], which is a systems analysis model operating with a temporal resolution of 1h. It was originally designed to analyse the integration between fluctuating RES and CHP-based district heating systems and has been used for this extensively both in the scientific journal literature and for research projects. A review in 2022 listed more than 300 applications in the scientific journal literature[73]. The model is a simulation model (as opposed to an optimisation model) meaning that while operation is indeed optimised, system design is not optimised endogenously, but rather through user engagement [74].

4.1 Opportunities in Poland

4.1.1 Poland's current energy system

Poland is a country, relying heavily on coal, which account for 42% of its total energy consumption in 2022 (See Figure 4-1). Coal is primary used in the generation of power and heavy industry. Coal also plays a crucial role in specific industrial processes like steelmaking. However, the combustion of coal results in substantial emissions of CO_2. This is followed by oil, which has the second largest share in Poland and accounts for 30%. Oil is mainly used to power cars, lorries, and ships. Then comes natural gas, which is used in power plants and for individual households. Last is the biofuels, accounting for 11% and these are used in all aspects of the energy sector [75].

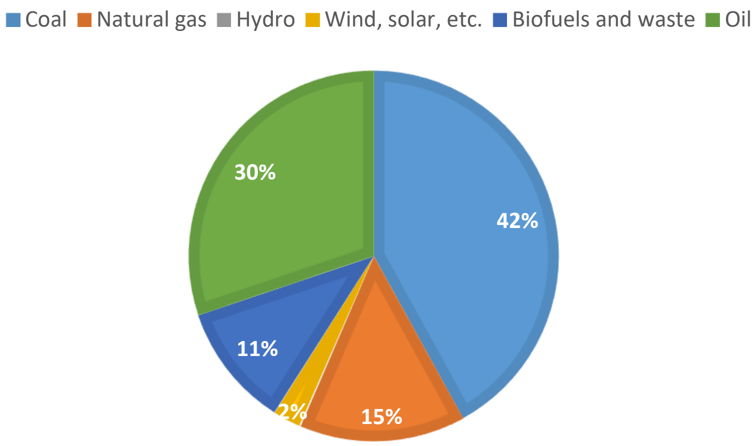


Figure 4-1: The total energy supply for Poland in 2022. Based on data from [75]

In 2022, the total energy consumption in Poland was 4,408 PJ (105.3 Mtoe) or 117 GJ per capita (2.8 toe) and the CO_2 emissions were on 7.94 t per capita[76].

4.1.2 Heating in Poland and goals

Poland relies heavily on fossil fuels for heating houses and for domestic hot water preparation, as the country's primary heating source for housing, is coal. In 2022, 46% of the heating came from individual coal boilers or stoves, 28% from municipal or local district heating systems, 22% from individual gas/oil/electric heating and the rest from other sources. The 28 % district heating share is also almost exclusively fossil based as is the share heated using electricity [77].

On the 2nd of February 2021 the Council of Ministers in Poland, enrolled the Energy policy lasting until 2040[78]. The goal specifically for the heating sector is, to have all households covered by district heating and by zero or low emission sources by 2030.

4.1.3 Possibilities and opportunities

Based on the Seenergies project, Poland has the possibility of reaching a 100% renewable energy transition by 2050, although it will require significant changes. By following the *Energy Efficiency First Principle* from Seenergies, Poland can reduce its final energy demand cost-effectively by 35% from the original 2050 baseline scenario, and combined with supply-side changes, a renewable energy- based system can be developed [78].

The transition requires adjustments in the electricity and heating sector, where the electricity sector will undergo a transition to being primarily based on RES [79]. The total heat demand in the residential and service building sector can be effectively reduced by 48%, with a cost of 64 billion EUR by 2050. Thus, the total heat demand can decrease to 142 TWh. Excess heat from industry in Poland has the potential to supply over 77% of the district heating [79].

The Polish housing sector is poorly insulated, as around 40% of the current building are constructed before 1970. The of lack insulation, usage of outdated heating systems, and inefficient windows, leads to significant energy losses[80]. The heat supply for 2015 and proposed distribution of technologies Seenergies for 2050 can be seen in Figure 4-2.

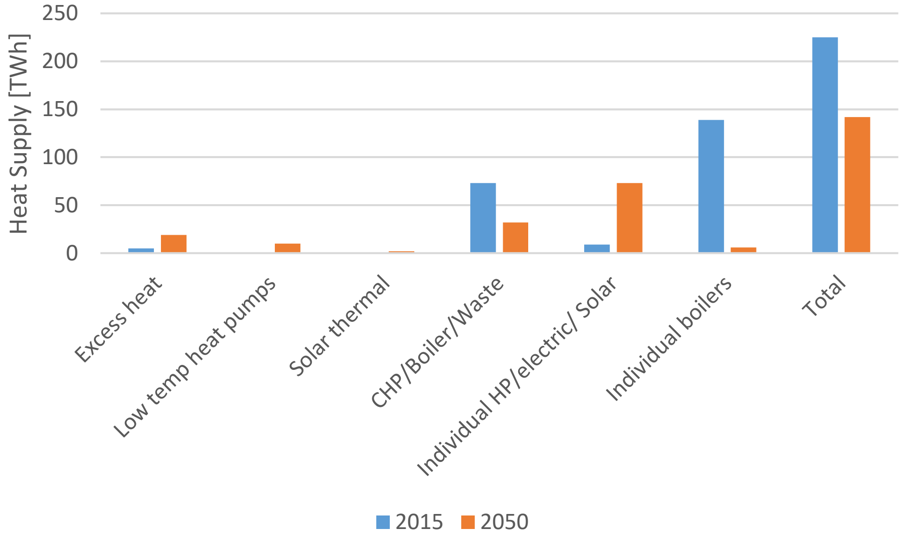


Figure 4-2: Heat supply for buildings in Poland for 2015 and proposal for 2050. Based on data from [79].

For 2050, it is notable that the demand can decrease, that individual boilers should be almost phased out for district heating and individual heat pumps.

4.2 Opportunities in Lithuania

4.2.1 Lithuania's current energy system

Oil dominates the Lithuanian energy supply market, accounting for almost half it, with 46% in 2022 (See Figure 4-3). Lithuania is heavily reliant on the import of oil, as nearly 100% of it is imported. Transport accounts for 84% of the oil usage in the country, and thus is the biggest consumer. Around 8% is used for electricity generation. Biofuels are the second largest energy source in Lithuania, and accounts for around 26% of the total energy supply. This is mainly used in the residential sector. Biofuels account for 97% of the heat supply produced. For electricity, this sector accounts for around 10% of the biofuels. Natural gas has the third biggest share and is entirely imported from other countries. Around 80% of it is used for heating as well as cooking. Around 10% is used for electricity. Coal is not a dominant energy source in Lithuania and is almost entirely used directly in the high-heat and industrial processes, such as steel making. Hydro, wind and solar has the smallest share in the total energy supply, but accounts for nearly 60% of the total electricity production (Data from [81].

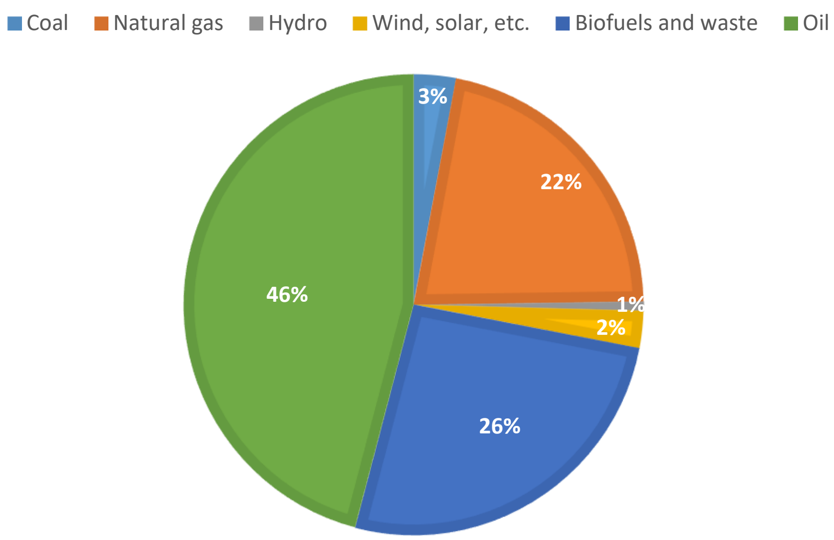


Figure 4-3: The total energy supply for Lithuania in 2022. Based on data from [81]

In 2022, the total energy consumption in Lithuania was 284.2 PJ (6.8 Mtoe) or 100 GJ per capita (2.4 toe) and the CO_2 emissions were at 4.11 t per capita [82].

4.2.2 Heating in Lithuania and goals

In 2021, around 68% of the energy consumption went for space heating and around 12% for hot water. The remaining energy was used for lighting, electric appliances, and cooking [80].

The total heat demand in Lithuania was 28 TWh in 2015. 21 TWh is accounted by individual heating and 7 TWh from district heating [83].

The national energy and climate action plan of the republic of Lithuania for 2021-2030, establishes targets for Lithuania at both national and EU levels, aiming to align with the overall EU energy and climate change targets for 2030 [84].

The strategic goal in the heating sector is to achieve consistent and balanced renovation (*optimisation*) of centralised district heating supply systems. This goal aims to ensure effective heating consumption, reliable, economically attractive (*competitive*) supply and generation, and provide a possibility for installation of state-of-the-art and green technologies, using local and renewable energy resources. Additionally, this goal ensures flexibility of the system and a favourable investment climate [85].

4.2.3 Possibilities and Opportunities

Lithuania has the possibility of reaching a 100% renewable energy transition by 2050. By following the suggestions from the Seenergies project, Lithuania can reduce its final energy demand cost-effectively by 42% from the original 2050 baseline scenario [83].

The transition requires adjustments in the electricity and heating sector. The total heat demand in the residential and service building sector can be effectively reduced by 66%, with a cost of 13 billion euros by 2050. Thus, the total heat demand will drop to 10 TWh. Excess heat from industry has the potential to supply over 50% of the district heating [83].

The Lithuanian housing sector is poorly insulated, as nearly 60% of the current building are constructed before 1970, resulting in houses with bad insulation [80].

The heat supply for buildings in Lithuania 2015 and 2050 can be seen in Figure 4-4

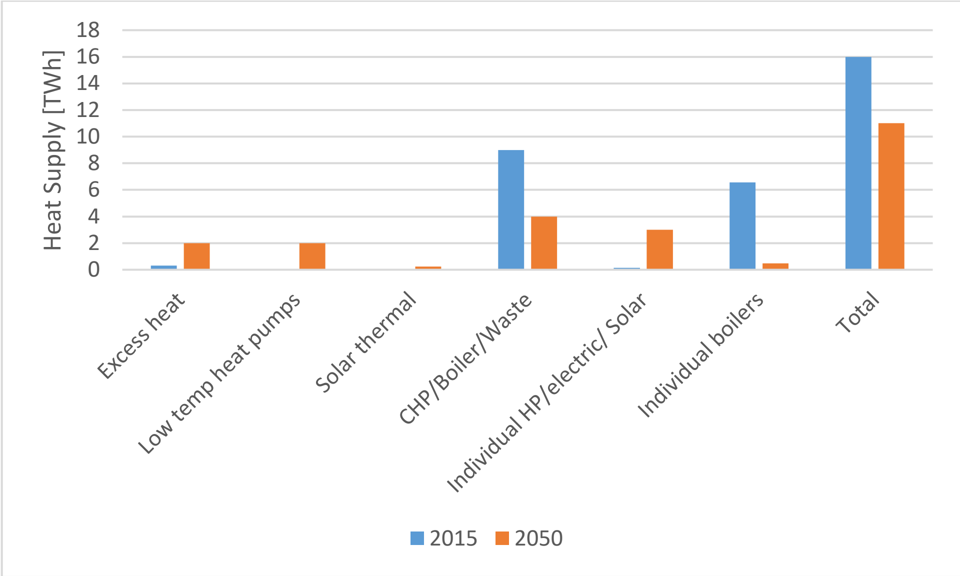


Figure 4-4: Heat supply for Lithuanian buildings for 2015 and potentials for 2050. Based on data from [83]

Again, in line with the other SET_HEAT countries, important potentials for decreases in heating demands are identified as is the nearly complete phase out of individual boilers, while individual houses switch to individual heat pumps or district heating based on various sources.

4.3 Opportunities in Croatia

4.3.1 Croatia's current energy system

Oil has the biggest share of the total energy supply in Croatia, accounting for 35% in 2021 (See Figure 4-5). Croatia imports around 75% of their oil use, while the remaining 25% is produced within the country. Oil is mainly used in the transport sector, accounting for 74% of the total oil usage, while the remaining is used in lesser extend in the electricity and heat generation sector. This is followed by Natural gas, which has the second largest share of the total energy supply, accounting for 30%. Croatia imports around 76% of their gas, while the remaining 24% is produced within the country. Natural gas is mostly used for heating and cooking, as well as industrial processes. Around 20% is used in the electricity sector. Biofuels are also used in all aspects of the energy sector and accounts for 20% of the total final energy demand. 86% is used for residential purposes, by generating heat and electricity. Hydro has the second largest renewable energy share, followed by wind and solar. These sources are primary used in the electricity sector, accounting for 60% of all the electricity generation. At last, comes coal, which has a share of just 5% of the total energy supply. All coal in Croatia is imported. 98% of the coal is used in the industry sector. (Data from [86])

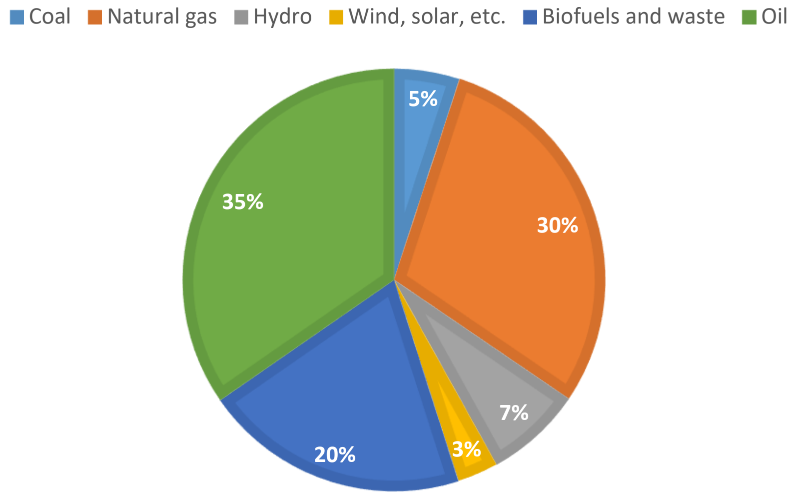


Figure 4-5: The total energy supply for Croatia in 2021. Based on data from[86]

In 2022, the total energy consumption in Croatia was 454.6 PJ (8.5 MTOE) or 92 GJ per capital (2.2 toe) and the $C0_2$ emissions were at 4.14 t per capita [87].

4.3.2 Heating in Croatia and goals

The primary energy source for heating in Croatia is natural gas. It is widely used for residential, commercial, and industrial heating purposes. Additionally, in rural areas, traditional solid fuels such as wood and biomass are commonly used for heating. However, natural gas remains the most prevalent energy source for heating in Croatia [88].

The total heat demand in the residential and service building was 27 TWh in 2015. 25 TWh is accounted by individual heating and 2 TWh from district heating [89].

Croatia has a goal national energy goal, called 2030 National Energy and Climate Plan[90]. Croatia wants to reduce its CO_2 emissions by 45% by 2030. The goal includes to increase the share of renewable energy, expand the district heating network and implement measures to implement energy efficiency [90].

4.3.3 Possibilities and opportunities

Croatia has the possibility of reaching a 100% renewable energy transition by 2050. By following the scenario developed in the Seenergies project, Croatia can reduce its final energy demand cost-effectively by 38% from the original 2050 baseline scenario. The transition requires adjustments in the electricity and heating sector, but here we focus on the opportunities for the heating sector based on Seenergies [89].

The total heat demand in the residential and service building sector can be effectively reduced by 70%, with a cost of 3 billion EUR by 2050. Thus, the total heat demand can decrease to 8 TWh. Excess heat from industry has the potential to supply over 42% of the Croatian district heating demand [89].

The Croatian housing sector is poorly insulated, as just under 40% of the current building are constructed before 1970, having poorer insulated houses [80].

The heat supply for buildings in 2015 and the proposed distribution of technologies Seenergies for 2050 can be seen in Figure 4-6.

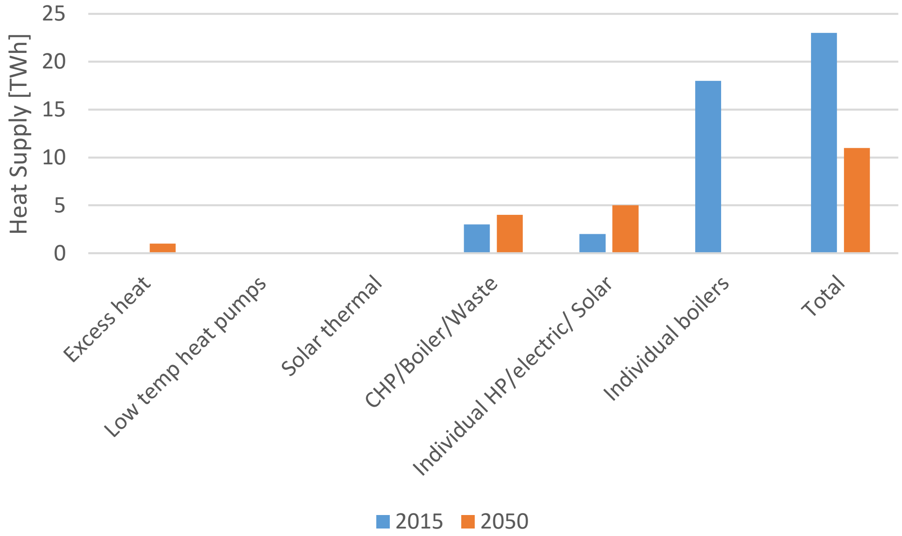


Figure 4-6: Heat supply for buildings in Croatia for 2015 and proposal for 2050. Based on data from [89].

For 2050, it is notable that the demand can decrease, and that individual boilers should be completely phased out for district heating and individual heat pumps.

4.4 Opportunities in Romania

4.4.1 Romania's current energy system

Oil is the biggest sector in the total energy supply, accounting for 31% in 2021 (See Figure 4-7). Around 70% of the oil is imported and the remaining is produced domestically. 70% of it, is used in the transport sector, while around 12% is used in the industry sector. Natural gas has the second largest share of the total energy supply, accounting for 29%. 75% of it is domestically produced. Around half of it is used in the residential sector, with heat and electricity accounting for the share. 35% is used in the industry sector. Biofuels account for 13% of the total energy supply and are mainly used in the residential sector for heat and electricity generation. Coal accounts for 12% of the total energy supply and is mainly used in the industry sector in Romania, accounting for around 90% of the usage. The coal used is mainly produced within Romania, with around 75%, while the remaining 25% is imported. Hydro, wind, and solar are explicitly used to generate electricity in Romania (all data from [91].

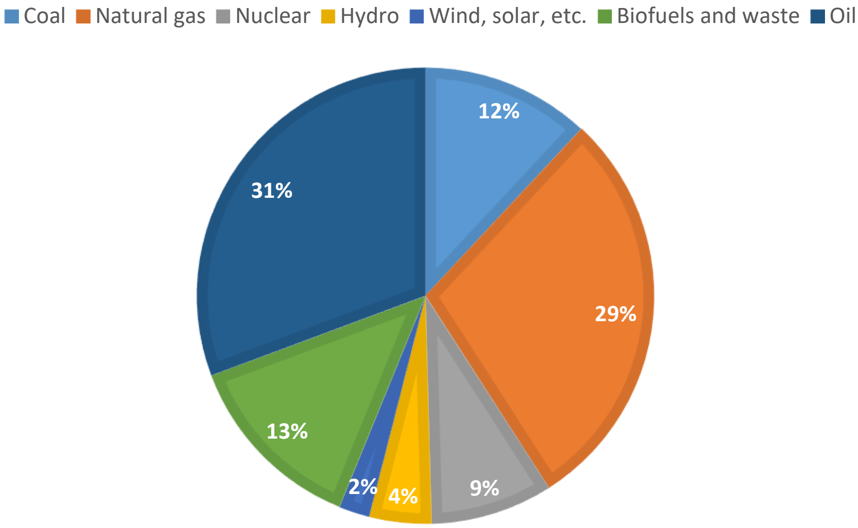


Figure 4-7: The total energy supply for Romania in 2021. Based on data from [91]

In 2022, the total energy consumption in Romania was 1352.3 PJ (32.3 MTOE) or 71 GJ/capita (1.7 toe) and the CO_2 emissions were 3.52 t per capita [92].

4.4.2 Heating in Romania and goals

The primary energy source for heating in Romania is natural gas. It is widely used for residential, commercial, and industrial heating purposes. Additionally, in rural areas, traditional solid fuels such as wood and biomass are commonly used for heating. However, natural gas remains the most prevalent energy source for heating in Romania.

The total heat demand in Romania was 71 TWh in 2015. 60 TWh is accounted by individual heating and 11 TWh from district heating [93].

Romania's heating goal is set in the 2021-2030 Integrated National Energy and Climate Plan[94]. The goals include increasing the share of renewable energy in their overall energy sector, making policies which support this action and assuring better energy efficiency.

4.4.3 Possibilities and Opportunities

Romania has the possibility of reaching a 100% renewable energy transition by 2050. By following the Seenergies project, Romania can reduce its final energy demand cost-effectively by 43% from the original 2050 baseline scenario.

The transition requires adjustments in the electricity and heating sector.
The total heat demand in the residential and service building sector can be effectively reduced by 44%, with a cost of 30 billion EUR by 2050. Thus, the total heat demand can decrease to 40 TWh [93].

Excess heat from industry has the potential to supply over 44% of the district heating demand in Romania, if following the recommendations from Seenergies [93].

The Romanian housing sector is poorly insulated, as nearly 50% of the current building are constructed before 1970, resulting in houses with bad insulation [80].

The heat supply for buildings in 2015 and proposal from Seenergies for 2050 can be seen in Figure 4-8.

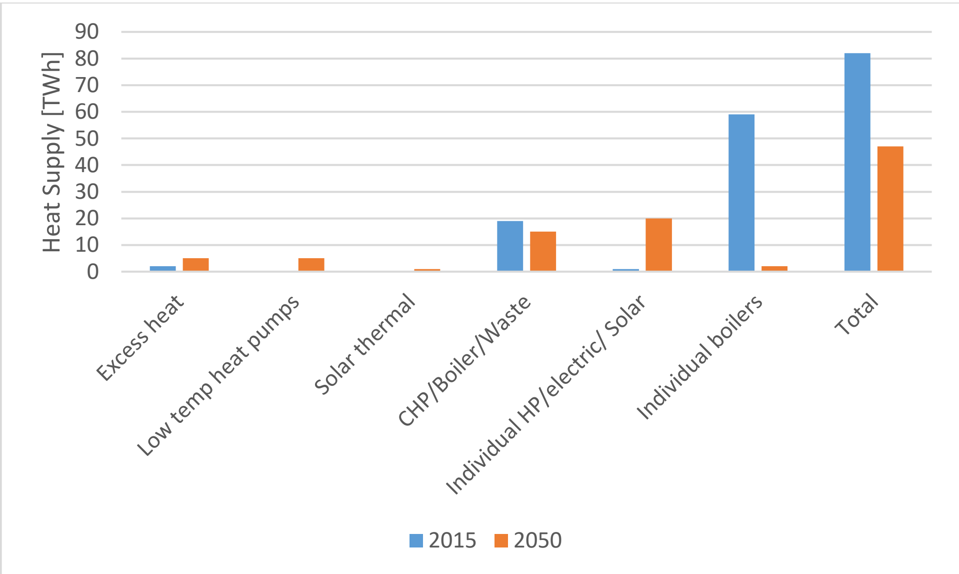


Figure 4-8: Heat supply for buildings in Romania for 2015 and proposal for 2050. Based on data from [93]

Again, in line with Poland and Croatia, significant potentials for decreases in heating demands are identified as is the nearly complete phase-out of individual boilers, while individual houses switch to individual heat pumps or district heating based on various sources.

5. Plans and developments in district heating technology stock in SET_HEAT countries

The main driver in this section is to seek which technologies are actively being considered – possibly even implemented – in the different SET_HEAT countries. The section will also focus on what affects decision-making and how decision-making is performed. The work is based on inputs from district heating companies in the four SET_HEAT countries, though the detail of the information from different varies as not all information is available for all places.

In general, the information provided aligns with this template

- Which technologies are in the process of being phased out
- Which technologies are in the process of being phased in
- How does the decision-making take place (e.g. based on business economic feasibility, technical integration with present system, Strategic development in generating stock, Environmental performance. Discount rate and time horizon. Rigorous systems analyses or not. Internal DH company capacity to assess DH options
- Drivers – what drives the (if any) changes in generating stock (e.g. Replacement of old technology beyond its technical/economic lifetime, Environmental concerns, Customer demand, or other factors)

Regarding technologies being considered – or actually being phased in, these can be from a range of technologies including various types of CHP (gas engines, gas turbines, steam turbines) run on a variety of fuels), power-to- heat technologies (both electric boilers and heat pumps utilising various ambient heat sources as low-temperature reservoir), solar collectors, was heat from power-to-x or industrial/commercial applications, geothermal energy and more. It is also relevant observing if district heating companies invest in renewable power production (wind, PV) for use with e.g. heat pumps. Lastly, heat storage is very relevant either in the short term for diurnal optimisation and for ensuring load-following capability of the energy system in general – as well as for long-term storage enabling storing e.g. solar heat of waste heat resources from periods or high availability to periods of high demand.

5.1 Initiatives regarding technology stock in Poland

The DH sector in Poland is basing on fossil fuels, mainly coal. The expected transformation of the DH sector is progressing very slowly. The main transition trend in Poland and other Eastern EU member states since around 2002 has been a shift from coal to natural gas, and from heat-only boilers to cogeneration. Decarbonization potential of district heating is largely untapped, and the gap between aspiration and reality in tackling climate change remains significant. It should also be stated, that the scale of the DH system correlates with its effectiveness. The majority of DH systems in Poland remain inefficient both in a thermodynamic sense and in terms of legal requirements included in Energy Efficiency Directive – see Figure 5-1.

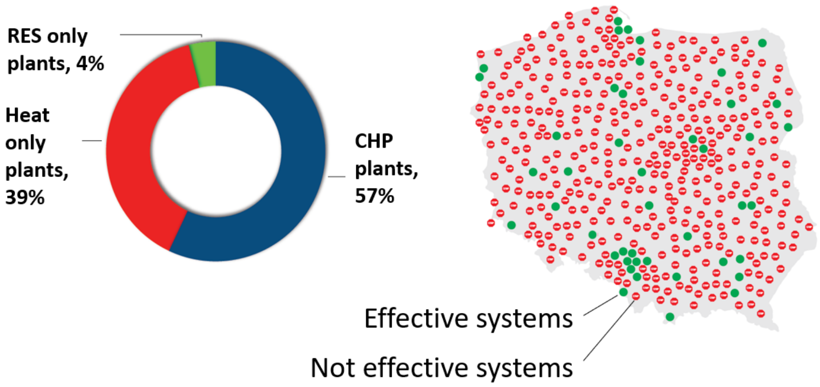


Figure 5-1: Fuel and effectiveness composition of district heating systems in Poland. The dots are based on the EU EED directive and thus based on technologies or fuel types. Effective systems have 75% CHP or 50% RES/CHP/Waste heat.

Regarding technology, the Polish district heating sector currently includes a large number of coal-fired units:

- grate boilers (stoker-fired boilers), which make up the majority in system heat sources,
- pulverized fuel boilers – only for larger capacity systems.

At present, the first natural stage of technological transformation is the gradual replacement of these units with gas-fired ones (both gas-fired steam or hot water boilers and high-efficiency gas-fired CHP systems). Gas CHP units that are more than 15-20 years old are also gradually being replaced either by new units or their legitimacy is fading due to the possibility of introducing new alternative sources, mainly waste heat.

The units under consideration for being phased in are natural gas-based and include:

1) Gas engine CHP
2) Single-cycle gas turbine CHP
3) Combined cycle gas turbine CHP
4) Organic Rankine Cycle plant fed with biomass and wastes

There are also other than natural gas-based technology being phased in. However, there are barely a few installations of such type under operation. The process of its application is just beginning, with a large number of such projects only in the concept stage. Such technologies are:

1) Boilers on biomass
2) Boilers on biogas
3) Electric boilers
4) Electric heat pumps (air, ground, surface water)
5) Solar collectors (thermal)
6) Waste heat from third parties
7) Geothermal energy (possibly with compression or absorption heat pump)
8) Heat storage (load shifting within a day or so)
9) Large-scale heat storage (load shifting from several days to seasonal)

The main transformation decisions are based solely on economic criteria, which is a factor inhibiting costly transformation processes. Replacement of classic coal technologies, with new technologies, usually with low thermal densities, requires large CAPEX. In addition, a major challenge is to invest in low-temperature technologies due to the high-temperature nature of most systems in Poland. In the first stage of the investment project, the decision-making process takes into account the following criteria:

- Technical constraints on integration with the current system (grid temperatures, available pressure),
- The results of system analyses of hydraulic considerations related to, for example, connection of external heat sources,
- Environmental performance (CO_2 emission savings)

Once the technical criteria are met, the profitability of a given project is analysed, after assumptions are made regarding the discount rate and time horizon. The value of the discount rate assumed for analysis is between 6 and 10%, and the time horizon is between 15 and 25 years.

An important investment criterion is the existing support mechanisms, both at the investment level (subsidies and preferential loans) and at the operational level (guaranteed premium in cogeneration, auctions for electricity produced in high-efficiency cogeneration, or from RES). Within the decision-making process, the heat price for the consumers is calculated and considered.

Driving the decision-making are the following drivers, which have been identified for implanting changes in the generating stock:

1) legal requirements imposed on DH companies with regards to meeting the criteria of efficient district heating system according to effectiveness criteria in EED Directive (EU/2023/1791),

2) legal requirements to building owners in order to boost the energy performance of buildings, according to the revised Energy Performance of Buildings Directive (EU/2024/1275) One of the solutions for increasing the rate of renovation of the building, particularly for the worst-performing buildings, defined in this directive is delivering heat from effective DH system.
3) increasing demand for green heat (both renewable and waste/excess heat) indicated by the heat consumers connected to DH systems and not yet connected (particularly industrial consumers expected to lower the carbon footprint of products),
4) expectation of organization's participation in local communities (CSR) and introduction of ESG reporting requirements in this regard,
5) free allowances for CO_2 emission available in form of additional funds for investment projects of changes in generating stocks
6) increasing prices of CO_2 allowances,
7) low or negative electricity prices available for power-to-heat technologies.

According to the data collected from questionnaires in the Appendix there are the following key threats to the implementation of new energy-efficient technologies:

1) lack of adequate transposition of EU directives into national law,
2) inconsistency of national law,
3) lack of appropriate system solutions (legal regulations), which are crucial from the economic point of view of conducting the business of supplying heat to consumers, e.g.:
   - lack of possibility to apply dynamic tariffs,
   - regulated heat prices for generation,
   - fixed heat prices during the tariff period,
   - lack of possibility to generate profit on heat trading,
   - no regulation dedicated to cost sharing in case of cogeneration (CHP).

5.2 Initiatives regarding technology stock in Lithuania

The DH sector in Lithuania accounts for more than 50% of the total heat market, with a higher proportion in urban areas, where district heating and hot water supply is about 70-80% of buildings. The remainder are individual consumers, mainly using natural gas or solid fuel boilers. In Lithuania, the connection to DH systems is also encouraged by the new amendments to the Technical Regulation for Construction, according to which district heating has been recognised as energy efficient and environmentally friendly, and is even suitable for A++ class buildings, as most of the heat is produced from renewable sources. Property developers rate it as the safest and most reliable of all heating methods, and the best value for money [95].

It should be noted that in many Lithuania's cities, DH systems supply heat produced exclusively from renewable sources. In 2022, 73.1% of heat was produced from RES, or almost 6% more than the year before. 7.1% of heat was generated from remaining municipal waste. The share of natural gas in the fuel mix fell to a record low of 14.6%, but the use of fuel oil increased slightly from 1.2% to 3.6% [7].

In Lithuania, as in other countries with large forest cover (Scandinavian countries, Latvia, Estonia, etc.), biofuel production is mainly based on biofuel feedstocks (logging residues, wood processing residues, firewood, etc.) from own forests [95].

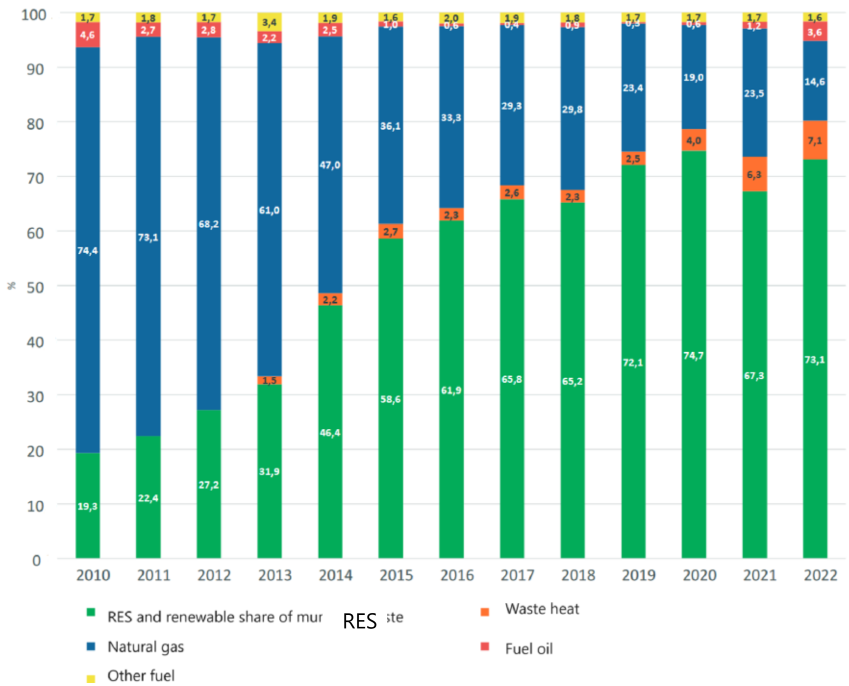


Figure 5-2: Structure of primary fuels in the Lithuanian DH sector [7]

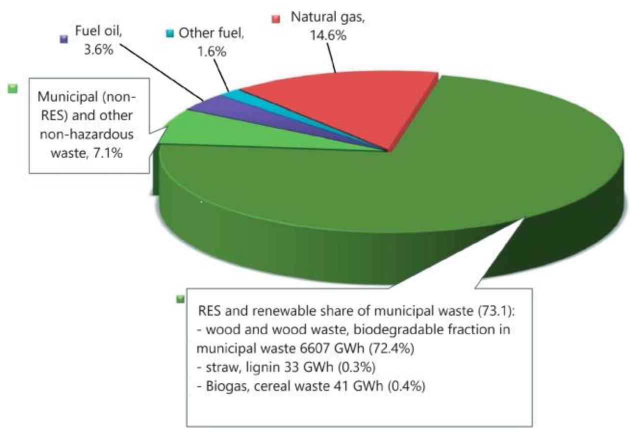


Figure 5-3: Primary fuel structure in DH [7]

The National Energy Independence Strategy aims to increase the share of RES in the DH sector to 90% by 2030 and to 100% by 2050. New requirements for biofuels used in boiler and power plants with a capacity of 20 MW and for installations participating in the Emissions Trading Scheme came into force on 1 May 2023. Biofuels must be sustainable and use as little fossil fuel as possible for their production and transport. This must be confirmed by sustainability certificates accompanying the biofuel [7].

In 2022, CHP plants accounted for around 31% of all heat supplied to DH systems, of which 13% was produced by power plants operated by heat supply companies and 18% by independent heat producers. In 2022, there were 19 bio-CHP plants in operation in the DH sector, with a total installed capacity of 145 MW of electricity generation (compared to 68 MW in 2013) and 497 MW of heat generation [7].

From 2030, there will be no more waste pollution permits. The gradual decrease in waste pollution permits requires companies to invest in technologies that reduce emissions. The increased use of biofuels and local resources also increases the amount of ash produced. In 2022, almost half of the ash produced (47%) was used for road construction (compared to only 18% the year before), 37% was given to waste management, 10% was simply disposed of in landfills, 5% was used for agriculture and a small proportion (1%) was used for forest fertiliser. As we move towards a circular economy, we should create the conditions and find ways to increase the use of bio-ash in green concrete, road construction, and forest fertilisation [7].

Consideration of technologies being phased out or phased in in Lithuania

The Lithuanian government, ministries, and other responsible institutions set forth a series of strategic documents (National Energy Independence Strategy [96], National Air Pollution Reduction Plan, Project of National Integrated Energy and Climate Change Plan) in 2018 to promote the development of DH systems and support existing and new consumers.

Lithuania's main objective in the field of the heat sector is decarbonisation and consistent and balanced renewal (optimisation) of DH supply systems, ensuring efficient heat consumption, reliable, economically attractive (competitive) supply and production, enabling the introduction of modern and environmentally friendly technologies using local and renewable energy resources, ensuring system flexibility and a favourable environment for investment. Following good practices in EU countries, Lithuania will promote the transition to fourth-generation (4G) district heating by integrating solar power plants into district heating networks and encouraging the use of surplus and waste heat for heating buildings.

To increase the use of RES for heat and cooling in the DH sector, €75 million is foreseen to be invested from the EU funds investment programme for 2021-2027. These investments

are earmarked for the development of new low-capacity RES technologies (e.g. biofuel boilers, biofuel cogeneration plants), modernisation of existing RES technologies, the replacement of worn-out biofuel boilers with other RES technologies, with priority given to the installation of RES-fired CHP plants and high-efficiency biofuel boilers with heat pumps or storage tanks, adapted to combusting logging residues (SM3-quality biofuel), and the promotion of the use of residual heat [97].
Therefore, such technologies are emerging, being developed and deployed in the Lithuanian DH sector [98]:

- Absorption heat pumps for deep flue gas heat recovery;
- Heat storage tanks;
- ORC-type power plant (e.g. in Panevėžys);
- Increasing the number of automated wood chip boiler plants.

EU 2021-2027 funding for such technologies is being secured accordingly:

- Waste heat recovery solutions in DH systems;
- Low-temperature network installation;
- Heat pumps (absorption/compressor);
- Installation of solar collectors in DH systems (for heat production);
- Construction of small-scale biofuel cogeneration plants;
- Installation of high-efficiency biofuel boilers in DH systems;
- Heat input metering devices with remote data reading equipment.

Promoting high-efficiency biofuel cogeneration is one of the key objectives of the National Energy and Climate Action Plan 2021-2030. The reconstruction and construction of cogeneration plants are important to achieve the national energy targets for 2030. In the DH sector, 90% of the heat would be generated from RES and at least 70% of the country's electricity consumption [95].

Below are details of changes foreseen in Vilnius through the First concept of the programme for the modification of the Vilnius city DH special plan

Small heat generation sources, such as small districts, individual, and container-type boilers, use fossil fuels. As these are relatively small producers, only technologies that can ensure full automation are considered to minimise their operating costs.

Currently, there are only a few fully automated and environmentally sustainable technologies available on the market: heat pumps (1) and wood pellet-fired boilers (2). Compressor heat pumps are a relatively more expensive heat generation technology, requiring higher initial investments, but their extremely high level of automation and heat generation efficiency (COP values) under favourable conditions result in a low level of variable costs for heat generation. The main negative aspect of heat pump technology is that at the design outdoor temperatures, when the user's heat demand reaches its maximum value, the COP of the heat pump is at its worst, and it operates like a conventional electric heater.

On the contrary, a biofuel pellet boiler requires a significantly lower initial investment. Although its operation is sufficiently automated, it still requires periodic maintenance (e.g. to receive a new batch of fuel or to clean the ash). For these reasons, as well as the relatively high cost of the fuel, the variable costs of heat production for this technology increase.

It is assumed that where technically feasible, two different technologies operating simultaneously could be used to optimise heat production. Due to the non-uniformity of heat consumption, the design heat output is only achieved in very few cases. A heat source operating in base-case mode, with a capacity of around 60% of the installed capacity, can produce almost 90% of the total heat energy required. The installation of a heat pump with a capacity of 60 % of the heat source's capacity and a biofuel pellet boiler with a capacity of 60 % of the heat demand would result in a minimal overinvestment in plant capacity and would allow for diversification of the primary energy mix within the heat source itself.

In normal operation, the compressor heat pump is assumed to operate in base mode and produce all the heat required, but in the event of a sudden increase in the electricity price, or if environmental conditions reduce the COP to values where it is cheaper to produce heat from biofuel pellets, the priority of production would be shifted to the biofuel pellet boiler. This would not only ensure environmental sustainability, but also diversification of primary energy sources and, at the same time, high production reliability.

It is estimated that the implementation of this heat generation technology in all small boiler houses would produce up to 34.6 GWh/year of heat from heat pumps and about 3.5 GWh/year from biofuel pellets. The total CO_2 emissions would then be 4 162 tCO_2/year, or an emission factor for the heat produced of around 0.118 tCO_2/MWh.

The second concept of the programme for the modification of the Vilnius city DH special plan

It is assumed that technical barriers would not allow the implementation of the described technologies in all cases, and therefore it is likely that some consumers will only be able to install heat pumps, and at times of projected heat demand, when the heat pump is not able to produce efficiently, they will be able to produce the remaining heat in the existing way, using natural gas. It is provisionally estimated that about half of the heat demand will be produced by heat pump technology with biofuel pellets, while the remainder will be produced by combining heat pump technology with existing natural gas boilers. In this case, the CO_2 emissions from the small boilers are estimated to be around 4 583 tCO_2/year, corresponding to an emission factor for the heat produced of around 0.130 tCO_2/MWh.

Several key factors are driving the changes in production resources in the DH system in Lithuania: environmental policy and regulation, financial incentives and support from EU funds, political and economic context, improving energy efficiency, fluctuations in resource prices, technological progress, state of infrastructure and modernisation.

Environmental requirements and directives in force in Lithuania and the EU encourage a shift towards cleaner energy sources. This includes stricter requirements on emissions and CO_2 emissions, which encourage investment in renewable energy and biofuels. EU funding and support for green projects provide financial assistance for the transition to sustainable energy sources. This includes support for biofuel boiler plants, solar panel systems and other renewable technologies. Political decision-making and the economic situation in a country also influence the choice of energy sources. Political objectives such as energy independence and ensuring national energy security encourage the diversification of energy sources and an increase in the share of local production.

Additionally, Lithuania's energy policy is planned for two time horizons (2020-2030 and 2030-2050) and includes actions for energy security, competitiveness, environmental impact reduction, and innovation.
Decarbonisation: increasing environmental quality and the sustainability of the use of natural resources, climate change mitigation and climate resilience, boosting the consumption of renewables, promoting renewable and alternative fuels in the transport sector, intermodal mobility, and pollution reduction measures.
Energy efficiency: improving energy efficiency and the use of energy from RES in residential and public buildings.
Research, innovation and competitiveness: becoming a leader in energy technology innovation, including for exports in the Baltic Sea region.
Internal energy market: making Lithuania part of the EU single energy market by integrating the Lithuanian natural gas market and interconnecting the Lithuanian power system with the continental European power system in synchronous operation.
Just transition: reducing the energy poverty of the population.
Energy security: ensuring the adequacy of the Lithuanian electricity market and system, increasing the share of locally generated electricity, boosting security in the Baltic Sea region, and safely decommissioning the Ignalina nuclear power plant and disposing of radioactive waste (supported by EU funding).

Table 5-1 Lithuania's energy and climate targets [99]

NEIS targets	Current status	By 2020	By 2030	By 2050
Binding target for greenhouse gas emissions (from 2005 levels) in the non-ETS sectors	+7%	+15%	-9%	-95% (energy and transport)
Share of renewables in gross final energy consumption	25.47%	23% by 2030	45% RES-E: 45% RES-H: 90% RES-T: 15%	80% RES-E: 100% RES-H: 100% RES-T: 50%
National contribution for energy efficiency (in Mtoe)	PEC:* 7.6 FEC:* 6.5	PEC:* 6.5 FEC:* 4.3	PEC:* 5.4 FEC:* 4.5	Reduce primary and final energy intensity by 2.4 times (from 2017 levels)
Level of electricity interconnectivity	62%	79%	111%	NN
Share of research, development and innovation budget in GDP in % (non-energy specific)	0.94%	1.9%	NN	NN

* The definitions of primary energy consumption (PEC) and final energy consumption (FEC) are calculated according to the EU rules set under the EU Directives and do not follow IEA standards.
Note: RES = renewable energy sources. Mtoe = million tonnes of oil equivalent. E = electricity. H = heating. T = transport. NN = no value.

Technological advances and innovations are making it possible to use energy sources more efficiently. Modern heat distribution systems, renovation of heat networks and the introduction of smart technologies reduce energy losses and increase overall efficiency. Fluctuations in the price of fossil fuels, such as natural gas or fuel oil, also lead to changes in production resources. Rising fossil fuel prices can encourage a shift towards cheaper and more predictable renewable sources.

The state of the existing heat supply infrastructure and the need to modernise it are also driving resource developments. Upgrading old infrastructure is often a good opportunity to switch to more modern and sustainable technologies. New technologies such as biofuel cogeneration plants, heat pumps, and advanced solar energy systems allow for more efficient heat production and distribution. This encourages the replacement of older, less efficient installations with new ones.

In summary, changes in generation resources in the DH system in Lithuania are driven by a complex set of factors including environmental requirements, financial support, technological progress, price fluctuations, political decisions, and public pressure. These factors are driving a continuous shift towards more efficient and less polluting ways of producing energy.

There are several main threats to the deployment of new energy-efficient technologies in Lithuanian DH systems: high initial investment, technological risks, adaptation of technological infrastructure, regulatory constraints and policy changes, technological compatibility and integration, economic and market risk factors, and lack of expertise.

New technologies often require high initial investments. This can be financially challenging, especially for municipalities or smaller companies. New technologies may not have been sufficiently tested in real-life conditions, and therefore risk not working as efficiently as expected or being difficult to integrate into the existing system. New technologies must be compatible with existing systems. Technical problems may arise during integration, which may disrupt heat supply. Adapting the existing infrastructure to the new technology can be complex and costly. This includes both technical and logistical challenges. New technologies require skilled professionals, and a lack of skilled professionals can complicate deployment and operation processes.

The following threats (Table 2) to the implementation of new energy-efficient technologies can be stated as well as in Lithuania as in other partners of the project:

Table 5-2 Threats to the implementation of new energy-efficient technologies in Lithuania

Threat	Explanation
Lack of feasible demand response business models and regulatory frameworks	Utilities and customers need to better understand the benefits of demand response (DR) in order to adopt it more widely. The regulatory framework should be adjusted to allow for the development of new business models and DR tariffs to incentivize customers to provide flexibility to the energy system [100]
The persistent issue of dwindling human resources continues to be a major concern	In small towns and cities, companies are struggling to find enough skilled workers. In the future, there is a risk that the heating industry will not have the highly competent engineering staff it needs to manage processes, design equipment, and operate heat-using technologies [101].
Reluctancy to apply academic research results in real-life application	The lack of close cooperation with researchers and sharing of research results hinders the deployment of energy-efficient technologies. There are not enough guarantees for continuous and increased benefits that are mutually beneficial for all stakeholders, not just network operators or residents alone, but for both [100]).
Intermittent and inconsequent application of policies to support DR, RES, DHC	Upon closer examination of the individuals responsible for proposing measures to DR, RES, and district heating and cooling (DHC), it becomes evident that they comprise a distinct group of stakeholders. This group includes civil servants from relevant ministries, members of parliament, and representatives from a7 variety of political parties affiliated with the government [100]
Low penetration rate and period between planning and commissioning of DHC systems	The slow development of DHC in operation forms a threat to the further uptake of DR. Development of DHC systems at a higher pace will trigger more DR actions in the new DHC systems. Nowadays, it is possible to mobilize a large spectrum of RES and waste energy sources in DHC systems, but understanding and forecasting the key technical features of such sources and assessing their long-term compatibility with the DHC network and connected buildings is still needed to develop reliable, flexible and cost-efficient DHC systems. [100].
Lack of funding for energy efficiency technologies.	A successful transition to low-temperature heat supply requires the modernisation and automation of heat points (upgrading of heat exchangers, installation of heat pumps in some buildings, digitisation of processes) [102]

In view of these risks, it is important to carry out a thorough risk assessment and plan countermeasures to mitigate the potential negative consequences of the deployment of energy efficient technologies.

District heating in Vilnius

District heating in Vilnius is a centralized system that provides heating and hot water to homes and businesses through a network of insulated pipes. This system currently relies on a mix of heat generation technologies, including biomass boilers and CHP units, also waste incineration CHP, as well as natural gas boilers and CHPs. All the renewable heat generation units in the integrated Vilnius network:

Table 5-3 Heat producers in Vilnius (integrated network)

Eil. Nr.	Boiler brand and number	Year of installation	Year of last repair	Installed capacity MW	In the process of being phased out
1	Idex Zietela UAB			23,7	
2	Idex Paneriškių UAB			48,7	
3	UAB „Kirtimų katilinė			23,8	
4	Idex Pakalniškių UAB			25	
5	AB „Grigeo			10	
6	AB „Vilniaus baldai“			4,5	
7	VKJ waste incineration	2021		57	
8	VKJ biomass CHP	2023-2024		174	
9	UAB „Forest Investment“			48,7	
10	AB Vilniaus šilumos tinklai			68,5	
11	**Sum capacity**			**184,4**	

However, as part of the city's commitment to sustainability and reducing carbon emissions, there is an urgent need to transition to a fossil-free energy system.

To achieve this, Vilnius plans to phase out natural gas and other fossil fuel-based heat production, mainly natural gas boilers and CHP (see Table 5-4).

Table 5-4 List of heat generation facilities of VST

Nr.	Boiler brand and number	Year of installation	Year of last repair	Installed capacity, MW	In the process of being phased out
1	**E-2**			**1104,175**	
1.1	PTVM-100M Nr.1	1965	1999	130	+
1.2	PTVM-100 Nr.2	1966	1994	116	
1.3	PTVM-100 Nr.3	1967	1995	116	Already +
1.4	PTVM-100 Nr.4	1972	1995	116	
1.5	KVGM-100 Nr.5	1975	1996	116	+
1.6	KVGM-100 Nr.6	1976	1995	116	+
1.7	KVGM-100 Nr.7	1979	1995	116	
1.8	BKZ-75-39FB Nr.3	1955	1997	60	
1.9	BKZ-75-39FB Nr.4	1957	2006	60	
1.10	BKZ-75-39FB Nn.5	1957	1996	60	+
1.11	BKZ-75-39FB Nr.6	1958	1998	60	+
1.12	GK D1500 Nr.4 (KDE)	2006		19,375	
1.13	CEG-10000 (KDE)	2019		10,3	
1.14	AŠS	2024		8,5	
2	**RK-8**			**495,44**	
2.1	DKVR-20-13	1969	1996	15,12	+
2.2	DKVR-20-13	1970	1990	15,12	+
2.3	PTVM-50	1976	1999	58,15	
2.4	PTVM-50	1977	1987	58,15	+
2.5	KVGM-100	1979	1992	116,3	+
2.6	KVGM-100	1981	1985	116,3	+
2.7	KVGM-100	1984	1989	116,3	+
3	**RK-7**			**96,51**	
3.1	DKVR-10-13	1974		7,55	+
3.2	DKVR-10-13	1974		7,55	+
3.3	PTVM-30	1978	2007	40,705	+
3.4	PTVM-30	1975		40,705	+
4	**Total capacity**			**1696,1**	

The phase-out strategy includes enhancing the capacity of biomass-based systems and integrating a range of advanced renewable technologies. The plan involves incorporating waste heat recovery, renewable source heat pumps, air-water heat pumps, and thermal energy storage solutions like TTES (Tank Thermal Energy Storage) and PTES (Pit Thermal Energy Storage).

Additionally, electric boilers and waste heat from third parties will be utilized, alongside the deployment of biomass CHPs and heat-only boilers (HOBs). The city also aims to use waste heat absorption heat pumps and PV systems to generate electricity for power-to-heat applications. Biogas HOBs and innovative technologies such as Power-to-X (including hydrogen production) are also part of the transition strategy. By implementing these diverse and sustainable technologies, Vilnius aims to create a more resilient and environmentally friendly district heating network, significantly reducing its carbon footprint and promoting cleaner energy solutions.

The changes in Vilnius' district heating generating stock are driven by several key factors. These include the replacement of outdated technology that has exceeded its technical or economic lifespan, addressing environmental concerns, and meeting increasing customer demand for sustainable energy solutions. Legal requirements and funding opportunities also play a significant role, providing the necessary financial and regulatory support for the transition. Additionally, access to new unregulated income sources, such as electricity and frequency balancing markets, incentivizes the shift and heat generation electrification: more heat pumps and electric boilers. The drive for operational and maintenance cost reductions, along with overall cost savings, is another crucial motivator.

Improving the reliability of the heating system is also a significant driver, ensuring consistent and dependable service for residents. The environmental benefits of transitioning to cleaner technologies cannot be overstated, as they contribute to reducing carbon emissions and promoting a healthier ecosystem. Utilizing local fuels, such as biomass, not only supports the local economy but also reduces dependency on imported fossil fuels, further enhancing energy security. Positive public relations, the reduction of manual labour, and the future potential to sell acquired know-how further support the movement towards modern, efficient, and environmentally friendly heating technologies.

Within Vilniaus šilumos tinklai company all these new projects, products, or strategic changes can be devised and initiated by anyone within the company. If a proposal looks promising, it undergoes approval and an in-depth analysis, either internal or external. The decision-making process is grounded in business economic feasibility, which includes a cost-benefit techno-economic analysis and considers the critical importance of CO_2 reduction. Keeping the heat price low for consumers is paramount since projects that increase heat prices, even slightly, are challenging to get approved by the national regulator. The analysis results are presented to company management, and for larger projects, to board members, who then decide whether to approve or reject the project proposal.

The four main aspects of decision-making include: achieving positive financial results (measured by internal rate of return, net present value, and payback time); reducing the heat price for customers; enhancing environmental performance by reducing CO_2 emissions and pollution, and moving away from fossil fuels; and adhering to the strategic goals of the company while responding to useful shareholder needs and vision. This comprehensive and strategic approach ensures that the Vilnius district heating system evolves in a sustainable, reliable, and economically viable manner now and in the climate-neutral future.

5.3 Initiatives regarding technology stock in Croatia

Today, Croatia has inefficient district heating systems, designed for high temperatures in distribution networks and an inefficient, mostly unrenovated residential building stock. The prevailing heating systems in Croatia are second-generation heating systems, which need to be upgraded to third- or fourth-generation systems. This implies new, modern generation installations, access to new sources of renewable energy, efficient distribution infrastructure, highly efficient buildings renovated for low-temperature thermal energy supply, improved control of the heating system and heat metering with charging based on the actual consumption.

The European Union Energy Efficiency Directive[5] includes the following definition: efficient district heating and cooling – a district heating or cooling system using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat. The Croatian government goes beyond this directive by issuing the Integrated Nacional Energy and Climate Plan and correcting the National Development Strategy for Energy-Sector, where different measures address district heating.

Energy efficiency measures for district heating systems in Croatia include the improvement of heat networks by renovating and reconstructing certain sections:

- the replacement of fuel oil boilers with heat pumps;
- replacement of natural gas in heat production with geothermal energy;
- replacement of natural gas in heat production with solar energy;
- replacement of old and inefficient CHP blocks at existing HEP facilities with two new gas high-efficiency combined-cycle cogeneration blocks;
- the use of waste heat from industrial installations and heat from waste incineration plants in district heating systems.

One of the first energy efficiency measure for district heating systems is aimed at reducing heat losses in the district heating grid. Only after that, and taking into account a lower quantity of produced heat due to reduced heat losses, the following measures relating to the modernisation of generation installations of existing district heating systems may be implemented.

As the run-down DH grids in Croatia is the cause of major losses, this measure provides for the continued replacement of hot water pipelines with deteriorated steel pipe insulation with

[5] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency (EED)

new pre-insulated piping and a technological shift towards the fourth-generation of district heating. In good engineering practice, losses for modern district heating systems using pre-insulated pipes are estimated at 6%–8% for systems with a high heat density such as in Zagreb. The losses in the existing Croatian district heating systems accounted for 12-15%. Thanks to the durability of pre-insulated piping material to external factors, the expected service life of the new pre-insulated pipes is up to 50 years. The expected outcome of the heat network renovation includes increased energy efficiency of the heating system, more reliable heat supply, a decrease in the number of contingency events, enhanced satisfaction of the final consumers of heat, reduction of heat losses and losses in process water refilling, as well as reduced pollutant emissions into the environment. In order for district heating systems to be sustainable by the rules of the profession [103] and according to best practices, the existing network should be renovated to reach a level at which losses are taken to be 7% by 2030. For Zagreb, total district heating grid investment is estimated at around HRK 1,650 million to reach a 7% grid loss, and it is expected that the renovation can receive support from the European Regional Development Fund through the Operational Fund for Competitiveness and Cohesion.

According to the Integrated National Energy and Climate Plan of the Republic of Croatia (NECP) for 2021–2030 [90] projections of the developments in the useful energy delivered and needed for heating/cooling were made for the following scenarios:

- reference or BAU (business-as-usual) scenario, which presumes development with the application of existing measures;
- SIM (scenario with integrated measures) according to NECP.

The SIM scenario measures for 2030 and 2050 foresee the following:

- complete decommissioning of fuel oil boilers (by 2030);
- complete phase-out of natural gas cogeneration;
- significant decrease in natural gas boilers;
- increase in biomass high-efficiency cogeneration;
- significant increase in geothermal energy use;
- use of heat from thermal waste treatment (significant potential in densely populated urban areas) – the figure shows electricity used as drive energy and heat taken from the environment;
- use of water-to-water compression heat pumps;
- use of industrial waste heat (small portion);
- use of solar energy (small portion).

Given that fuel oil is an environmentally unacceptable fossil fuel with a high CO_2 emissions factor, a complete phase-out of fuel oil from district heating systems is foreseen under SIM scenario measures by 2030. Two measures have been proposed: replacement of fuel oil boilers with wood chip boilers and heat pumps (e.g., groundwater, river water, waste heat etc.). The proposed measures should result in a reduction of CO_2 emissions by 9 500.95 tonnes and in 32.05 GWh in primary energy savings from DH production by 2030.

The measures proposed in NECP provide for the complete replacement of existing natural gas cogeneration with high-efficiency natural gas cogeneration by 2050. These measures would ensure CO_2 emissions savings of 29 475.79 tonnes by 2050 and 146.58 GWh in primary energy savings from drive energy products at the entry point to the DHS. A description of the two measures for EL-TO Zagreb and TE-TO Osijek, integrated into the BAU scenario, is provided below.

The development and maintenance of centralised thermal systems is one of the key measures in the energy security dimension. District heating systems have been identified as one of the priorities of the energy policy of the Republic of Croatia. The most significant potential for the development and improvement of existing district heating systems is primarily to increase the energy efficiency of production units, infrastructure and equipment at end-users and to increase reliability and security of energy supply. Therefore, this measure envisages the maintenance and upgrading of existing DHS systems, stopping the trend of disconnecting customers from the DHS systems, introducing heat storage tanks for electricity, and using RES for DHS and replacing existing DHS production with renewable sources (e.g. biofuels) as well as the use of heat pumps.

Most Croatian heat plants operate on natural gas. The heat losses from heat generators transmitted to different types of consumers have been around 6 % in recent years. There are additional losses within each DH system, for instance, heat loss of 9.45 % for Zagreb DH and 6.8 % for Osijek DH. A 2015 report commissioned by the International Finance Corporation (IFC) indicates 22 % overall heat losses for Karlovac and 26 % in Rijeka. There are opportunities to utilize biomass (including wood chips or straw), waste heat from industry, waste-to-energy incineration, and geothermal in DH. In general, the heat losses in Croatian district heating networks are around 15-25%, compared to a figure of around 5-10% in EU-15 countries.

In the existing large centralized heating systems, a large source of losses is the deteriorated distribution network, and this measure foresees the continuation of the replacement of deteriorated steel hot water pipes and steam lines with new pre-insulated pipes and a technological shift towards the fourth generation of district heating. In smaller systems with their own boiler room, it is necessary to allow for the reconstruction of boiler stations, in particular by replacing them with high-efficiency cogeneration systems or systems using heat pumps. The measure also envisages the development of new heating and cooling systems, which use high-efficiency cogeneration or RES. In view of the provisions of the Directive 2018/2002 on energy efficiency, and in particular with the introduction of the obligation of individual measurement at the level of the end-user, district heating systems have become systems with variable heat demand, which requires the introduction of advanced metering systems as an additional step towards the integration of different energy systems and increasing overall energy efficiency [90].

Hrvatska elektroprivreda (HEP Group) is the national energy company, which has been dealing with the generation, distribution and supply of electricity for more than a century. In the last few decades, it has been dealing with the distribution and supply of heat energy and natural gas to customers. HEP is organized as a concern, a group of connected companies (daughter companies). One of them is HEP toplinarstvo, which deals with generation, distribution and supply of heat energy and it works in Zagreb, Zaprešić, Samobor, Velika Gorica, Osijek and Sisak.

A number of projects and activities are part of various plans developed by the leading energy organizations. However, as the National Energy Strategy is being updated, this is the time to review and reprioritize projects and activities to fit the National Energy Strategy and the upcoming National Energy and Climate Change Action Plan. Efficiency improvement and expansion in district heating systems and efficiency gained in gas-fired power and heat generation are the following:

- Capital expenditures in district heating have been relatively small in recent years (less than 5 per cent of HEP Group's overall capex) and should be more emphasized in the coming years.
- The revised district heating tariff methodology should allow additional capital expenditures to be made in a financially viable manner and should support the expansion of services to more customers.
- Further use of geothermal energy and biomass fuel in district heating, building on initiatives [104].
- Implementation of combined-cycle gas-turbine power and heat generation to replace old and inefficient gas power generators (e.g. EL-TO Zagreb CCGT).
- Implementation of natural gas and/or the LNG import project to supplement the declining domestic gas supply, reducing coal import while ramping up the next phase of RES.
- In addition to utility-scale renewable generation, Croatia is considering improving the framework for facilitating decentralized or distributed renewable generation solutions.
- Wood chip boilers should be used in biomass district heating systems, but they are also can be used to heat large buildings or a group of buildings.

It is extremely important to improve the DHS, especially by reducing heat losses in the existing distribution network (National Energy Climate Plan (NECP) measure ENU-17 [90]), as well as by further developing generation installation of existing district heating systems, which implies the integration of RES and a reduction in the use of fossil fuels.

In response to the gradual downward trend in interest rates on the money and credit markets, the Croatian National Bank Council at its session decided to reduce the discount rate from 9% annually to 7%. Although this rate has no significant direct impact on domestic monetary developments, the reduction should have an additional effect on the decrease in interest rates in relations between legal persons and between legal and natural persons.

How to best use Croatia government’s budgetary resources is an overarching question. In the energy sector, fully state-owned enterprises (SOEs) such as HEP Group and Plinacro are financially self-funding, including through methods such as borrowing and bond issuance, and do not require direct government budgetary allocation. However, they gain either directly or indirectly from their parastatal status, which benefits their credit standing or ratings. The government’s investments in SOEs are a cross-cutting issue that warrants careful analysis and decision-making. Questions surrounding this issue include going forward, should fully state-owned SOEs continue to reinvest a majority of their internally generated funding surplus into their businesses? Would it be more economically beneficial for the country if these SOEs remit more dividends back to the government for other needs? These SOEs could perhaps tap more private capital for their future. Or the government could divest its equity stakes in financially viable SOEs and use the proceeds for other needs.

All HEP's thermal power plants and combined heat and power plants have obtained Decisions on the Use of Hazardous Chemicals, issued in accordance with the Chemicals Act, and relating to the chemicals used in water treatment for the purpose of power and heat generation and for regeneration of ion exchangers in chemical water treatment plants.

Strategic development of indicators of potential for the use of high-efficiency cogeneration and efficient district heating and cooling is taken from the document “Programme for use of efficiency potential in heating and cooling for the period 2016-2030” from November 2015, which was prepared for the Ministry of Economy (today under the Ministry of Environment and Energy) in accordance with Article 14, paragraph 1 Directive 2012/27/EC. The established overall (theoretical) potential for high-efficiency cogeneration plants in the Republic of Croatia is observed through two scenarios of shares of future consumers of DHS coupled with high-efficiency cogeneration: conservative and optimistic. Scenarios are based on the share of consumers of district heating systems that are assumed based on the determined existing trends (conservative scenario), or optimistic assumptions of positive changes in the economy of the Republic of Croatia (optimistic scenario). Indicators of potential for the use of high-efficiency cogeneration and efficient district heating and cooling are presented in

Table 5-5.

Table 5-5 Potentials for use of high-efficiency cogeneration and efficient district heating and cooling. Data from [105]

Indicator	Unit	Conservative scenario, 2030	Optimistic scenario, 2030
Total heat demand (theoretical heat demand for 2030)	GJ	18,312,866	29,982,128
	MWh	5,086,907	8,328,369
Required heating capacity (theoretical)	MWt	3,178	5,262
Share of DHS consumers	%	30.1	55.0
Equivalent heat demand	GJ	5,506,528	16,625,599
	MWh	1,529,591	4,618,222
Equivalent thermal capacity	MWt	956	2,903
Potentially produced electricity	GJ	8,653,115	26,125,941
	MWh	2,403,643	7,257,206

The changes in the generating and transmitting facilities of Croatian DHS are mostly driven by the condition of the existing equipment. The selection of new equipment and changes in the main paradigm of district heating companies depend on economic efficiency and environmental issues. Ecological aspects are regulated by the legal requirements of Croatian law and by law. In the Republic of Croatia, the district heating sector is regulated by the following acts:

- Energy Act („Official Gazette“ No. 120/2012, 14/2014, 102/2015 and 68/2018);
- Act on Regulation of Energy Activities („Official Gazette“ No. 120/2012 and 68/2018);
- Act on Heat Market („Official Gazette“ No. 80/2013, 14/2014, 102/2014, 95/2015, 76/2018, and 86/2019);
- Act on Renewable Sources of Energy and High-Efficiency Cogeneration („Official Gazette“ No. 138/2021);
- Act on Energy Efficiency („Official Gazette“ No. 27/2014, 116/2018 and 42/2021).

These documents also force the Croatian district heating companies to perform changes in generating and transmission facilities. For instance, in mid-2013, a new Act on Heat Market was adopted, introducing significant innovations in the district heating sector planning, organisation, and functioning. The main goal of the act is to create conditions for the safe and reliable delivery of heat, market development, the protection of end customers, heat price competitiveness, efficient production and use of heat, and to minimise negative impacts on the environment and sustainable development, in line with EU rules.

Besides, different EU entities provide funding opportunities for the Croatian District heating sector to increase its efficiency and expand opportunities. These are the targeted renovation projects financed by entities, like EBRD and different research projects and joint actions of which there are now about 10.

Reaching the 2030 goals will be more challenging for the Croatian district heating sector, as: (i) Croatia is lagging behind the planned schedule for phasing out the existing support system and introducing new market principles; (ii) technical (smart metering), legislative, and regulatory, barriers (including a market design impedes the efficient integration of energy produced from renewable sources into the market); (iii) role of end-users in heat energy market is limited and (iv) methodology for allocating the costs of balancing energy to renewable generators is lacking and (v) there is no market for ancillary services. The threats for the implementation of new technologies in Croatia are the following:

High energy intensity (EI). Croatia has more than a decade of experience in energy efficiency (EE) actions and financing of the district heating sector. However, Croatia's EI remains 55% higher than the EU average, mainly due to inefficiencies in the building and transport sectors. Building on its EE experience institutions in Croatia can leap forward and achieve more ambitious EE and EI targets by scrutinizing sub-sectoral EE and EI targets as envisaged under Croatia's 4th EE Action Plan (households, construction, service and industrial sectors), submitted to the European Commission. Croatia must also focus on improving energy efficiency in district heating, as well as addressing poor households' inefficient energy usage. On the supply side, moving ahead with adding state-of-the-art combined-cycle gas turbines and increasing the efficiency of district heating will advance Croatia's EE and EI goals.

Lack of appropriate support for renewable energy. Croatia has committed to decarbonizing its district heating sector through expanding renewable energy and reducing the carbon emissions of fossil fuels. The key question is "how can the deployment of renewables be driven forward in Croatia"? Adding more renewables, the potential of which is still largely unused, could help reduce Croatia's carbon intensity by displacing fossil fuels such as fuel oil and natural gas. The implementation of the renewable energy law only partially occurred, which halted the development of a new heat generation of renewable energy projects. Amendments to the law adopted in December 2018 are expected to help foster the development of new projects in the district heating sector.

Social support mechanisms for energy consumption. To address concerns about energy affordability, the Croatian authorities have put in place an energy allowance to lessen the burden of energy consumption for households that fall under the poverty line. Although energy-poor households above the poverty line have no dedicated support, some measures have been implemented to prevent price increases. While these measures are crucial, further refinement to better target the support for the economically poor will help improve their effectiveness and minimize the fiscal cost.

Energy efficiency financing through traditional financial institutions remains limited. There is a mature energy services market in Croatia. However, although there are energy efficiency financing fundamentals in place, there is still large untapped potential. Energy service companies develop, implement and sometimes finance, energy efficiency projects in the district heating sector, which are then compensated through energy savings. Croatia has over a decade of experience with the ESCO model. The first ESCO, HEP ESCO, was established in Croatia under the aegis of the national utility company HEP in 2003 to provide financing support to improve energy efficiency in public buildings (schools, hospitals, offices), public lighting, the residential sector, and the commercial and industrial sectors. The use of financial instruments, of about EUR 70 million in total (of which roughly half would be from European structural and investment funds, and the other half from commercial banks participating in the instrument) are being considered. However, the gap in Croatia's ESCO model continues to be scaled up through traditional financial institutions. Confirming and addressing the constraints of ESCOs at a micro-level could help to substantially expand EE financing options and optimize their performance. There are presently about tens of active ESCOs operating in Croatia. Despite the presence of ESCOs, surveys and perceptions continue to indicate limited available financing for EE, mainly as a result of high interest rates. Mainstream financial institutions are generally not active in EE financing.

Delays in the implementation of a competitive element to the allocation of state support being offered to renewable energy producers are dampening investment. The Law prescribes a multi-technology scheme in which all types of heat and power generation based on RES as well as high-efficiency cogeneration can participate. It describes the option of introducing quotas for specific technologies and/or installation sizes. However, progress with the implementation of the new system, which aimed to gradually phase out the support mechanism and introduce market-based pricing, has stalled. The Government did not adopt the necessary implementing regulations. Instead, two regulations were adopted by the Government, delaying the introduction of the premium model and the implementation of balancing responsibilities –first until January 1st, 2018, and then again until January 1st, 2019. The delay in the establishment of the eco-balancing group has had a negative impact on the volume of intra-day trading, since other market participants had to cover the imbalances, resulting in additional financial burdens on HOPS.

Limited market competition. Since joining the European Union (EU) in 2013, Croatia has implemented a number of EU directives aimed at opening its energy sector to competition and integration into the single EU energy market. However, competition in Croatia's district heating market is still very limited. Market reforms are needed to improve the investment climate and create incentives for new entrants. Croatia, like the rest of the world, is seeing a growing demand for cooling and air conditioning in the summer months, especially in the south along its Adriatic coast.

Main biomass industry constraints in Croatia forestalling the advancement of the industry include: 1) Sluggish and convoluted administrative procedures; 2) Biomass supply logistics and routes to market issues for private forest owners; 3) A lack of knowledge and technologies for market development; 4) Capacity deficiencies at all levels (policy makers, businesses, customers, etc.); 5) Institutional quality control issues (certificates are not always a guarantee of pellet & wood quality.

5.4 Initiatives regarding technology stock in Romania

In Romania, there are a number of initiatives in the district heating sector. Compania Municipala Termoenergetica Bucuresti/C.M.T.E.B. develops investment strategies to ensure an efficient energy transition of the existing plants in intelligent and decarbonized systems with multiple sources of heat without fossil fuels. The energy transition and decarbonization of district heating systems is a complex but necessary challenge. First of all, CMTEB opts for increased energy security and the significant reduction of CO_2 emissions and for a cleaner and healthier environment.

The new Energy Efficiency Directive at (EU/2023/1791) level stipulates that an efficient heating system falls within the following specifications:

- by December 31, 2025, a system that uses at least 50% renewable energy, 50% waste heat, 75% cogeneration heat or 50% of a combination of such energy and heat;
- from 1 January 2026, a system that uses at least 50% renewable energy, 50% waste heat, 80% high-efficiency co-generated heat or at least a combination of such heat energy entered into the network, where the share of renewable energy is the less than 5%, and the total share of renewable energy, waste heat or high-efficiency co-generated heat is at least 50%;
- from January 1, 2035, a system that uses at least 50% renewable energy and waste heat, where the share of renewable energy is at least 20%;

Of more specific activities, there are feasibility studies being conducted in Bucharest of mini power plants 1.5 - 4.4 MW gas CHP units as there is lacking of sufficient capacity in some areas hence small distributed units. Also some work on working on mini hubs with solar, geothermal or drawing heat from DH pipe galleries.

Geothermal energy has been considered. The geothermal reservoir in North Bucharest and Ilfov county is a very generous one, even compared to those in Bihor or the Olt Valley. It has a so far-determined area of 300 square km, and the temperature increases the further north you go, from 58 to 84°C. Of the 24 wells drilled in this basin, 18 of them produce geothermal water, and their flow rates are between 22 and 35 l/s. Due to the qualities of the reservoir, the geothermal resources in the land in the north of Bucharest could be used for heating and preparing hot water for consumption, in residential buildings, social services such as hospitals, schools, or kindergartens, but also for the industrial sector or greenhouses.

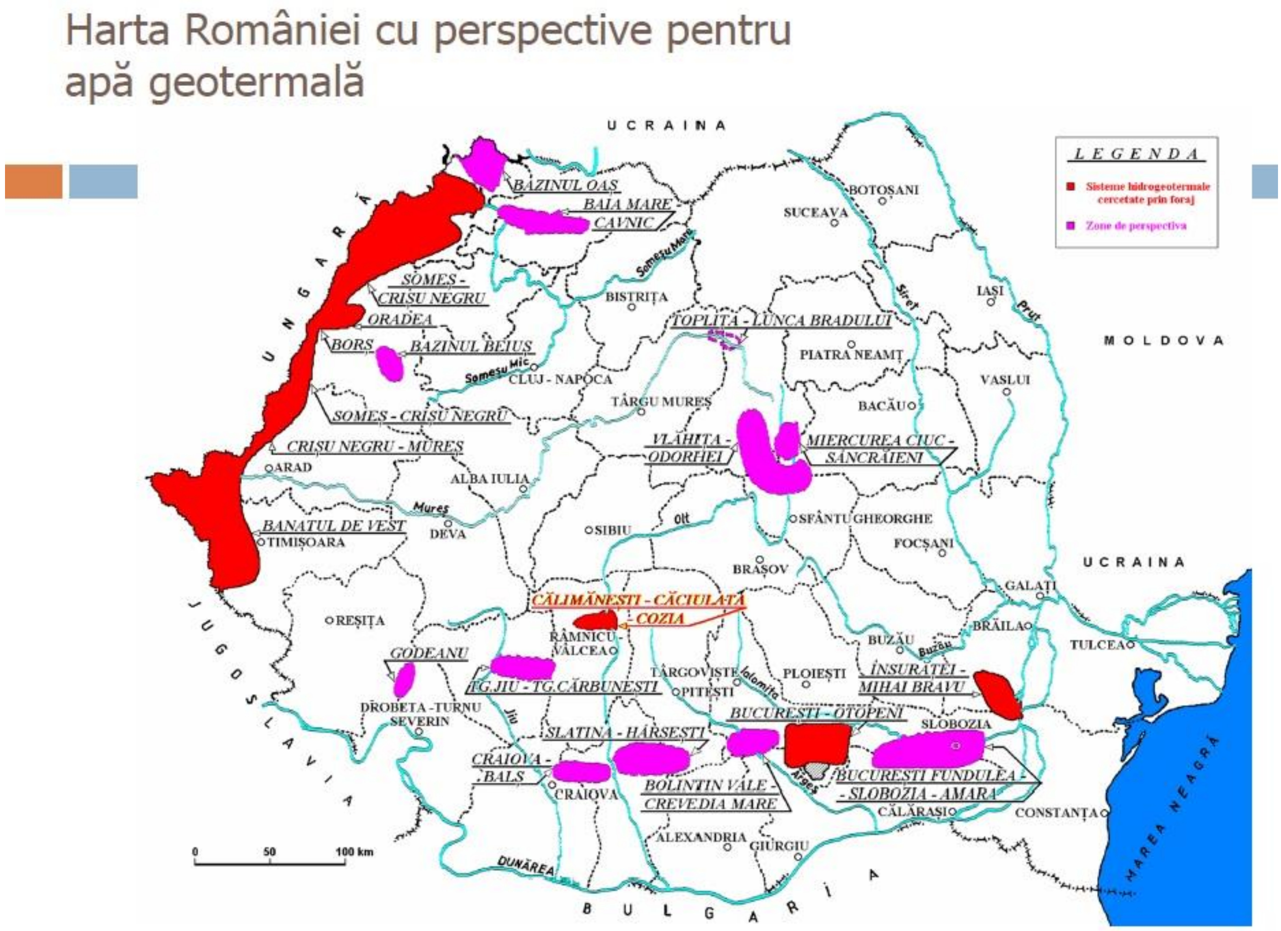


Figure 5-4: Map of Romania with indication of areas with geothermal potentials

While temperatures outside the capital 80°C hot water can be found at a depth of 2000 m – inside the city it is only 40° at that depth. Otherwise, at a cost of 3-5 M EUR per 20 MW well, geothermal energy is interesting.

One of the big problems of Bucharest is related to the heating system, a deficient area from a thermal point of view. There was the proposal of a project through which geothermal water would be injected directly into the CET of the Press House (CTZ Casa Presei). The heating agent could have been provided for 10% of the Capital's inhabitants and the costs would have decreased by up to 15%.

The Lindal diagram shows that in the CET Press House area the water temperature is around 60°C. Certainly, the energy value is much higher at Snagov, where the water temperature reaches 90°C and where even electricity can be obtained. Theoretically, the basin in the Ilfov Nord area could be suitable for areas with agglomerations and blocks in Otopeni, Balotești or Snagov, but also for the neighbourhoods in the north of Bucharest.

CMTEB manages a large number of facilities spread over a large area of Bucharest, positioned in areas of urban agglomeration in the middle of neighbourhoods. An opportunity has identified to use the outdoor spaces, courtyards, terraces of the thermal points both in the production of electricity that can be used in the thermal points as well as an integrated service centre for the community. Figure x shows the high number of CMTEB facilities in the Bucharest area.

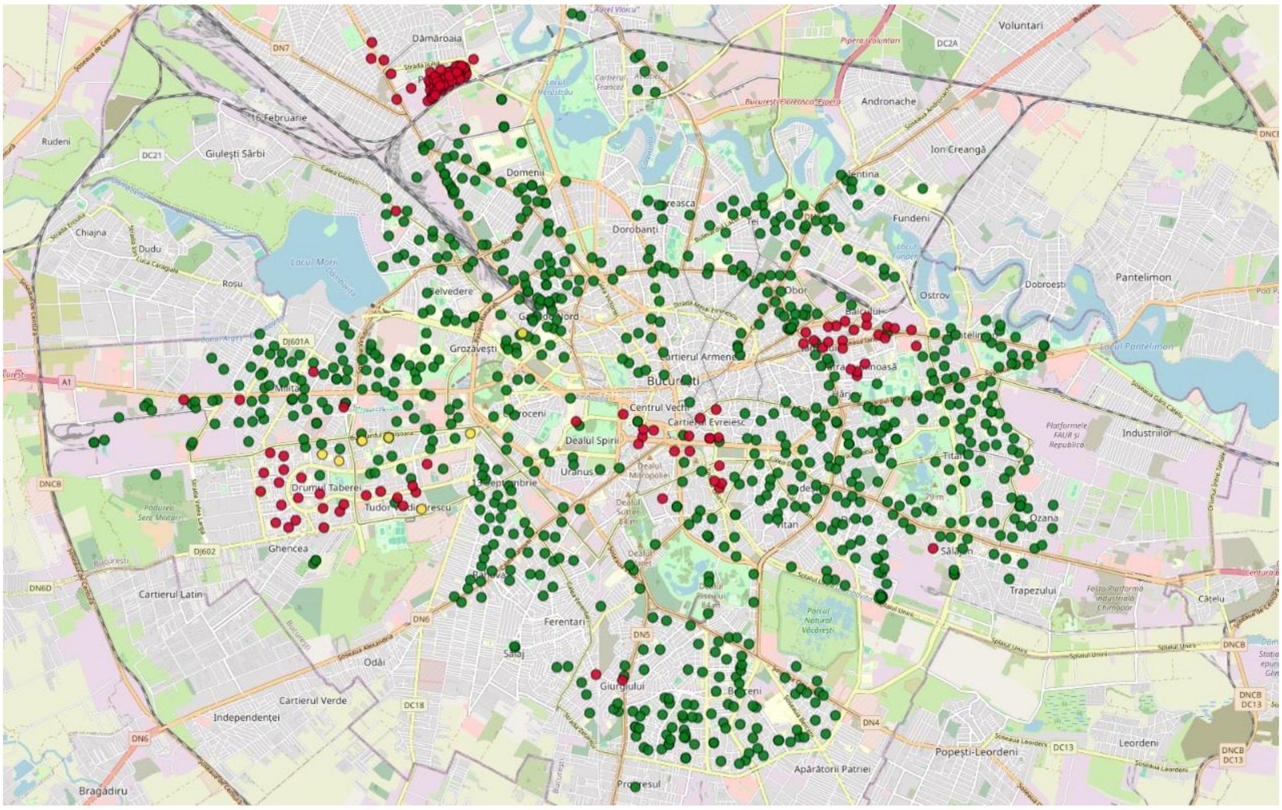


Figure 5-5: Facilities operated by CMTEB in Bucharest. Green - Normal operation, Yellow - Deficiency in supply, Red - Stop supply.

Average annual solar radiation in Romania varies between 1,100 and 1,300 kWh/m^2 for more than half of the country's surface, thus areas and rooftops can also be used for solar panels.

The general proposal is to use solar water panels, to raise the temperature of the water on the secondary circuit, especially in summer, for the additional heating of hot water for consumption.

CMTEB propose the use of solar water panels with the following characteristics: pressurized solar panel, thermal power: 1 734 W per 2.33 m^2 useful area, and is looking into systems with 88 solar panels located on the terrace of the substation building and with 30 m^3 of storage. Such systems could provide approx. 635 kWh/m^2/year, resulting in a total of 190 MWh/year/substation – and with 300 substations in the system, the potential is significant. The production would clearly be concentrated in the summer months and impact the supply of domestic hot water. The annual solar uptake for approx. 200 substations would be 38 GWh/year.

The northern area of the Bucharest, especially the consumers connected to the centralized system in the Aviației area, are affected in terms of the quality of the public thermal energy delivery service, due to the disappearance of CET Pipera that served that area. In this sense, due to the current configuration of the heating system, the area is supplied from CET Grozăvești or from CET SUD on long routes and there is a permanent risk of a decrease in the operating parameters following any breakdown on the route.

Consequently, heat pumps are considered here, aiming on the one hand to reduce the cost of thermal energy supplied to the population, and, on the other hand, to reduce the pollution generated by district heating. Therefore, in October 2022, The Municipality of Bucharest approved a concept note "Installation of Heat Pumps in the North Area of the Municipality of Bucharest". For the realization of this project, discussions were held with Siemens representatives, as a potential supplier of the equipment, the heat pump, which will be installed.

Siemens representatives came to the headquarters of C.M.T.E.B. and there were discussions on the subject in which the conditions necessary for mounting were explained. Furthermore, nine potential locations for the placement of a pump were identified. Following the field trip, their number was reduced to two, behind the UTCB gym and on the pontoon at Lake Floreasca. In the next phase, a meeting was arranged with the management of A.L.P.A.B. (City Lakes and Parks Management), following which A.L.P.A.B will contact Romanian Water to analyse the possibility of placing a heat pump and the use of water. It was ensured that the considered locations have access to all utilities, therefore places were searched where there is either a thermal point or a power plant, or the primary heating agent network. Most were not compliant due to the lack of necessary space, approximately 500 m^2 or the high pedestrian traffic and a too brutal intervention in the parks of Bucharest.

Considerations regarding waste heat from data centres are being made, with potential sites on Blvd. Energeticienilor and Blvd. Timisoara.

Waste heat from the metro system is also considered. There are dozens of stations in Bucharest's of the Metro system, and every year, a combined 62 GWh of heat is wasted from the metro stations. This is the equivalent to the annual heating demand for the homes of over 14,000 people living in Bucharest. With technologies that already exist today, this heat could be captured and recirculated in the district heating network, helping pave the way to a fully decarbonized heating system in Bucharest.

There are also studies on district cooling being made.

In general, the cost of heat needs to be lowered to under 80 €/MWh. Currently, there are subsidies from the municipality which make it expensive for the municipality, while less so for consumers.

Decision-making changes in the DH system are difficult as it is a political decision.

A number of particular targets regarding particularly the grid are in the pipeline with implementation and completion 2023-2029.

a) Modernization of primary thermal networks - on the existing pipe routes, the installation solution of pre-insulated pipes, equipped with a system of detection, signalling and localization of losses, rehabilitation/reconfiguration of valve platforms and constructive elements will be implemented
b) Modernization of secondary thermal networks related to the thermal points that serve domestic consumers
c) Modernization of district heating plants - the installation of new condensing boilers, equipped with modern automation systems to ensure the optimization of their operation with maximum efficiency and the transmission of data to the SCADA dispatcher system, which will ensure the monitoring, supervision and coordination of their operation
d) Modernization of thermal grids related to thermal power plants - it will be carried out on existing pipe routes by implementing the solution for mounting pre-insulated steel pipes, equipped with a system for detecting, signalling and locating losses, in order to reduce them, for the secondary circuit heating and pipes Pre-insulated PEX for the hot water circuit for consumption and recirculation
e) Modernization of thermal points that serve domestic consumers - replacement of thermal energy pipes and pipe elements on all circuits (primary, secondary heating, hot water for consumption and recirculation), repair of buildings (interior and exterior), new sanitary installations, lighting, floor repairs, installation of sludge separators and impurity filters on the primary and secondary circuits, installation of safety valves, as well as the replacement of automation systems, pumps driven by converters, pumps of expansion

systems and softening stations in PTs in which they are no longer functional and for which spare parts compatible with the existing ones are no longer manufactured

f) The transformation, where it is possible and justified, according to a comparative technical-economic study, of thermal points into sources of production of thermal energy in the area, by modernizing them and equipping them with modular capacities to produce thermal energy, by attracting private capital
g) Optimizing the operation of thermal modules that serve domestic consumers - replacing existing equipment with high-performance equipment
h) Modernization projects of ELCEN's thermoelectric plants.

6. District heating coverage expansion in SET_HEAT systems

The main driver in this section is to seek DH expansion potentials in the different SET_HEAT countries given urban developments. Such developments can arise from various factors where an overarching demographic factor is an urbanisation trend with a move from sparsely inhabited rural areas to densely inhibited urban areas, which clearly favours communal systems like district heating.

Urbanisation, population growth in general and increasing wealth all contributed to increasing demands in urban areas with district heating. New built-up areas or densification within urban areas with low buildings being replaced by tall buildings all increase demands inside district heating areas. In some, it may also imply a matter of increasing connections rates among existing buildings and dwellers to existing district heating grids.

Yet an option lies in connecting existing built-up areas that have other types of heating system despite a heat concentration sufficient for district heating. This can villages or towns in the vicinity or larger district heating-supplied cities which only have individual boilers possibly with natural gas

The analyses take their starting point in the sites represented by energy companies (Opole, Vilnius, Zagreb, and Bucharest) but also tentatively moves beyond the case-level for national trends based on qualitative considerations on the replicability of site assessments.

6.3 Expansion opportunities in Opole and Poland

There are approximately 930 cities in Poland, including 712 small and 202 medium-sized ones. In almost every city there is a district heating system.

Overall in Poland, cities are depopulating. According to Statistics Poland, the migration balance for cities is negative and for villages positive. This is depicted in Fig. 6-1. The largest population outflow is observed in small and medium-sized towns with up to 200,000 inhabitants. Their main problem is the lack of a comprehensive development strategy. Many medium-sized cities are losing their social and economic functions. Some of them are in danger of disappearing from the map altogether within 50-70 years. On the other hand, in the group of medium-sized cities, there are 39 cities described as growth locomotives, where the population is growing. In those cities there are considerable district heating expansion opportunities due to new urban developments.

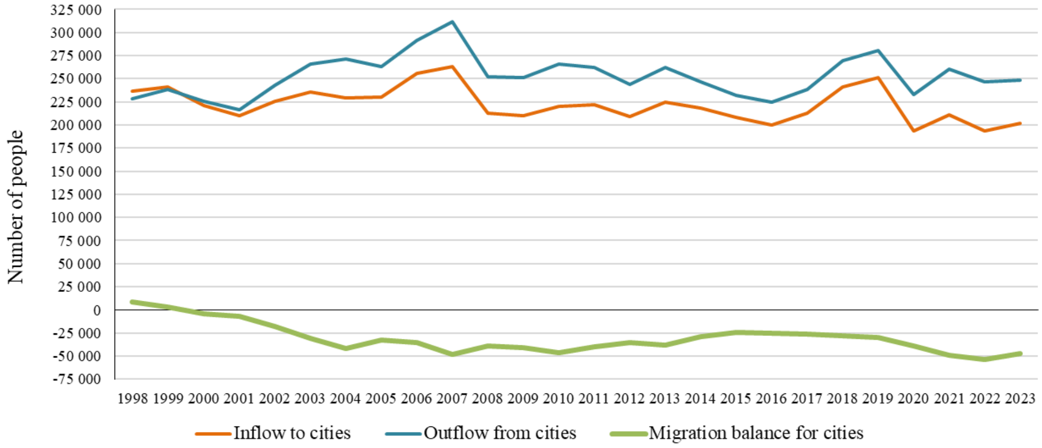


Figure 6-1: Migration balance for cities in Poland.

Opole is a medium-sized city with a population of approximately 126 thousand people as for 2023, is the capital of Opole Voivodeship (province) and the seat of Opole County. It is the largest city in the province. Despite the dynamic development of the city, the population continues to decline (Figure 6-2), except for a one-time increase resulting from the expansion of the city's territory and the inclusion of neighbouring settlements in 2017.

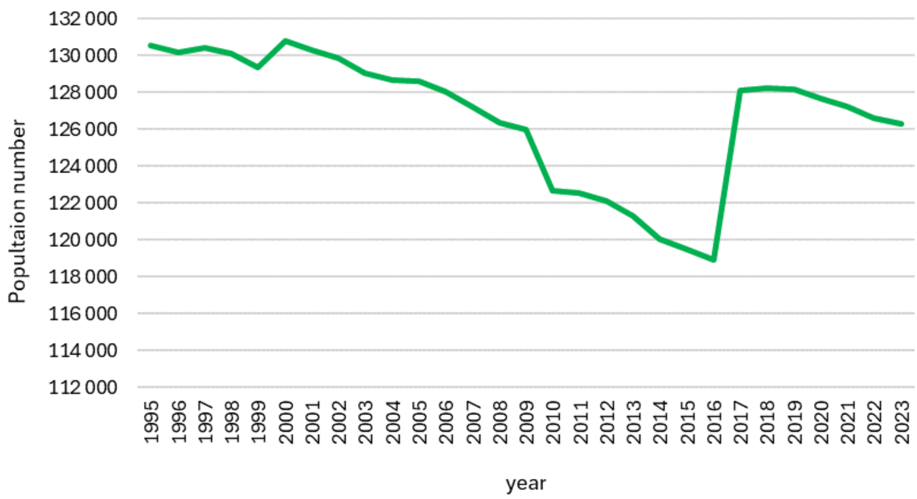


Figure 6-2: Population change in Opole from 1995 to 2023, data available from Statistics Poland (GUS) at https://stat.gov.pl/en/

In terms of territorial development, the city has dynamically increased its area over its more than 1,000-year history, with the last significant change in recent decades occurring in 2017 (Figure 6-3). On January 1, 2017, Borki, Chmielowice, Czarnowąsy, Krzanowice, Sławice, Świerkle, Winów, Wrzoski, Żerkowice as well as parts of Brzezie, Dobrzeń Mały and Karczów became a part of Opole, enlargening its population by about 9,500 and its area by over 5,300 ha. The area of the city is around 14,900 ha.

It can be stated that Opole city, despite the noticeable decreasing trend of population number, is a medium-sized city under development regarding territory, buildings and facilities. This is a challenge and at the same time an opportunity for the district heating system, which can stem the adverse impact of the city's slow depopulation.

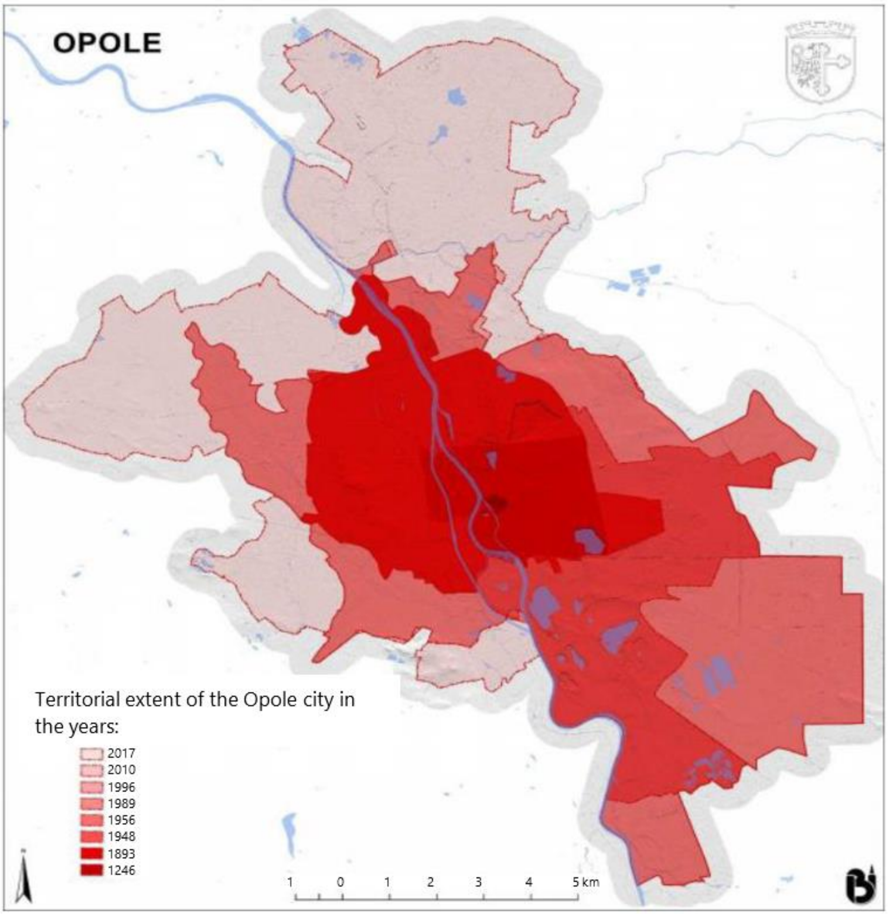


Figure 6-3: Territorial expansion of Opole city.

Opole has numerous investment areas located in various parts of the city. **Some of the sites are located in the city centre for services and office buildings, which are within direct reach of the district heating system.** Attractive sites, including more than 100 hectares of land in the Wrzoski district (the western part of Opole, on the border of its territory), are also available on the outskirts of the city for industrial development or warehouse space, with some of these areas outside the reach of the district heating system.

Year after year, the city is seeing **an increase in office buildings that meet the requirements of companies in the modern business services sector**. Local and international players in the modern business services sector are leasing office space in the city. In Opole, a new office and administrative district is being built near the city center. In addition to modern architecture, it is perfectly communicated with the city and in its immediate vicinity is the region's largest transportation center combining rail, regional bus, public transportation along with car parking. Opole not only has attractive investment areas but also offers active industrial developers and industry investors locations dedicated to industry (newly developed industrial zones).

Residential construction is also growing strongly in Opole, largely due to developers. Most of the multi-family residential buildings under construction are connected to the district heating network: these are buildings that are either being built within the direct reach of the district heating network or the district heating network is being extended towards new development areas where multi-family residential buildings are being built.

The extent of the city's district heating system against the background of the city's area and specific functions planned for specific locations is shown in the Figure 6-4.

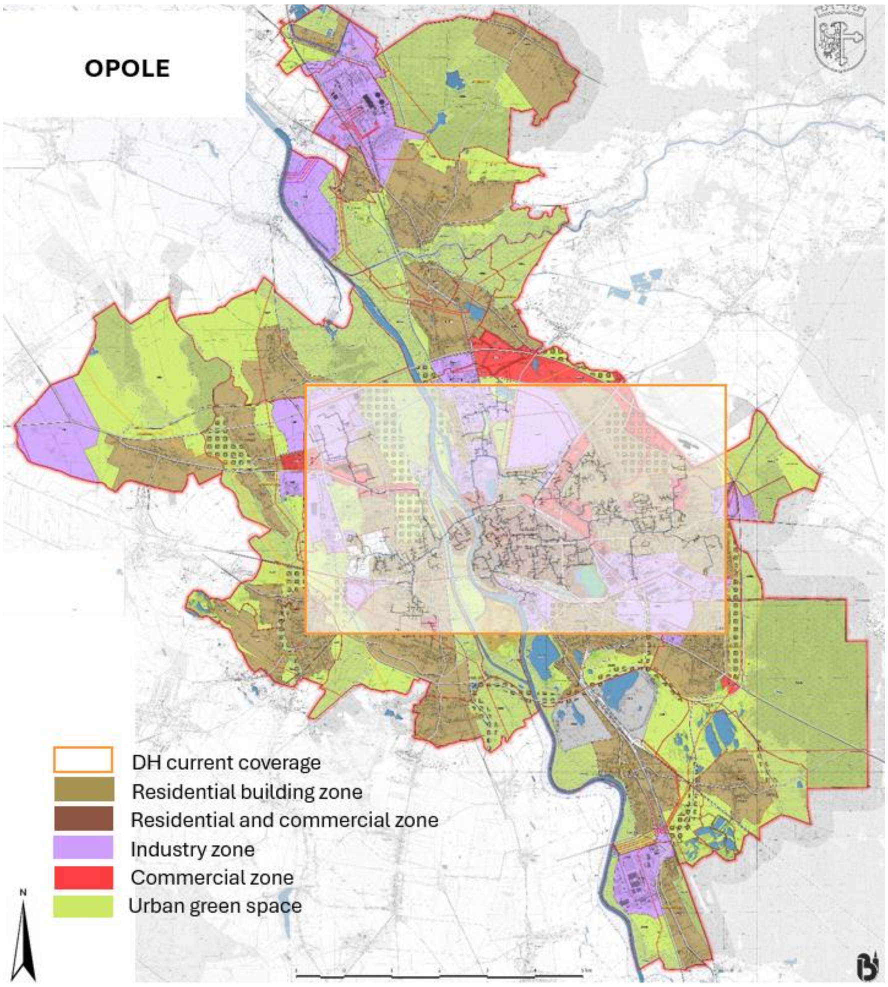


Figure 6-4: Opole urban spatial development plan versus DH coverage, prepared on the basis of the map taken from the Urban Spatial Development Plan of the Opole-city.

As can be seen from Figure 6-4, a considerable part of the development areas are outside the range of the district heating system. However some of the areas dedicated to multi-family housing (labelled as residential buildings zones) as well as one of the industrial zones are within its range.

It should be noted at this point that in addition to the potential for the district heating system to supply the heat to the city's new development areas, significant potential lies “inside” of the system, where there are buildings currently supplied with heat through individual sources (natural gas, coal, wood and others). Due to expected requirements for the energy efficiency of buildings (EPBD Directive), in a few decades all such buildings will have to change their heat sources to decarbonized ones or connect to an efficient district heating system.

Regarding possible expansion of district heating system in Opole, there are three main factors that will have affect this expansion (note: the minus sign (-) denotes the factor limiting the development of the system and the plus sign (+) denotes the factor contributing to development):

i. :decline in demographics (-)
ii. construction development and development of development sites (+)
iii. increasing the energy efficiency of existing buildings: both already connected (-) and unconnected (+) do DH system, toward transformation to zero-emission buildings, as defined by the EPBD.

As mentioned before, the highest concentration of residents in the city of Opole is in the central part of the city covered by district heating system. However, demographic conditions of recent years, indicate negative trends in demographic forecast (Fig 6-5).

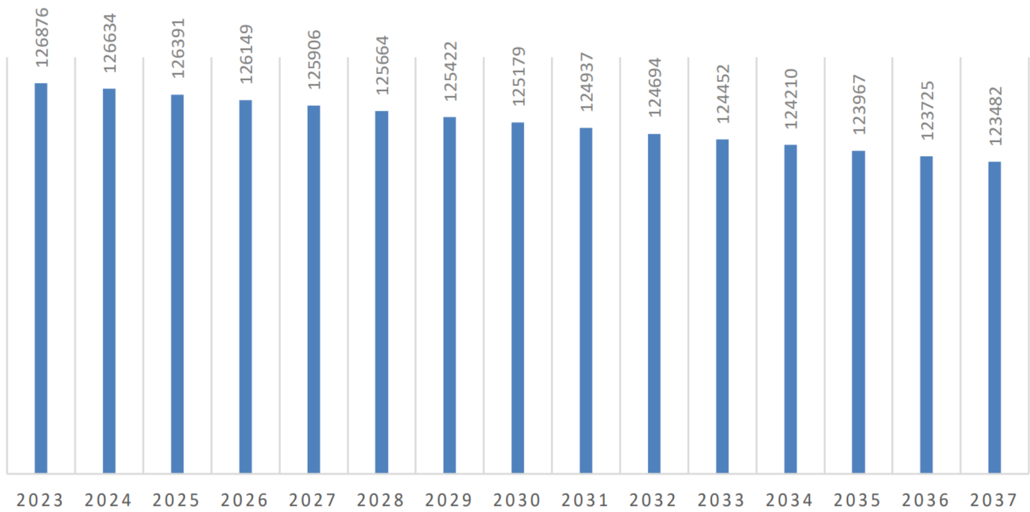


Figure 6-5: The population forecast for the Opole city.

The population forecast from 2023 to 2037, developed on the basis of the average annual trend of change observed in 2017-2021, **assumes a further decline in the number of residents**. These result from an unfavourable economic structure of the population - the aging of the population and the decrease in population resulting mainly from negative natural growth.

In counterpoint to demographic trends, projected number of residential building in Opole is expected to grow, as presented in Fig. 6-6 . According to available forecasts, in 2037 it will reach more than 77,000, with 30% of these being multi-family buildings that could potentially be supplied by the district heating system. Compared to the current number of buildings, the expected growth is about 13 thousand buildings, which is more than a 20% increase.

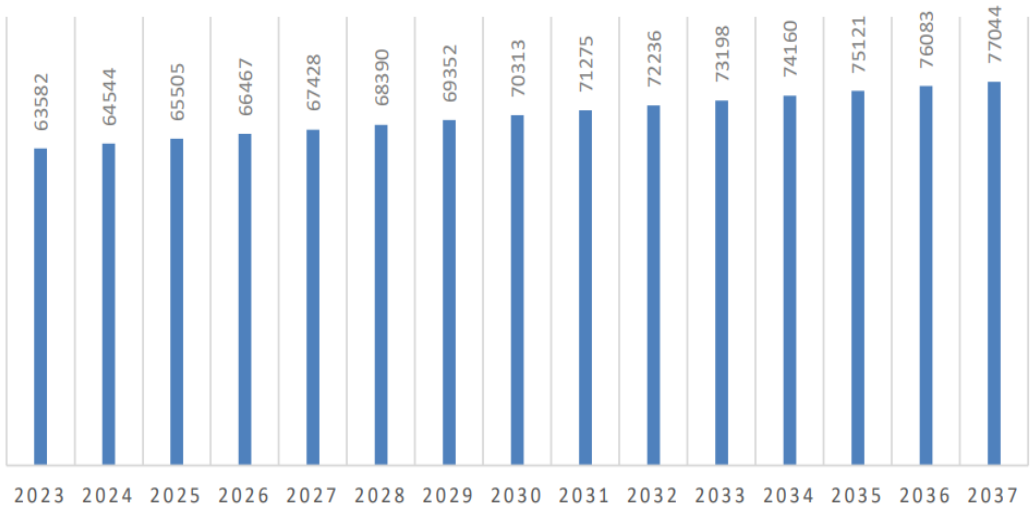


Figure 6-6: The projected number of residential dwellings in the city of Opole by 2035. The residential dwellings are mostly located in the range of DH system.

On the basis of the assumed scenarios of the city's development, including demographic and economic conditions, it is possible to determine forecasts of changes in the heat demand of the entire city of Opole. The figure 6-7 shows three potential scenarios for the evolution of the city's heat demand.

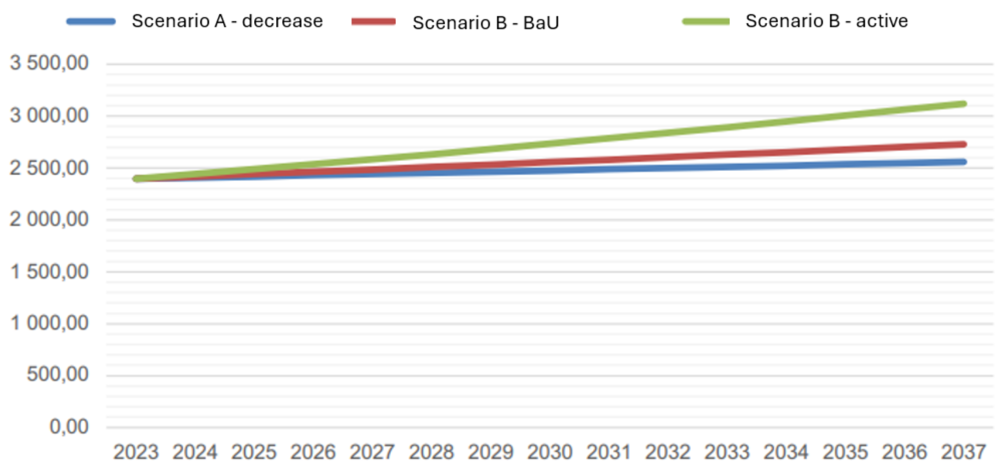


Figure 6-7: The projected heat demand of the entire city of Opole, in TJ, predictions by 2037, according to "Update of the Draft Assumptions for the Plan for Supply of Heat, Electricity and Gas Fuels for the City of Opole, 2022"

Each of the assumed scenarios is characterized by an increase in the city's heat demand, which is related to the assumed strong development of the city, mainly in the outlying areas in the area of existing and planned industrial zones.

The presented scenarios for changes in the city's heat demand, do not correspond to the expected heat demand covered by the city's district heating system. The heating company ECO SA, which owns the district heating system of the city of Opole, assumes that heat demand will stabilize and gradually decline. Figure 6-8 shows historical changes in heat sales as well as forecests by 2035. Historical (2010-2023) heat demand corrected by degree days relative to 2010 indicates a relatively stable level of heat demand. The forecast for the next ten years, however, indicates a gentle downward trend, even after taking into account the system's expansion into development areas. By the end of 2035, demand is expected to drop from about 430 GWh to 415 GWh per year.

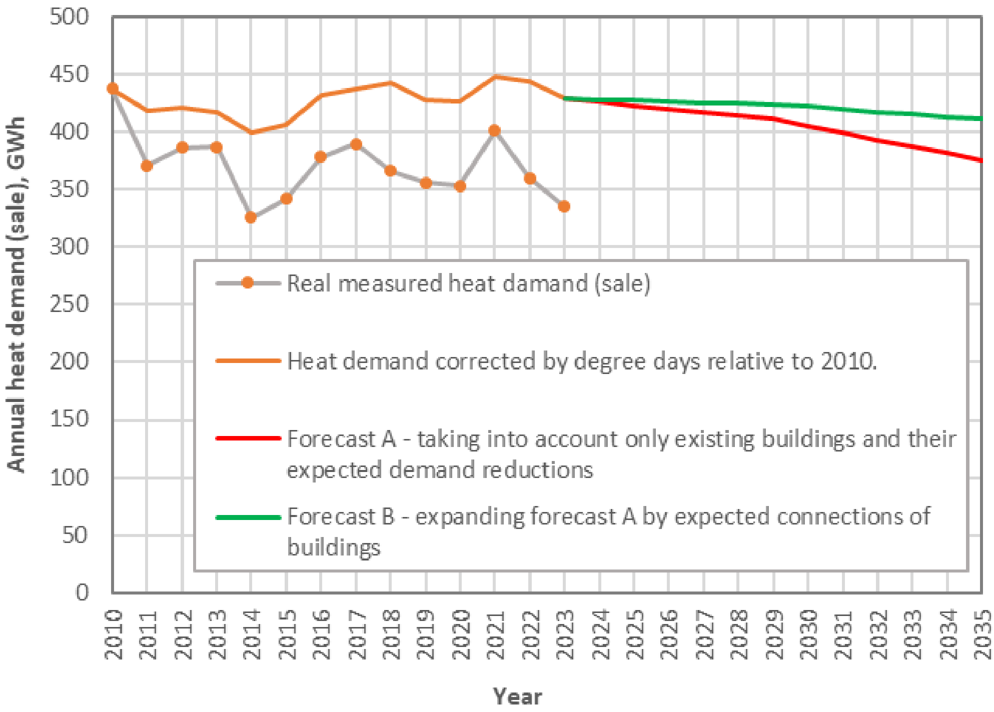


Figure 6-8: Heat demand (sale) of Opole District Heating system, in GWh, predictions by 2035.

6.4 Expansion opportunities in Vilnius and Lithuania

New built-up areas (new constructions of buildings) in Vilnius

Vilnius city is about a further orientation towards conversion projects, towards a more efficient use of the city territory, before building new micro-districts, where it is difficult to find costs for the creation of infrastructure later. The development of new construction housing in Vilnius is given to the areas around the city center: Naujamiestis, Vilkpėdė districts, the southern part of the city. City growth also creates demand for efficient heat supply, so the number of district heating users is likely to increase.

There are opportunities to develop new projects and it is designated as a priority area for urban development. The potential of Pilaitė can be seen as already reaching its peak, so there is hope that such a large development polygon will also appear in that northern part of the city. Pilaitė and Pašilaičiai districts are the ones, where density has changed significantly due to new constructions – for Pilaitė it has increased even 38.9 percent.

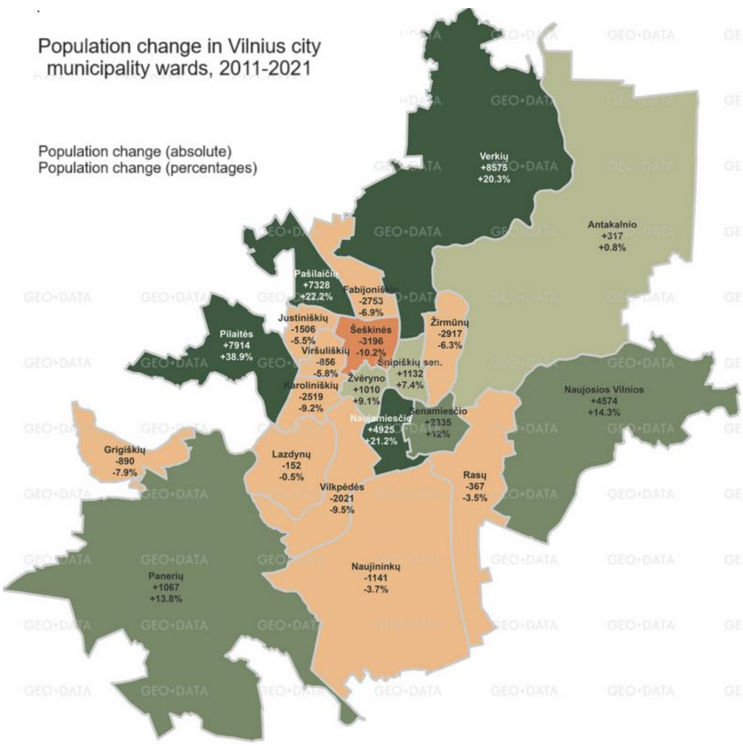


Figure 6-9: The residents density change in Vilnius city (2011-2021).Source: [106]

Figure 6-10 also shows new construction projects in Vilnius city. Here we may notice quite high density of new construction in the south part of the city, as it was predicted according to Vilnius city plan. The municipality and district heating suppliers decide which new customers will be connected to the DH system. However, it is likely that part of the new constructions will be heated centrally and part decentrally. There is a trend that not only new customers are joining, but also those who have previously disconnected are coming back. According to Lithuanian DH association data, the number of DH customers has been increasing since 2016 and stood at 716,003 on 31.12.2020. In Vilnius, 1 056 new consumers connected to DH in 2019, in Kaunas - 271, in Vilnius - 4 061 new consumers connected in 2020 and in Kaunas – 901 [107].

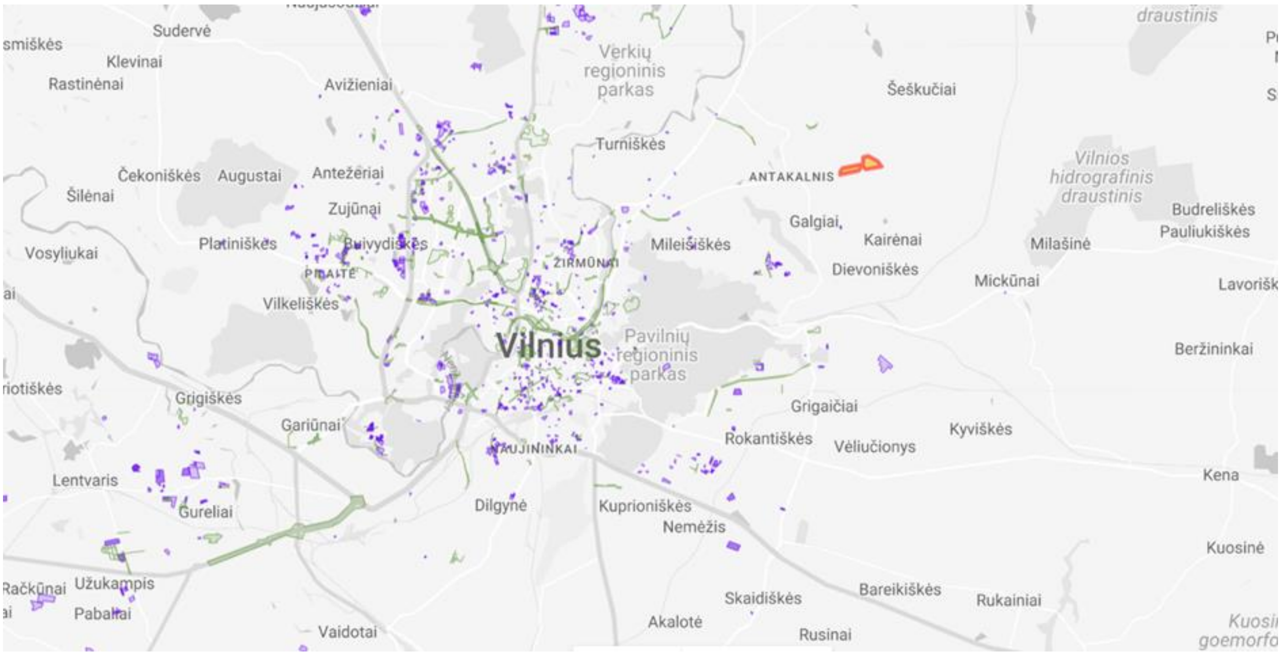


Figure 6-10 Map of Vilnius' new construction projects. Map from [108]

By the 2030s, the Vilnius municipality will seek to renovate the districts built during the Soviet era by making them more suitable for modern lifestyles, some of the streets are promised to be more suitable for pedestrians in the next two years. The priority is to comprehensively renovate the Soviet buildings that are still safe to operate and their territories, creating blocks of new construction housing concepts in them, while those that are in an emergency condition and pose a threat to the safety of the population may have to be demolished and new apartment buildings built in their place.

Vilnius is one of the few growing cities in Lithuania, and if growth trends continue, the demand for heat will increase due to new consumers. As of today, AB Vilniaus šilumos tinklai has already issued technical connection conditions to more than 370 new consumers with a total useful area of 2.95 million m² (almost 10% of the total heated area of Vilnius City). However, it should be noted that the connection to the grids is planned mainly for new buildings, whose relative heat demand is lower than that of a typical district heating network user. This should take into account that not all consumers will be connected and that the rate of connection itself is not always dependent on the heat supplier.

According to the data published by AB Vilniaus šilumos tinklai, over a four-year period, an average of 464,000 m² or ~50 MW of installed heat demand capacity has been connected to the DH system:

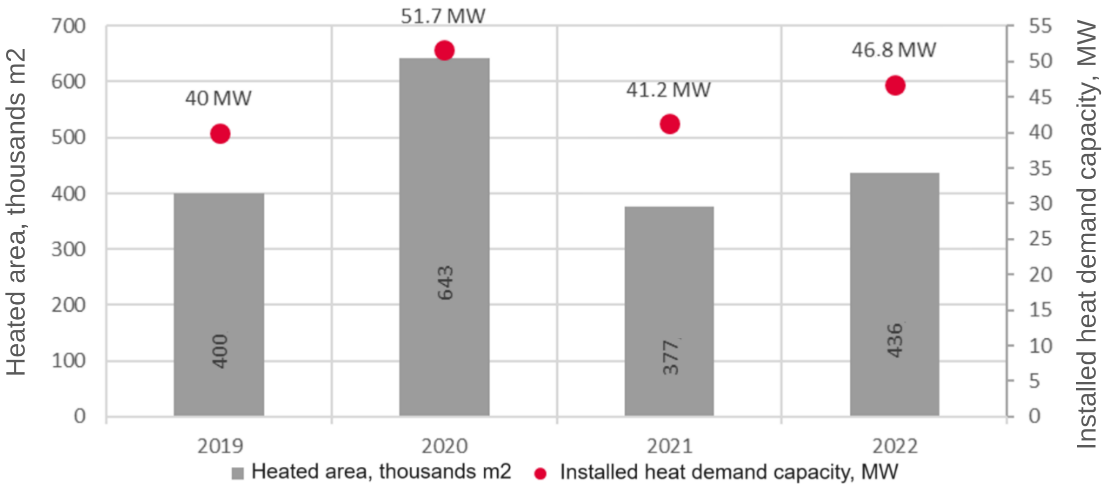


Figure 6-11. AB Vilniaus šilumos tinklai Connection rates of new consumers

This is a small sample of data, but it shows a steady connection of the heated area to the district heating system, which suggests that similar rates of connection of new customers will continue in the future.

Keeping the historical proportion of connected buildings and assuming that a similar number of buildings will be connected per year as in the last 4 years (approx. 464,000 m^2 of heated area, which roughly corresponds to approx. 10% of the currently issued building permits eligible for connection to DH), this results in an increase in heat demand of approx. 25 GWh/year.

Urbanisation (move from rural to urban areas) in Vilnius

The General Plan of the Republic of Lithuania shows that urbanisation processes are taking place only in the major cities of Lithuania, i.e. Vilnius, Kaunas, Klaipėda, Šiauliai and Panevėžys. Other municipalities do not fall within the minimum density of 30 inhabitants/ha of development in a residential quarter or district recommended in the normative documents of Lithuanian spatial planning [109].

The highest migration occurs in Vilnius County, and in 2022 it reached as many as 5543 persons. While in other regions even Kaunas region is smaller by a factor of 5.9 and Klaipėda by a factor of 3.9 [110]. The population projections for Lithuania by regions show population change in the major regions in the short term, with population growth projected only in Vilnius County [111]

Three scenarios are presented for the demographic projections of Vilnius Municipality: the most probable, the optimistic and the pessimistic. One of the key assumptions of the population projection is the total fertility rate (number of children per woman). In recent years, this indicator has been low in Vilnius at -1.46 (Lithuanian average -1.70). In the most likely scenario, it is assumed that this rate will reach 1.70 in 2030 and 1.90 in 2050.

Migration is also a major influence. Again, in the most likely scenario, it is assumed that net migration will gradually increase from 2000 in 2016 to reach 4000 in 2050 [112].

In the medium scenario, the number of registered inhabitants in Vilnius is projected to reach 544,000 in 2030 and 533,000 in 2050. If the assumptions are changed, the optimistic scenario would result in a population of 552,000 in 2030 and 566,000 in 2050. In the pessimistic scenario, the population would be 539 000 and 510 000 respectively. The median age in Vilnius in 2050 could reach 46 years [112].

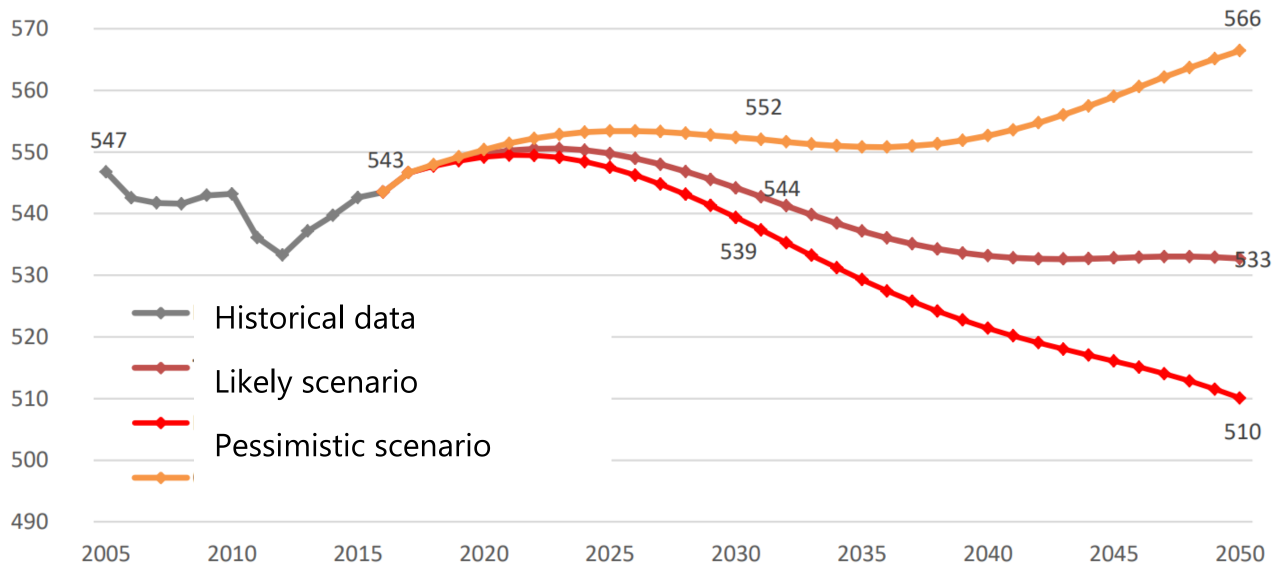


Figure 6-12 Forecast of the registered population of Vilnius City Municipality [112]

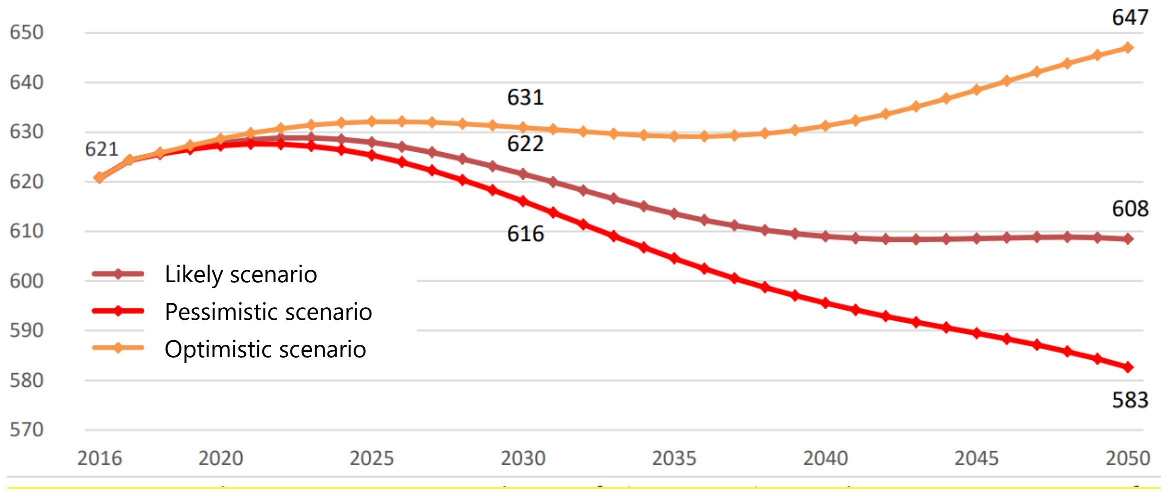


Figure 6-13: Demographic forecast of the population of Vilnius, including unregistered users of the infrastructure [112]

In line with current trends, the demand for DH is also growing with increasing urbanisation. The VST expects heat demand to grow (0.8% each year) and DH demand to increase in parallel.

Adjoining existing built-up areas with individual heating in Vilnius
According to [113], on 01/02/2024, the second alternative of the concept of changing the special plan of the Vilnius city DH was approved [114]. In this case, the stage of preparation of the concept of changing the special plan for the DH of Vilnius was completed and the stage of concretization of solutions began. In the concept, there are no plans to connect individual consumers with boilers to the DH network.

In buildings not connected to the district heating system, there is no accurate data on the heat sources used and there is no accounting of the energy produced by these heat sources, so there is no reliable data on the energy consumed in these buildings. According to the 2019 data from the Statistics Department, the households in urban areas were heated by district heating systems (79.5%), district heating from a local boiler house (0.8%) and individual heating (19.7%), with an average heated area in the city of 62 m^2 and an average thermal energy consumption of 60.5 kWh/m^2.

In 2019 48.55% of decentralized heat consumption in households, industry and service sectors was produced from RES. Residential and non-residential buildings with a total area of 14.08 million square meters are supplied with heat in a decentralized manner in the municipality. The main source of energy for heat production in households is biomass, in the industrial and service sector - natural gas. in 2019 about 2939.8 GWh (253 ktoe) of heat energy was consumed decentrally, of which 1427.3 GWh (123 ktoe) was produced from RES (biomass and biogas) [115].

Small heat sources, such as small districts, and individual and container-type boiler houses, use fossil fuels. These boiler units produce a relatively small amount of heat energy, only 36.2 GWh/year of heat energy (about 1.1% of heat consumption in Vilnius). The production of this heat generates emissions of up to 8.7 kt CO_2/year and has an emission factor of 0.24 tCO_2/MWh.

In summary, the prospects for the development of Vilnius DH systems are promising, focusing on sustainability, efficiency and innovation to create a clean and reliable heat supply infrastructure for future generations.

Population density in Lithuania (as of 1 January 2022) is 42.9 inhabitants per square kilometre. At the beginning of the 1990s, this figure was around 57 inhabitants per square kilometre. The population density map in Figure 6-14 shows the population density of the districts in 2020. The most densely populated districts are located around the major cities, while the least densely populated districts are located in Eastern and Southern Lithuania [116]. Vilnius and Kaunas counties are home to about half of Lithuania's population - 1 431 679, or 50.05% [107].

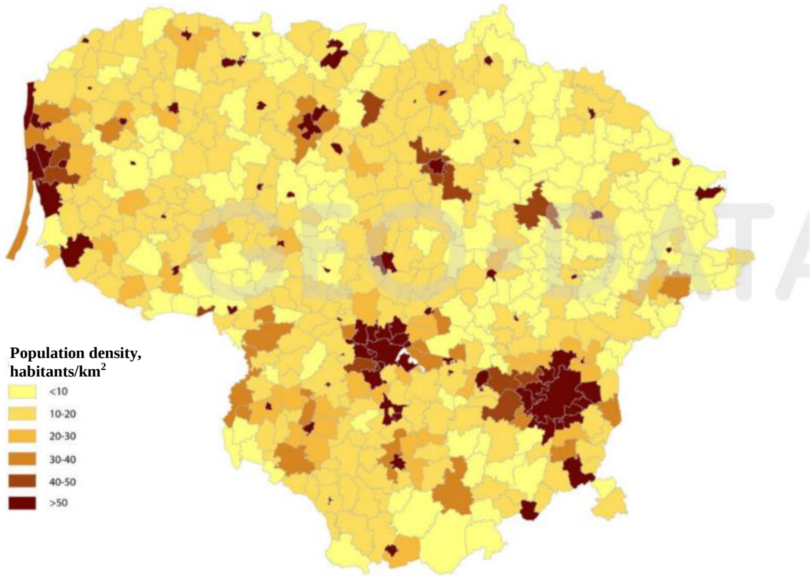


Figure 6-14: Population distribution in the territory of Lithuania (2020) [116]

Vilnius is the fastest-growing city in the region, with a 2.7% increase in population over the last three years. Vilnius is the only major city where the number of people arriving to live and work is higher than the number of people leaving the city. Every third baby born in Lithuania is born in Vilnius: 7,000 little Vilnius babies are born here every year [117]. According to data of 1 January 2024, the population density in Vilnius City Municipality is 1,502 inhabitants per km^2. However, the overall population density of the entire municipality does not reflect the real situation. Excluding sparsely populated districts or parts of districts, densely populated districts in the city have population densities of between 3 000 and almost 9 000. In recent years, the population has been growing at a particularly fast pace, mainly due to internal and international migration. However, population change is very unevenly distributed spatially. The north-western outskirts and suburbs of Vilnius are growing fastest and to some extent the eastern outskirts as well. The old housing estates in Vilnius City and the rural districts further away from the city are declining quite rapidly [106]. As the city densifies, the DH network is also planned to expand.

As more and more people move to cities, cities will need to be densified or expanded. Densification is a potential way to achieve more compact cities, combat sprawl and improve urban sustainability. Meanwhile, ageing buildings that need to be renovated or replaced offer an opportunity to develop modern projects that can reduce overall energy consumption while improving quality of life. The advantages of reconstruction and major modernisation with extension are densification, where more inhabitants can live in the same area. This can lead to energy savings in building maintenance and transport (reducing travel distances and associated congestion and/or pollution) [118].

Thermal energy density and potential for heat energy savings in Vilnius

The current thermal energy density in Vilnius City is shown in the figure below. The city is continuously renovating its buildings to maximise their energy efficiency and urban sustainability.

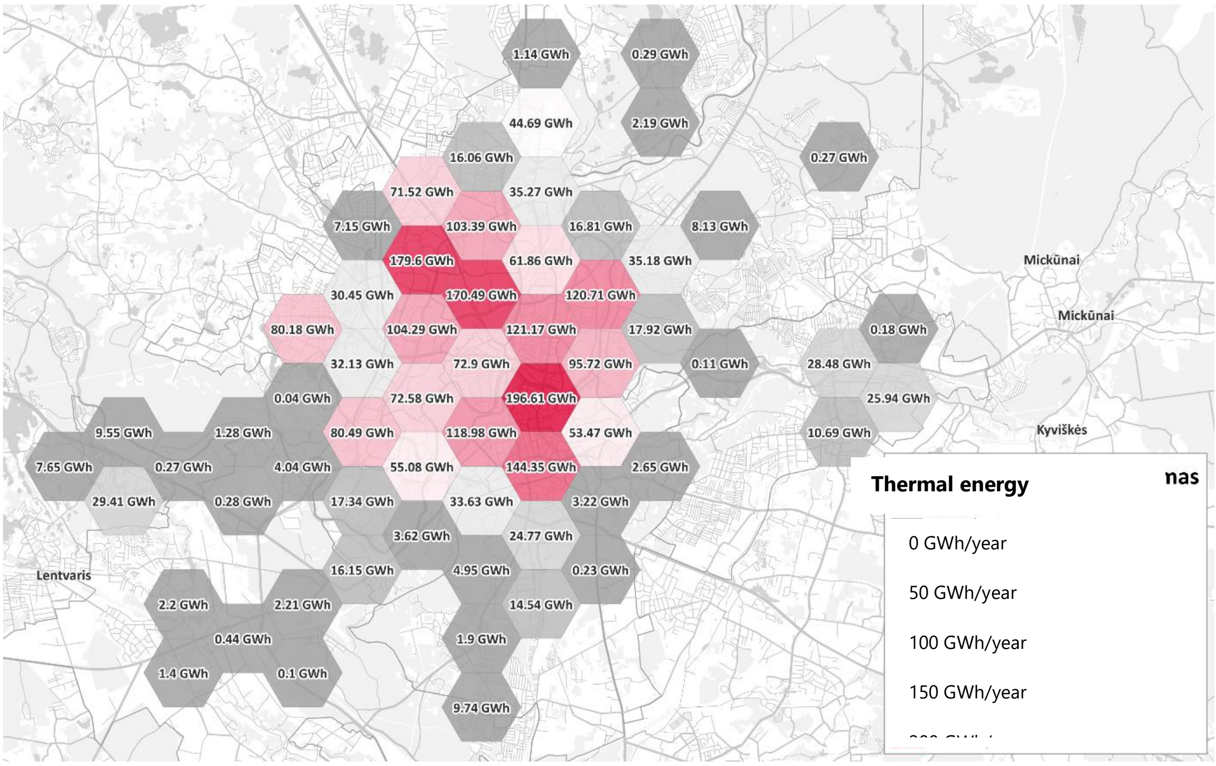


Figure 6-15: Yearly thermal energy density in Vilnius

In order to determine the potential for heat energy savings, the dataset of buildings to be renovated in Vilnius City Municipality was geo-referenced with the data of consumers of AB Vilniaus šilumos tinklai. The result was 2 880 buildings that are connected to the DH system and are suitable for renovation. The results of the savings potential obtained are presented in the figure below:

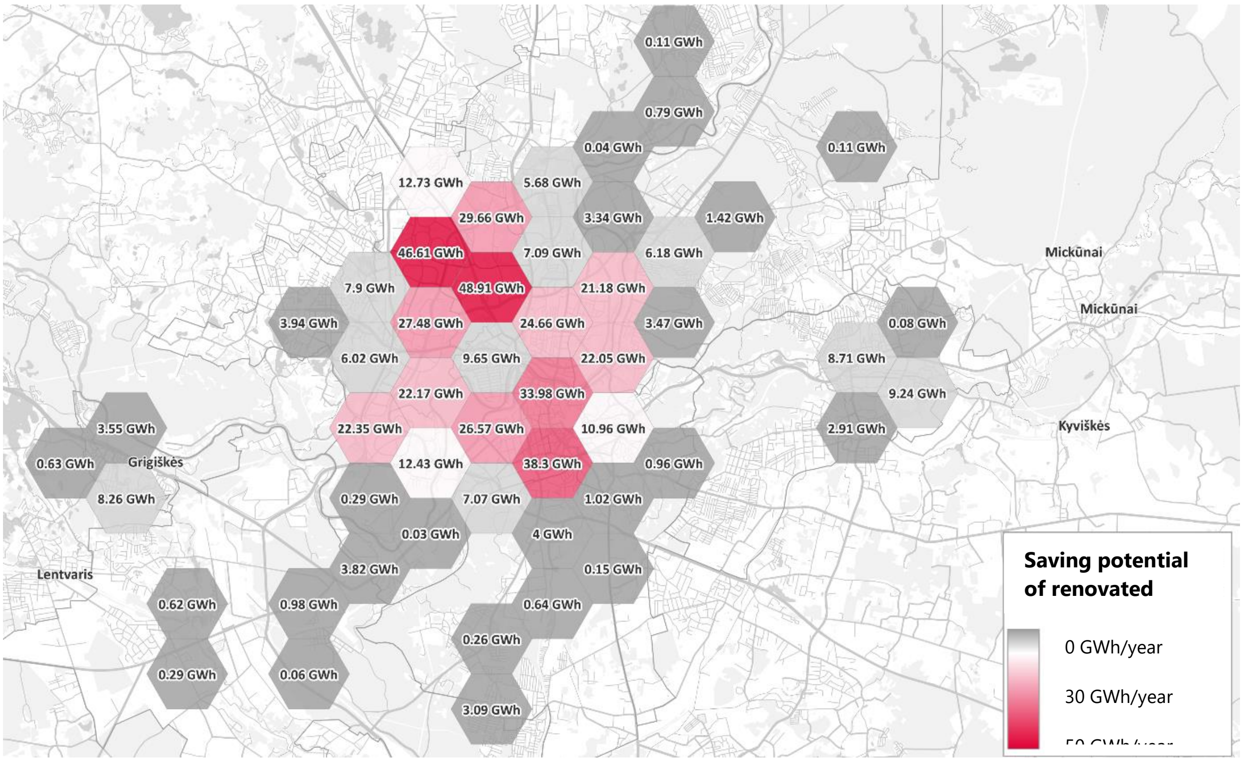


Figure 6-16: Potential for saving heat energy for space heating from the renovation of all multi-apartment buildings

It is estimated that the renovation of all the remaining apartment blocks to be renovated and connected to the DH system would result in savings of around 521 GWh/year of thermal energy for space heating. On average, the data shows that a renovation of a multi-apartment building can be expected to save about 181 MWh/year of heat energy. Using this indicator and assuming that at least 40 apartment buildings will be renovated per year, the potential for reducing heat energy demand due to the ongoing renovation of residential buildings in Vilnius City Municipality can be estimated at 7.24 GWh/year.

Investing in the expansion of the heat supply system

Vilnius is a rapidly growing and developing city in Lithuania, which is why Vilnius district heating networks are one of the few heat networks in Lithuania that are forecast to expand. Currently, the total length of pipelines in operation and in continuous use is 1 517 km (758 km in terms of route length). As of today, AB Vilniaus šilumos tinklai has made preliminary plans for the routes to be laid for the connection of some consumers or districts. For example, it is estimated that the connection of the Gulbinai district will require about 14.4 km of routes, the Pilaitė district may require about 36.2 km of routes, and the Pavilnionys district 13.1 km of routes. In addition, it is already foreseen that the network will need new transmission lines, one interconnector at the western bypass and another one to connect Dvarčionys district to the integrated network, totalling about 7.1 km.

The Special Plan for the Vilnius City Municipal Heat Industry is currently being finalised. This plan foresees additional development of district heating zones. If the intensity of the heat supply networks in the new zones is assumed to be at a similar level as in the existing DH zones, it can be expected that about 70 km of additional lines will be laid as part of the network expansion.

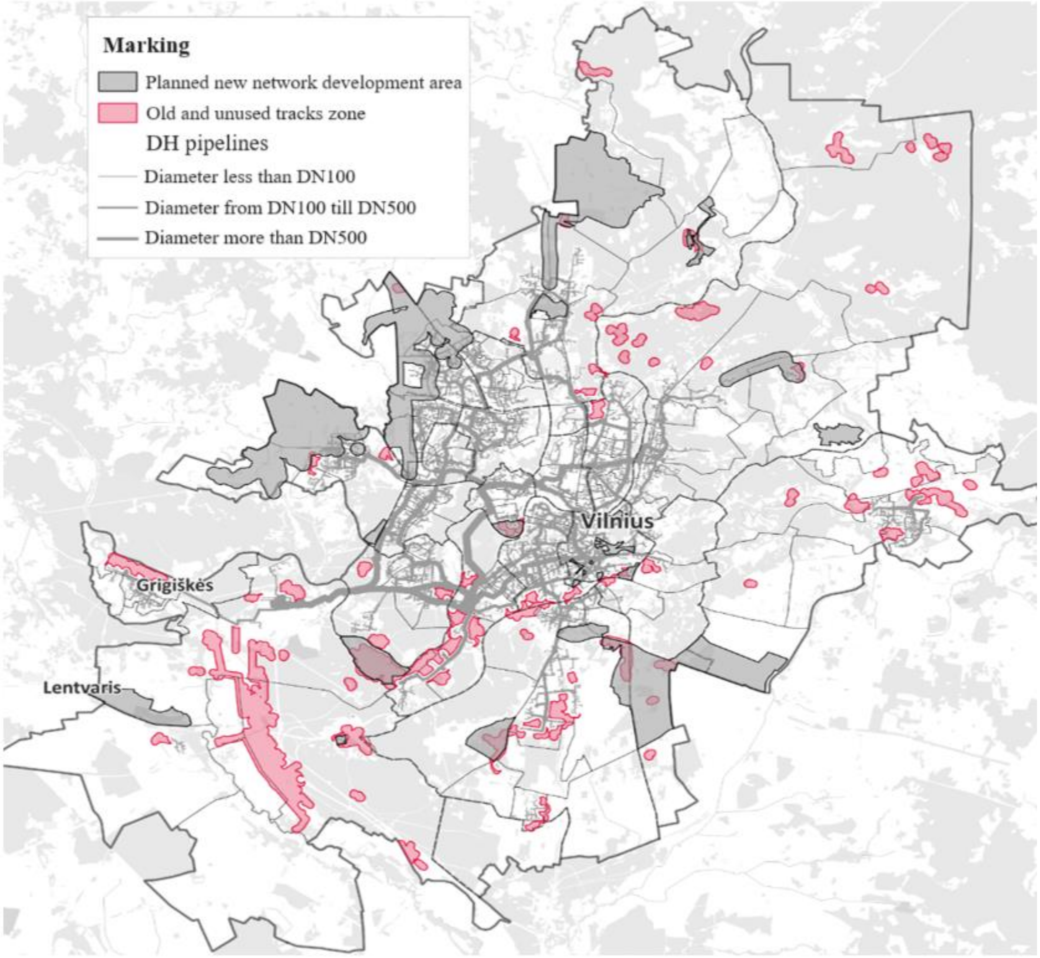


Figure 6-17: Potential development areas for the district heating network

In the map in Figure 6-17, the grey areas indicate areas where possible future network expansion is foreseen, in red the areas where heat networks were laid in the past, but for one reason or another they are now conserved and no longer in use.

Figure 6-18 below shows the prognosis of future head demand. It is estimated to grow by 0,8% each year.

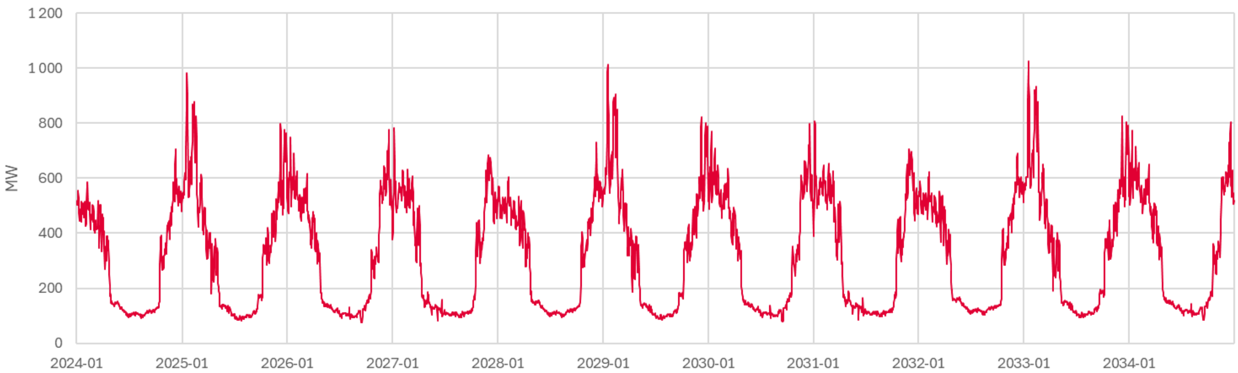


Figure 6-18: Heat demand prognosis for the coming 10 years. Source:[119]

National Energy and Climate Action Plan 2021-2030 foresees an increase in the number of new heat consumers connected to the DH system. The development of the heat sector in Lithuania will aim to centrally produced energy from renewable and local energy sources up to 100 % of total DH and at least 90% of buildings in urban areas are supplied with DH systems by 2050. It is estimated that as the number of DH customers grows, accompanied by rapid investments in more efficient energy consumption, by 2030 district heating systems will supply 8.5 TWh, and by 2050 – 8.0 TWh of heat energy.

According to the information provided by Lithuanian DH Association, 28 473 buildings in Lithuania were supplied with district heating in 2020. The total number of buildings supplied with district heating has increased on average by almost 1.1% per year since 2015 [102].

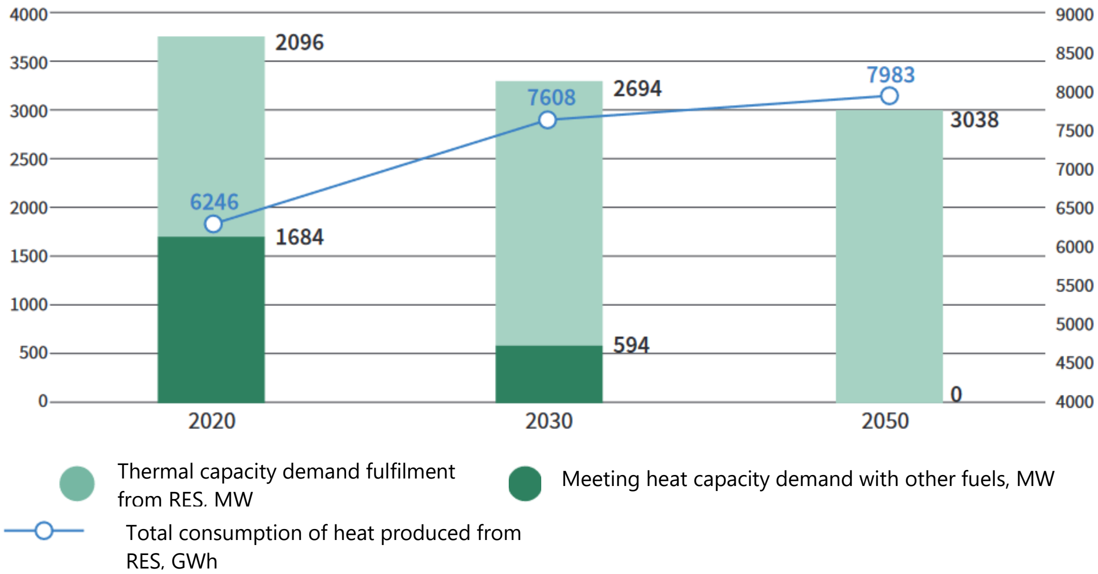


Figure 6-19: District heating capacity needs by fuel type Source: [120]

The greatest potential for improving energy efficiency lies in the renovation of buildings and the reduction of the energy intensity of industry. At the same time, other factors such as

climate change, changes in the building stock, and industrial development are also influencing heat demand.
Main changes in demand in DH sector from 2020 till 2050 [121]:

- **2020 demand: 9.480 GWh**
- Buildings renovation: -1.138 GWh
- Construction of buildings: +740 GWh
- Demolishing of buildings: -346 GWh
- Climate change: -704 GWh
- Increasing the efficiency of the industry: -735 GWh
- Development of industry: +1.108 GWh
- **2050 demand: 8.406 GWh**

To summarise the results of the assessment of the potential for DH development, the current potential for DH development is effectively exploited, with the potential of decentralised consumers to be connected not exceeding 2% of the total number of DH consumers. From 2020 to 2050, it is estimated that the planned connection will be around +650 GWh in the DH sector [121].

6.5 Expansion opportunities in Zagreb and Croatia

A considerable issue of district heating in Zagreb is that the heat production sites are located in the southern and northwest parts of the city and the network does not cover the central part of the city, including the old town. There is considerable potential for the extension of the district heating network in Zagreb City by connecting customers currently using individual natural gas boilers. New hot water pipes will be constructed to support future residential development zones across all parts of the city. There is also potential for the integration of Zagreb district heating with systems in Velika Gorica, Samobor, Zaprešić and other areas around Zagreb. In that way a metropolitan district heating system can be established.

The main goals of expanding district heating in Zagreb are as follows:

- Replacement of classic hot water pipes since the remaining traditional hot water pipes will be replaced to modernise the infrastructure.
- Increasing security of supply. To enhance the reliability of the heating supply, a connecting link between the EL-TO and TE-TO power plants can be constructed. This connection will traverse several key areas: Sajmišna cesta, D. Tomljenovića Street, Antallova Street, Cimermanova Street, Dubrovnik Avenue, and across the Sava River to Jarunska Street.

- Switching steam pipe consumers to hot water pipes. Consumers currently using steam pipes for heating will be gradually transitioned to a hot water network, enhancing efficiency and reducing reliance on steam.
- Achieving prerequisites for expansion and improvement of DHS hydraulics. The network will be enhanced by constructing connecting links between various parts, creating "rings" that improve hydraulic conditions and ensure a more stable supply.

The expansion and modernization of Zagreb's district heating system can provide a more reliable, efficient, and sustainable heating solution for the city's growing population.

6.6 Expansion opportunities in Bucharest and Romania

The Draft ENERGY STRATEGY OF ROMANIA 2025-2035, WITH THE PERSPECTIVE OF THE YEAR 2050 points that the final thermal energy consumption in the buildings sector represented 42% of the total final energy consumption in 2021, of which 35% is residential buildings, and 7% commercial and public buildings. Thermal energy demand is concentrated in the industrial, residential and service sectors. The residential sector has the largest share of energy consumption (about 83%), while all other buildings combined (offices, schools, hospitals, commercial premises and other non-residential buildings) account for the remaining 17% of total energy consumption the final.

Romania currently has a total of approximately 8.5 million homes, of which approximately 7.5 million are inhabited. Of these, approx. 4.2 million are individual homes, and approx. 2.7 million homes are apartments located in residential blocks (condominium). Only 5% of the apartments are energetically modernized through thermal insulation.

More than half of the homes in Romania are partially heated during the winter. Of the total number of homes, only approx. 1.2 million are connected to SACETs (approx. 600,000 in Bucharest).

A third of Romania's homes (almost 2.5 million) are heated directly with natural gas, using individual boilers, but also low-efficiency stoves (at least 250,000 homes). Approximately 3.5 million homes (the vast majority in rural areas) use solid fuel - mostly wood, but also coal - burned in low-efficiency stoves. The rest of the homes are heated with liquid fuels (oil, diesel or LPG) or electricity.

In the Bucharest Ilfov region - an area potentially covered by SACET, the potential for new consumers amounts to 2,000,000 people (The stable population of 1.83 million inhabitants (2019) makes Bucharest one of the largest cities in the European Union. According to some estimates that take taking into account the people without residence in the city, or in transit, Bucharest gathers more than three million people every day. To these is added the fact that the localities around the city, which are part of the Metropolitan Area, have a population of approximately 4,300,000 inhabitants) .

There is a potential for attracting new consumers. Currently, the cost is high, so people do not wish to have DH currently. If the price was lower, then maybe 2 million people would join, so focus on costs is important for further expansion. There are six "mini cities" built outside of Bucharest with 100,000 inhabitants each without DH – but they could be with DH. All areas within a new ring road around Bucharest could be supplied by DH.

7. Financing opportunities

Ambitions require money. Energy transition and decarbonisation in the district heating sector require significant capital expenditures (CAPEX) to be incurred. The spending must cover land, new heat production and storage technologies, new network infrastructure, digitisation of district heating and other energy systems in municipalities, and development of software tools and control algorithms. In addition, the specific costs of new technologies are high and in most cases, financial support is required. On the other hand investment capital is not easily available to district heating companies. External funds are regarded either as extremely or very important for undertaking investment projects.

Resources allocated to public support have been constantly increasing for the last decade. New funding programmes and mechanisms are continuously being developed at both national and European levels. Various funds are nowadays available from national and European institutions. For example, 37% of the National Recovery Plan (NRP) under the Instrument for Recovery and Resilience is to be allocated to climate objectives, including the clean energy transition, and 20% to digital transformation. Examples of new programmes include the auction mechanisms in the Innovation Fund, the LIFE-CET or InvestEU programmes. The list of EU funding opportunities for district heating includes the following sources:

- European Regional Development Fund (ERDF)
- Recovery and Resilience Facility (RRF)
- Horizon Europe Programme (HE)
- LIFE Programme
- European Innovation Council
- Innovation Fund
- Modernisation Fund
- Invest EU Programme

From 2026, EU member states will be able to use funds from the Social Climate Fund, which is EUR 86.7 billion fund to support energy efficiency measures and the decarbonisation of heating and cooling in buildings.

In principle, projects which are financed by European institutions should represent a certain degree of innovation. Commercial projects can be financed by national institutions within a number of national and local (municipal) programmes and funding schemes, including Recovery and Resilience Plans and international funding schemes based on bilateral agreements (e.g. Norway Grants).

Regarding innovation, project developers should have in mind the following definitions used in the Horizon Europe Programme, Innovation Fund and other programmes:

- Incremental innovation: minor changes or improvements to existing products, processes or business models; implies limited new knowledge/technology; such projects will not be retained;
- Intermediate or strong innovation: new or considerably changed technologies or processes or business models; novel combinations of mature technologies; scale-up of innovative technologies;
- Very strong or breakthrough innovation: completely new technologies or processes or business models; innovations leading to significant changes that transform entire markets or industries or create new ones.

To increase chances for public funding district heating companies must nowadays seek innovations in the following key areas:

- Considerable lowering of district heating network temperatures;
- Integration of renewable energy and waste heat sources with the district heating networks;
- Integration of district heating with other sectors such as electricity, cooling, industry and transport;
- Digitalisation and smartness;
- Storage;
- Flexibility and resilience through diffused production and storage assets;
- Integration of prosumers.

The biggest sources of EU funding nowadays are:

- Recovery and Resilience Plans with REPowerEU chapters, with EUR 20 billion budget for grants for 27 EU member states;
- Innovation Fund with estimated budget of EUR 40 billion available for 2020 – 2030 (assessed using ETS EUA price of EUR 75/tonne).
- LIFE CET Programme with the budget of EUR 1 billion over the period of 2021-2027.

Small projects can be also funded by

- International Energy Agency District Heating And Cooling Technology Collaboration Programme (only for eligible countries)
- Danish Energy Agency (only for eligible countries)

An emerging source of financing district heating projects in Europe is private capital. Private financing is gradually becoming fundamental to accelerate the decarbonisation of district heating systems. This is because a significant gap exists between the needs of district heating companies and the availability of public capital resources. According to Euro Heat and Power, this gap is estimated at EUR 65 billion by 2030. On the other hand, due to the increase of awareness of private investors and the relatively stable and long-term climate and energy policy of the European Union, many companies have started looking for opportunities for investing in energy transition projects. Usually different Third Party Financing (TPF) schemes are taken into consideration.

A solution can be also so-called crowdfunding, which is nowadays gaining popularity. This is a form of alternative finance, which allows funding a project by raising small amounts of money from a large number of people, usually via web-based platforms. In such a scheme, diffused investors can potentially accept lower returns on investment and longer payback periods in exchange for tangible social and environmental benefits.

8. Summary

This SET_HEAT project's report has investigated past developments and future development prospects of district heating both from a general perspective focusing on trends in energy system transition and from a local perspective looking at the four different SET_HEAT sites and countries in more general.

Important for the future evolution of the district heating sector is the integration with other sectors to exploit synergies and provide energy system services that enable the transition to a carbon-neutral energy supply largely based on RES. This includes

- CHP where this has not already been implemented largescale including the use of thermal storage to provide flexibility for help integrating variable RES into the electricity system
- Sector integration with electricity through heat pumps and electric boilers to exploit electricity production when supply from variable RES is abundant
- Sector integration with P2X and transportation to draw on the significant waste heat resources from this activity which is expected to grow significantly in the future due to indirect electrification of the parts of industry and transportation where direct electrification is not feasible.

- Sector integration with cooling, where particularly the two latter generations of district cooling focus on the wider energy system efficiency through the exploitation of heat from compression chillers to assist the district heating system.
- Sector integration with industry and service sector to exploit waste heat resources. As noted in Section 1.2, recoverable waste heat was in 2015 estimated at 43% of the total fuel input to power generation and industry in Europe

For all integration with the electricity sector, it includes realising appropriate flexibility through acting in relevant electricity markets to maximize utility and economic performance. As an example, it is shown how an existing Danish district heating station equipped CHP, an electric boiler and more can even have CHP and electric boiler operating at the same time. This would be an operation defying the logic of an hourly day-ahead market – but not when taking intraday markets into account.

Further exploitation of RES is clearly an important element, but while there are general categories, consideration and selection are clearly a local matter. This exploitation can be combined with sector integration with electricity through heat pumps drawing on ambient heat sources – and clearly with electricity in general once electricity transitions to RES supply also. Other main RES options include biomass and solar energy.

Assisting the transition is a lowering of district heating temperatures from superheated water towards temperatures below 100°C. This can be 80/90° as in 3rd generation district heating or even lower as in 4th generation district heating. This will decrease losses in district heating systems and improve efficiencies in CHP and heat pumps. This would also enable better utilisation of waste heat resources without having to undergo temperature boosting as well as facilitate the use of solar collectors.

A main motivating factor is the current climate and energy policy of the European Union, which calls for increasing levels of CHP and RES in the energy supply, but from the case descriptions, the decision criteria are mainly economic. Decision-making is a complex issue as district heating can be a politicised area with concerns transcending the mere supply of heating to also include social effects and thus ultimately a just transition. According to the survey among district heating companies, the top five key drivers of energy transition in the district heating sector are nowadays increasing prices of EU ETS emission allowances, decreasing acceptance of fossil fuels, increasing prices of fossil fuels, municipal energy efficiency and climate protection programmes and increasing public awareness regarding climate and energy issues.

The SET_HEAT cases all work with the transition, and on phasing out old and obsolete technologies with poor economic and or environmental performance and phasing in newer and better technologies ranging from modern CHP units to heat pumps.

The city cases also demonstrate large development prospects for district heating. In general, there is a move from rural areas to urban areas which increases the heat demand concentration and thus improves prospects of district heating. It is however also clear from the cases that there is a large potential in simply increasing connection rates. While this is 99% for a place like Copenhagen, the SET_HEAT cities have more varied heating technologies deployed – even within areas with district heating.

In Poland, stringent economic regulation of the district heating market is seen as a factor which hinders energy transition and decarbonisation. Adapting the legal framework is necessary to enhance investment and operational flexibility for district heating companies. New heat tariff rules should increase flexibility, influence consumer behaviour, incorporate seasonality, and consider the marginal cost of heat generation. This is supported by the questionnaire, which further identifies:

- lack of adequate transposition of EU directives into national law,
- inconsistency of national law,
- lack of appropriate system solutions (legal regulations), which are crucial from the economic point of view of conducting the business of supplying heat to consumers, e.g.:
  - lack of possibility to apply dynamic tariffs,
  - regulated heat prices for generation.
  - fixed heat prices during the tariff period
  - lack of possibility to generate profit on heat trading
  - no regulation dedicated to cost sharing in case of cogeneration (CHP).

The questionnaire – mainly with inputs from Polish respondents (12/14) was very clear on external funding, with all respondents saying that external fundings is very or extremely important for the decarbonisation of the district heating sector. 82% of the respondents furthermore indicated that existing opportunities are insufficient.

For Lithuania, a literature review revealed barriers or threats to the transitioning and expansion of district heating systems

- Lack of feasible demand response business models and regulatory frameworks
- Dwindling human resources
- Reluctancy to apply academic research results in real-life application
- Intermittent and inconsequent application of policies to support demand response, RES, and district heating and cooling
- Low penetration rate and period between planning and commissioning of district heating and cooling systems
- Lack of funding for energy efficiency technologies.

In Croatia, a generally high energy intensity was identified, along with a lack of support for RES as well as social support mechanisms for energy consumption. Financing of energy efficiency measures is scarce while on the other hand, lack of competition and allocation of public funding also impacts application negatively. Within biomass more explicitly, a series of constraints include procedures, logistics, knowledge gaps, and more.

In all countries, district heating companies must seek opportunities, which are favourable external elements in the socio-economic environment that can be used to develop effective decarbonisation solutions and carry out a successful energy transition. The key ones can be summarised as follows:

- Growing awareness of the global energy transition among consumers and the opportunity to take action to protect the climate. Declining acceptance of fossil fuels.
- An ageing population, so that an increasing number of people may prefer systemic solutions.
- Climate change, increasing ambient temperature, and reduced probability of severe winter conditions for which existing systems were designed.
- Increasing the capital resources being allocated to public support under both national and European programmes.
- Growing awareness of the global energy transition among potential investors (private equity owners, investment funds) and awareness of the value creation opportunities of decarbonised products and services.
- The projected long-term increase in the price of CO_2 allowances in the EU ETS promoting investment in zero-carbon sources. In the survey responses, this was the most important factor influencing action toward decarbonisation planning.
- Introduction of ETS2 in 2027, which will increase the competitiveness of DH solutions against individual heating based on fossil fuels.
- Considerable increase in installed and achievable capacity in RES sources in the electricity sector.
- Growing demand for grid stabilisation and support services in the electricity sector. Opportunity to work in the balancing market for Demand Side Response (DSR) services Unlike individual heat pumps, district heating has the opportunity to use technological diversification, decarbonised fuels and heat storage to reduce the load on the electricity grid during peak loads and capacity shortfalls.
- Possible reduction in the level of market electricity prices (only in favourable scenarios for the development of the national energy system).
- Economies of scale allowing the district heating company to obtain lower prices for energy carriers, e.g. electricity on the competitive market, and lower unit investment costs.

- Growing number of new technologies for district heating (e.g. industrial heat pumps, seasonal heat storage).
- Much greater flexibility for technology uptake and diversification, and typically much more favourable energy efficiency ratings for high-power equipment.
- Greater capability to store various forms of energy, including fuels.
- The opportunity to exploit synergies arising from system integration.
- Local actions of municipalities aimed at energy management and improvement of energy efficiency and new investments in this area.
- Further regulatory pressure towards decarbonisation of the buildings sector and the phasing out of fossil fuels from the sector, including limiting the scope for escape from the ETS by lowering the entry power threshold and introducing ETS2. This has the effect of encouraging an increase in the competitiveness of system heat.
- The need to meet the requirements of the revised EPBD and the limited technical feasibility of its implementation in high-density urban settings. In light of the lack of natural gas, which has so far been a competitive solution to district heating, district heating may be the only acceptable alternative.
- The need to decarbonise the transport and industrial sectors, which can be used by district heating companies to create a new local offer of both decarbonised products and services (e.g. system cooling). Such an offer can become the basis for entrepreneurs to locate activities, including so-called new businesses and start-ups, in municipalities where systems are available to reduce the carbon footprint of end products and services, and can therefore be a driver for local economic growth.
- New energy planning obligations for municipalities under the EED and RED III directives.
- Significant increase in the number of new buildings to a high energy standard.
- Progressing programme to reduce energy intensity and modernise buildings. Further investment in deep refurbishment is driven by the need to meet the requirements of the EPBD.
- Local air quality improvement programmes in municipalities.
- First experiences in the reduction of water temperature in district heating networks. Technology offers, and first implementations of zonal connections of high-temperature district heating zones to low-temperature district heating zones by implementing local mixing systems.
- Growing technology portfolio for digitisation of district heating networks and smart grid technology for district heating.
- The search by renewable electricity generators for bilateral contracts with consumers that avoid forced outages of RES sources and ensure an acceptable price level. Emergence of new structured product offerings (e.g. electric boiler with storage and electricity).

The are also considerable threats to the effective energy transformation of the district heating sector. Those are unfavourable elements or events in the socio-economic environment that may result in the failure to achieve the assumed objectives and prevent the achievement of the status of an efficient district heating company. The main risks arise primarily from insufficient action to remove identified barriers and reduce investment risks. In addition, significant threats to district heating include:

- An enormous scale of transformation, which is required both sectorally and geographically. Decarbonisation efforts are required across all sectors of national economies resulting in competition for scarce capital resources.
- The massive scale of investment and modernisation (replacement) projects required across the entire heating sector, due to the limited action to date aimed at moving away from fossil-fuel monoculture and the rapid pace of change required by the EED.
- Potential loss of access to some external funding programmes due to failure to become an efficient district heating company on time.
- Insufficient involvement of consumers in the transition process due to lack of knowledge and trust.
- Still high competitiveness of gas-fired CHP sources.
- Inadequate pace of implementation of EU energy and climate policies, including in the electricity and fuel sectors.
- The likelihood of insufficient development of generation and transmission infrastructure in the electricity sector in Poland, including the increasing likelihood of power shortages in the system.
- Increasing competition in the electricity market resulting from the electrification of transport, hydrogen and power-to-X projects, which may increase electricity prices. An increasing number of hydrogen projects.
- Low awareness of external stakeholders regarding their role in the heat transformation and limited willingness to participate and act. For example, efforts to identify and integrate waste heat sources into the energy system are characterised by low participation of industry stakeholders.
- Reluctance of industrial companies and inability to reach appropriate agreements and business models for introducing waste heat into the district heating network.
- High uncertainty about the long-term availability of waste heat sources as a result of changes in industrial production.
- Worsening of competitiveness due to the increase in the cost of heat generation resulting from the increase in the price of CO_2 emission allowances in the EU ETS. Inability to build up own capital resources.

- Inability to carry out deep renovation as defined in the EPBD revision proposal and achieve highly energy-efficient building stock due to insufficient availability of funds in municipalities.
- Increased supply and significant development of individual heating technologies for buildings (e.g. heat pumps, fuel cells, etc.).
- Potential disconnection of industrial customers from carbon-intensive district heating systems due to their efforts to reduce the carbon footprint of products and services.
- Development of new, competitive organisational structures such as energy cooperatives, energy hubs with complex technological structures and others on the consumer side, which may result in the disconnection of consumers from the district heating system.
- Insufficient availability of land for the development of RES heat sources.
- Insufficient industrialisation of municipalities and lack of waste heat.
- Increasing likelihood of events of a natural disaster or armed conflict nature.

9. Conclusions

The district heating systems we know today in countries participating in the SET-HEAT project were largely defined in the second half of the 20th century and replicated as a result of technological developments and choices made by decision-makers, energy consumers, energy companies, and energy companies. Anticipating the future shape of district heating in Croatia, Lithuania, Poland, and Romania is a challenge. The expected transition, which according to the revised Energy Efficiency Directive should take place by 2050, assumes a shift from fossil fuel-fired systems to systems with a significant proportion of various forms of renewable energy and waste heat. This leads to radical change in the district heating generation and transmission infrastructure, including technologies, heat sources, storage, and organisational and asset management approaches. Taking into account current practices, one can conclude that some tasks are difficult and significantly go beyond the state-of-the-art, requiring new knowledge, skills, and creativity, which would create a new framework for the operation of district heating systems.

From a technical point of view, the energy transition and decarbonisation of district heating are not a major issue. There are many already mature technologies, that nowadays may enable district heating companies to meet requirements of legal regulations. The issues are however the socio-economic cost of the change and the competitiveness of district heating against individual heating solutions. There are also issues of systemic, infrastructural, legislative, economic, business and social nature. Implementing changes in those areas is a long-term and iterative process and requires significant resources. Undoubtedly, district heating companies must seek opportunities, that will allow them to develop effective and sometimes unique systemic solutions.

Opportunities exist and their number is constantly growing. There is already a certain base of knowledge and good practices, and many projects' examples are oriented towards the use of renewable energy sources and waste heat. This is however not enough to formulate clear and comprehensive recommendations. Many of the existing opportunities are site-specific. In many cases, the opportunities that exist are not obvious or easily identifiable. Much needs to be initiated by well-targeted collaboration between local stakeholders. For example, important opportunities for decarbonising district heating may arise when investments in other sectors are attracted to cities or when urban multi-energy systems are established. With all certainty, it can also be concluded that making full use of existing opportunities requires district heating companies to acquire new knowledge and develop new skills and competences that will enable them to go beyond their current operating framework and take on the challenges of the broad energy market.

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Appendix - Survey among DH companies

The survey is still ongoing and can be accessed at https://ec.europa.eu/eusurvey/runner/OandT_DH

Contribution ID: f694daf5-e76d-4a04-80e8-1a4405126aee
Date: 18/06/2024 11:43:43

Survey on the perception of opportunities and threats for district heating

SET HEAT

Co-funded by the European Union

Supporting Energy Transition and Decarbonisation in District Heating Sector
https://setheat.polsl.pl/

Disclaimer
Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

The SET_HEAT project aims to integrate low-temperature renewable and waste heat sources into district heating networks, allowing the elimination of fossil fuel combustion. Opportunities for decarbomnisation must be explored and threats identified.

In this questionnaire we wish to explore readiness of key actors to transition existing systems. It also aims to identify long-term perspectives on changes in energy system structure and operations.

Note. The survey is in English. In case you need it translated, use the translation capability of your browser. Right click mouse button and choose translate into ... option.

Also note. We do not collect contact details in the survey. To recieve project updates, please register at **htt ps://set_heat.polsl.pl.**

Respondent characterisation

1. Company/Organisation name

2. Country

3. Stakeholder type
- District heating heat producer
- District heating distribution company
- Municipality
- Energy community
- District heating organisation
- Other

If other, please specify.

4. Respondent type
- Decision-maker or co-decision-maker
- Analyst or other function supporting the creation of decision-making material
- Consultant
- Other

If other, please specify.

5. Education
- Craftsmanship
- Engineering
- Natural science
- Economics
- Organisation and Management
- Other

If other, please specify.

1 General perception

1.1. Do you think the energy transition and decarbonisation in district heating sector is necessary?
- Yes
- No
- Don't know

1.2. Do you think the district heating sector may benefit from energy transition?

- Yes
- No
- Don't know

1.3. Which of the following opportunities are important for planning future district heating systems?

1.3.1. Investments in solar and wind technologies in the electric power sector

1.3.2. Emerging markets of alternative fuels (hydrogen, ammonia, methanol, e-fuels, etc.)

1.3.3. Growing demand for grid stabilisation services in the electricity sector

1.3.4. Increasing public awareness regarding climate and energy issues

1.3.5. Decreasing electricty market prices

1.3.6. Growing demand for electric energy storage

1.3.7. Growing demand for lowering carbon footpring in industry

1.3.8. Municipal energy efficiency and climate protection programmes

1.3.9. New obligations for municipalities regarding energy planning, which result from the European Union's Energy efficiency directive (EED) and Renewable Energy Directive (REDIII)

1.3.10. New urban developments

1.3.11. Decreasing acceptance of fossil fuels

1.3.12. Increasing prices of fossil fuels

1.3.13. Increasing carbon prices (emission allowances)

1.3.14. Revised policy targets and upcoming legal regulations

Other opportunities:

1.4. How important is external funding for energy transition and decarbonisation of your district heating company.

- Extremely important
- Very important
- Somehow important
- Neither important nor unimportant
- Almost unimportant
- Unimportant

1.5. Do you think existing funding opportunities are sufficient for effective decarbonisation of district heating sector?

- Yes
- No
- Don't know

1.6. What funding programmes do you know? (Provide names)

1.7. How do you intuitively perceive the relevance of different district heating technologies as future investment options in the context of your district heating system?

1.7.1. Gas engine CHP

Free comment on gas engine CHP

1.7.2. Gas turbine CHP - simple cycle

Free comment on gas turbine CHP - simple cycle

1.7.3. Gas turbine CHP - combined cycle

Free comment on gas turbine CHP - simple cycle

1.7.4. Biomass CHP

Free comment on biomass CHP

1.7.5. Heat only boilers - gas

Free comment on gas fired heat only boilers

1.7.6. Heat only boilers - biomass

Free comment on biomass fired heat only boilers

1.7.7. Heat only boilers - hydrogen, ammonia, methanol, etc.

Free comment on boilers fired with alternative fuels

1.7.8. Waste fired boilers (CHP and heat only)

Free comment of waste fired boilers

1.7.9. Electric boilers

Free comment on electric boilers

1.7.10. Heat pumps

Free comment on heat pumps

1.7.11. Solar thermal technologies

Free comment on solar thermal technologies

1.7.12. Waste heat recovery technologies

Free comment on waste heat recovery technologies

1.7.13. Power-to-X technologies

Free comment on power-to-X technologies

1.7.14. Daily (short-term) heat storage

Free comment on daily heat storage

1.7.15. Seasonal (long-term) heat storage

Free comment on seasonal heat storage

1.8. What do you think are the key elements for building a vision and effective decarbonisation strategy for the district heating sector?

2 Expertise and skills

2.1. Does your district heating company have the internal capacity to assess technical and economic feasibility of investment opportunities?

- Yes
- No, it fully relies on external consultants
- Partialy, some studies are performed in-house
- Don't know

2.2. What expertise is missing on board to ensure effective planning?

- None, the required expertise is on board.
- Technology performance modelling
- DH system modelling – energy modelling
- DH system modelling – hydraulic modelling
- Strategy development - Financial modelling
- CO2 emission avoidance modelling
- Writing project proposals

Other (please specify)

2.3. Do you use third-party consulting for strategic planning?

- ☐ Yes
- ☐ No

If yes, please specify services you order?

- ☐ Technology sizing and system simulations/energy balancing.
- ☐ Techno-economic studies.
- ☐ Hydraulic calculations/simulations.
- ☐ Legal expertise
- ☐ Environmental studies.
- ☐ Development of new business models.

Other services

2.4. Are external consulting services easily available?

- ◯ Yes
- ◯ No
- ◯ Don't know

2.5. Is there a dedicated group of people (team) working on strategic planning in your company/organisation?

- ☐ Yes
- ☐ No

2.6. Do you use any specific software for planning for planning or assessing investment options?

- ☐ Yes
- ☐ No

If yes, please specify what software you use:

2.7. What do you think are the most critical hurdles of energy transition planning in your company?

- ☐ Lack of knowledge about available technologies.
- ☐ Lack of skilled personnel.

- ☐ Lack of relevant software tools.
- ☐ Low awareness about forthcoming changes.
- ☐ Lack of willingness to change business-as-usual practices.
- ☐ Low level of collaboration with external stakeholders (e.g. municipality, policymakers, etc.).
- ☐ Lack of knowledge about potential funding sources.
- ☐ Lack of experience and expertise in running DH systems with multiple distributed sources of low-grade heat.
- ☐ Uncertain legal framework.
- ☐ Uncertain future of the energy market overall.
- ☐ Lack of well-established strategic planning practices.
- ☐ Low level of risk acceptance.
- ☐ Complicated administrative and decision-making procedures.
- ☐ Lack of external support due to unavailability of competent consultants or high costs.

Other

3 Planning practices

3.1. When changes are happening at your district heating company? Weigh importance of the following drivers:

3.1.1. Replacement of old technology beyond its technical/economic lifetime

3.1.2. Environmental concerns

3.1.3. Customer demand

3.1.4. Legal requirements

3.1.5. Funding opportunities

3.1.6. Competition

3.1.7. Technological innovations (new technologies)

3.1.8. Cost effectiveness

3.1.9. Public acceptance

Other driver, please specify.

3.2. Are goals of development planning explicitly and clearly defined?

- Yes
- No
- Don't know

3.3. Is energy transition and decarbonisation planning a standard (daily) activity in your comapny/organisation?

- Yes
- No

3.4. Do you cooperate with external stakeholders in strategic planning?

- Yes
- No

If yes, please specify groups of stakeholders you engage with.

3.5. Are plans communicated to external stakeholders?

- Yes
- No
- Don't know

3.6. Does the municipality have a steering/advisory committee to support the planning and implementation of tasks by the district heating companies?

- Yes
- No
- Don't know

3.7. Is planning of heating and cooling an integral part of the Municipal Planning (eg. spatial planning)?

- Yes
- No
- Don't know

3.8. Do you use published guidelines and manuals, which result from EU funded projects?

- Guidelines for strategic planning and lessons learned.
- Guidelines for lowering grid temperatures and lessons learned.
- Guidelines for overcoming barriers.
- Investment project development practices.
- Approaches to engage external stakeholders.
- Approaches to prioritisation of connections of identified renewable and waste heat sources (which one to connect first).
- Approaches to prioritisation of operation of connected heat sources.
- Technology recommendations.
- Business models.
- No, we don't use such documents

Other guidelines (please specify)

3.9. Are general data for the regional energy system collected and taken into consideration?

- Yes
- No
- Don't know

3.10. Do you use geographic information systems to map the resources you have identified?

- Yes
- No
- Don't know

If yes, what components are mapped?

- Heat sources
- Heat sinks
- Temperature zones
- Available terrain
- Other

If other, please specify.

4 Envisioned changes in the existing generating stock

4.1. Specify your current heat generating stock.

- [ ] Coal-fired heat only boilers
- [ ] Gas-fired heat only boilers
- [ ] Biomass-fired heat only boilers
- [ ] Coal-fired CHP (steam turbines)
- [ ] Gas-fired CHP
- [ ] Biomass-fired CHP
- [ ] Heat pumps - air source
- [ ] Heat pumps - ground source
- [ ] Heat pumps - water source
- [ ] Geothermal
- [ ] Industrial waste heat
- [ ] Other waste heat
- [ ] Other

If other, please specify.

4.2. What is the heating capacity currently installed in existing heat sources?

4.3. Does you distric heating system meet the criteria of efficient system according to the revised Energy efficiency directive (Regulation (EU) 2023/955)?

- ◯ Yes
- ◯ No
- ◯ Don't know

4.3.1 If no, does the plan to meet those criteria exist or is being developed?

- ◯ Yes
- ◯ No
- ◯ Don't know

4.3.2 If the plan exists or is being developed, which year your district heating system will meet the criteria?

- [ ] 2028
- [ ] 2035
- [ ] 2045
- [ ] 2050
- [ ] Don't know

4.4. Who delivers heat to the heating network?

- ◯ Heat is supplied from own heat sources of the district heating company
- ◯ Heat is supplied by external suppliers, the cost is based on tariffs
- ◯ Heat is supplied by external suppliers, the cost is based on auctions
- ◯ Heat is supplied from own sources and by external suppliers (mixed)

Do you have further comments on heat supplies?

4.5. Are there any current production technologies that your DH company is considering phasing out / discontinuing the usage of?

- ◯ Yes
- ◯ No
- ◯ Don't know

4.5.1. If yes, specify which technologies are considered to be phased out.

- ☐ Coal-fired heat only boilers
- ☐ Gas-fired heat only boilers
- ☐ Biomass-fired heat only boilers
- ☐ Coal-fired CHP (steam turbines)
- ☐ Gas-fired CHP
- ☐ Biomass-fired CHP
- ☐ Other

If other, please specify.

4.5.2. If yes, when the indicated technologies will be phased out?

- ☐ At the end of technical life-time
- ☐ At the end of economic life-time
- ☐ Before the end of technical life-time
- ☐ Before the end of economic life-time

4.5.3. If yes, what are the reasons for phasing out the indicated technologies?

- ☐ Legal regulations
- ☐ Economic performance
- ☐ Environmental performance
- ☐ Technical conditions
- ☐ Problems with fuel supply
- ☐ Public acceptance
- ☐ Other

If other, please specify.

4.5.4. If no, will you consider phasing out existing heat generation technologies in the future?

- Yes
- No, we expect to continue with the present type of production technologies
- No, we expect to continue with the present type of production technologies but supplementary options are considered
- Don't know

4.6. Is your DH company is considering phasing in new technologies?

- Yes
- No
- Don't know

4.6.1. What technologies are considered to be phased in?

- A. Gas engine CHP - natural gas fired
- B. Gas engine CHP - hydrogen fired
- C. Gas engine CHP - other fuel (e.g. biogas)
- D. Gas turbine CHP - natural gas fired
- E. Gas turbine CHP - natural gas + hydrogen
- F. Gas turbine CHP - other fuel
- G. Combined gas and steam turbine cycle CHP - natural gas fired
- H. Combined gas and steam turbine cycle CHP - natural gas + hydrogen
- I. Biomass-fired CHP (steam turbine of ORC)
- J. Biomass gasification integrated CHP
- K. Heat only boilers - coal
- L. Heat only boilers - natural gas
- M. Heat only boilers - biomass
- N. Heat only boilers - RDF or non -conventional fuel
- O. Heat only boilers - methanol
- P. Heat only boilers - hydrogen
- R. Heat only boilers - ammonia
- S. Electric boilers
- T. Heat pump - ground source
- U. Heat pump - water or waste water source
- W. Heat pump - air source
- X. Solar thermal plant
- Z. Geothermal plant
- ZA. Waste heat from third parties - high temperature / direct use
- ZB. Waste heat from third parties - low temperature / through heat pump
- ZC. Heat storage tanks - short-term storage
- ZD. Large scale heat storage - seasonal storage
- Other

If other, please specify

4.6.2. What is the state of play?

- [ ] A. Early planning
- [ ] B. Prefeasibility studies triggered
- [ ] C. Prefeasibility studies completed
- [ ] D. Feasibility studies initiated
- [ ] E. Feasibility studies completed
- [ ] G. Positive investment decisions taken
- [ ] H. Investment projects triggered
- [ ] I. Financial close reached
- [ ] J. Key contracts signed
- [ ] K. Ongoing construction works

Match technologies to the project development stage (use symbols from 4.6.1 and 4.6.2, for example A -B, E - D).

4.6.3. In case you consider renewable energy and waste heat sources, which resources have you identified?

- [ ] Available biomass
- [ ] Available land for solar plants
- [ ] Geothermal resources
- [ ] Water or waste water sources for heat pumps
- [ ] Available land for ground source heat pumps
- [ ] Available land for air source heat pumps
- [ ] Sources of industrial waste heat
- [ ] Other sources of waste heat
- [ ] Demand for cooling where potenetially heat pumps can be implemented
- [ ] Other

If other, please specify.

4.6.4. Do you consider conversion of your district heating system into a multi-energy system by implementation of power-to-X technologies?

- [ ] Yes, we consider hydrogen technologies (e.g. electrolysis)
- [ ] Yes, we consider hydrogen technologies and conversion of hydrogen to other carriers (e.g. SNG, ammonia, etc.)
- [ ] Yes, we consider hydrogen technologies and use of captured CO2 (e.g. from cement plants)
- [ ] Yes, we consider hydrogen technologies and production of e-fuels
- [ ] Yes, we consider biorefinery

- [ ] No, we do not consider new businesses
- [ ] Other

If other, please specify

4.6.5. Do you consider investing in renewable power generation technologies?

- [ ] Yes, we consider own PV plant/plants
- [ ] Yes, we consider distributed small wind turbines with vertical axis
- [ ] Yes, we consider wind turbines in rural areas outside the city
- [ ] No
- [ ] Other answer

If other, please specify

4.6.6. Which location of the new production assets do you consider?

- [ ] Central at existing heating plant
- [ ] Distributed locations away from the existing heating plants
- [ ] Combination of central and decentralised locations.

Do you have any comments regarding the location?

4.7. Do you consider appearance of heat prosumers in your district heating system?

- ○ Yes
- ○ No
- ○ Don't know

4.8. Is the creation of a local competitive heat market for suppliers of waste heat or renewable heat being considered?

- ○ Yes
- ○ No
- ○ Don't know

4.9. Has the possibility of creating a central cooling market been either considered or identified?

- ○ Yes
- ○ No
- ○ Don't know

4.10. Does the district heating company's development plans take into account the possibility of creating new service markets (e.g. emergency power offtake services from the electricity system)?

- Yes
- No
- Don't know

4.11. Is a plan being developed to reduce the temperature of the network water?

- Yes
- No
- Don't know

5 Making decisions

5.1. When assessing investment options, what factors influence the decision-making in your district heating company?

Rank the following parameters.

5.1.1. Business economic feasibility

5.1.2. Technical integration with present system

5.1.3. Strategic development in generating stock

5.1.4. Environmental performance

5.1.5. Compliance with national/EU strategy for district heating

5.1.6. Compliance with climate and energy policies

5.1.7. Compliance current legal regulations

5.2. What economic assessment method do you apply?

- ☐ Net Present Value (NPV)
- ☐ Internal Rate of Return (IRR)
- ☐ Payback time
- ☐ Cost of heat per GJ
- ☐ Other
- ☐ Don't know

If other, please specify

5.3. What discount rate do you use in net present value calculations/threshold for internal rate of return?

- ○ Obligatory, set by legal regulations
- ○ Self assessed
- ○ Don't know

If possible, please specify value in [%]

5.4. Do you take into consideration external costs and benefits?

- ○ Yes
- ○ No
- ○ Only if required by funding organisation
- ○ Don't know

5.5. What time horizon do you use in the economic assessment of investment projects?

- ○ Same as technical lifetime of a specific technology
- ○ Same as technical lifetime of the most durable technology alternative
- ○ Fixed value
- ○ Other

If fixed value or other, please specify

5.6. What is your apparaoch in case several projects are analysed in a strategic development scenario?

- ○ Each project is analysed individually
- ○ Projects are analysed all together using the same starting year
- ○ Projects are analysed all together assuming a time sequence of their implementation

5.7. Does your district heating company perform overall energy system analyses/simulations to assess technical and economic feasibility of investment opportunities?

- Yes
- No
- Other answer

If other, please specify

If yes, please specify the tools you use.

5.8. Do you simulate the investment's electricity market behaviour for instance in the Day-Ahead Market?

- Yes
- No
- Other answer

If other, please specify

5.9. Is availability of external funding essential for making positive investment decisions in your company?

- Yes
- No
- Other answer

Other answer:

6 The environment of the district heating company

6.1. Has a plan for achieving climate neutrality been adopted in the municipality/region or is such a plan under development?

- Yes
- No
- Don't know

6.2. Does the municipality monitor the activities of the district heating companies in the context of optimising the cost of heat for citizens?

- Yes
- No

- Don't know

6.3. Does the municipality have a plan to reduce (eliminate) dispersed emissions from individual domestic boilers or is such a plan under development?

- Yes
- No
- Don't know

6.4. Does the municipality have an energy efficiency improvement plan or is such a plan under development?

- Yes
- No
- Don't know

6.5. Is the municipality implementing a programme to reduce the energy intensity of buildings?

- Yes
- No
- Don't know

6.6. Is planning of heating and cooling mandatory in your municipality?

- Yes
- No
- Don't know

6.7. Are local spatial development plans being developed in cooperation with district heating company in the context of including the need for new district heating infrastructure in the plan?

- Yes
- No
- Don't know

6.8. Do local spatial plans allow for energy transition and decarbonisation of your district heating system?

- Yes, fully
- Partially, small minor changes are required
- Partially, major changes are required
- No
- Don't know

6.9. Can connections to the district heating system be subsidised by your municipality?

- Yes
- No
- Don't know

6.10. Are there any local programmes available to financially support district heating investments from the municipality's own resources (for example, from an emission reduction programme)?

- Yes
- No
- Don't know

6.11. Is an electricity, gas and heat supply plan in place and being implemented in the municipality?

- Yes
- No
- Don't know

6.12. Is there a developed market for system services in the electricity sector in the country?

- Yes
- No
- Partially
- Don't know

6.13. Is the country experiencing negative market prices for electricity?

- Yes
- No
- Don't know

6.14. Is the planned development of the domestic renewable energy market in the electricity sector significant?

- Yes
- No
- Don't know

6.15. Are carbon capture projects under development in the region? (e.g. from cement or power plants)

- Yes
- No
- Don't know

6.16. Has the country adopted a national plan to achieve climate neutrality?

- Yes
- No
- Don't know

7 Identification of key threats

7.1. What is the level of competition from individual sources of heating in your local heat market?

- High
- Medium
- Low
- There is no competion

7.2. Who are the main competitors of your district heating company, if any?

- Natural gas companies (gas boilers)
- Electricity companies (domestic heat pumps)
- Suppliers of solid fuels (solid fuel-fired boilers)
- Suppliers of liquid fuels (liquid fuel-fired boilers)
- Other

If other, please specify.

7.3. Is district heating coverage expansion possible in case of your system?

- Yes
- No
- Don't know

7.4. Is there a considerable need for electricity storage in the national energy system?

- Yes
- No
- Don't know

7.5. Is the rate of disconnnections from the district heating system significant?

- Yes
- No
- Don't know

7.6. Which of the following are revelant threats for the effective decarbonisation of your district heating system?

The level of cooperation between DH companies and local stakeholders such as waste heat suppliers is not sufficient.

Significant investment capital is required for the decomposition and reconfiguration of existing DH systems, which is not easily available for DH companies.

Insufficient organisational and economic resources of DH companies.

Low level of awareness and low engagement of stakeholders.

Restraint and scepticism among investment decision makers towards EU and national energy and climate policies.

Historically conditioned public acceptance of combustion technologies.

The level of cooperation between DH companies and local stakeholders such as waste heat suppliers is not sufficient.

Limited market availability of renewable energy and waste heat recovery technologies - low flexibility of supply chains and high costs.

Most DH companies have very limited experience and expertise in running DH systems with multiple distributed sources of low-grade heat.

Unfavourable previous experiences with renewable energy projects (low profitability and significant requirements for financial support).

Long-lasting promotion of cogeneration technologies, and availability of funding programs for this technology, which results in shaping preferences of DH companies and hamper the deployment of combustion-free technologies.

The legal framework is evolving and strategic investments are usually postponed.

Regulated DH market - profitability indices of investment projects are usually not satisfactory enough to attract private capital.

Insufficient knowledge of DH companies on energy transition and the future role of district heating systems, which disables definitions of effective investment plans.

Lack or ineffective administrative and organisational support for investment projects.

Social and cultural factors such as attitude towards renewable energy projects and low availability of sufficiently skilled human resources and significant demand for training activities.

Do you see any other threats?

Thank you for taking the time to complete this survey. Your responses will help us understand your needs and assess our potential for satisfying them. Stay in touch, register your account at https://setheat.polsl.pl

Your free comment on the survey.

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