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Characterisation of High-Temperature DH Systems

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Executive Summary

The present document reports an analysis of the status of District Heating sector in Poland (PL), Slovakia (SK), and Lithuania (LT). These three countries are characterised by an extended availability of district heating networks in the local municipalities. This is due to the massive diffusion that this technology had during the Soviet period when most of the existing infrastructure were developed.

The district heating technology available in PL, SK and LT belongs to the so-called third generation of District Heating (DH), with distribution temperature of around 70-120 °C. The DH network is usually connected to a large cogeneration plant and complemented by simple boilers to cover the heat demand peaks (e.g., during winter).

Poland. PL is characterised by a heat generation for District Heating of 81 TWh and it represents the second largest EU market after Germany. 60% of the heat generation is provided by Cogeneration of Heat and Power (CHP) plants and fossil fuels dominate the generation with over 85% of the market share. The dominant fossil fuel source is coal; thus, PL DH sector is highly carbon intensive and it needs urgent interventions for decarbonisation. The main sector of consumption is represented by the residential one, which account for approximately 70% of the total consumption. Different ownership models are available in the country involving public and private subjects and there is not a dominant framework. DH prices are regulated and based on a *cost-plus approach*. For heat sources in which heat is produced in cogeneration units, an energy company may use a simplified method of calculating heat prices if they are not higher than the reference price set by the Energy Regulatory Office. Third Party Access is formally implemented in PL and three conditions must be satisfied to inject heat in the network, namely: technical feasibility, lower price of energy and energy generated by RES or by energy-efficient sources as defined by EED. In large cities, there are large sources belonging to different owners and supplying heat energy to one, extensive heating system.

Slovakia. SK is characterised by a heat generation for district heating of 9 TWh, with CHPs having a share in generation of about 60% while the remaining 40% is represented by boilers. The heat generation is dominated by fossil fuel with about 80% of the share. The remaining part is represented by renewables (mainly biomass and renewable waste) and by a constant share (about 5%) of nuclear district heating. The dominant fossil fuel is natural gas. The largest end user sector is the residential one representing about 75% of the total consumption. Different ownership models are available in the country which include public and private participation. SK market has a regulated price based on a *cost-plus approach*. Third Party Access to the network is possible, but it only applies to heat generated through renewables or CHP.

Lithuania. LT is characterised by a heat generation for District Heating of 12 TWh. CHPs have a market share between 40-50%, while the rest is covered by boilers. The LT district heating sector experienced radical changes in terms of fuel share. Till 2010 it was dominated by fossil fuels (mainly natural gas), but from the 2010 onward a quick transition to renewables has been implemented, and today, about 80% of the generation is obtained by using renewables, with biomass representing more than 90% of the renewable generation. The residential sector is the largest end user sector with a market share of about 60%, the commercial and industrial sectors have similar market shares of about 20% each. Heat supply in each city is a monopoly (e.g., there is one supply company per municipality), whereas the generation is market based and monthly auctions are organised. The network is usually publicly owned, and it can operated by the municipality itself or given in concessions. Concessions were popular in the 2000s, but the results were not satisfactory, thus, many municipalities are engaging with the operation by themselves. The tariffs for DH are regulated and subjected to the approval of competent authorities. Third Party Access is fully implemented in LT, and it works quite well since the heat generation market is fully liberalised.

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List of Acronyms and Abbreviations

Abbreviation	Definition
CAGR	Compound Annual Growth Rate
CHP	Cogeneration of Heat and Power
DH	District Heating
DHC	District Heating and Cooling
EU	European Union
GDP	Gross Domestic Product
HDDs	Heating Degree Days
LT	Lithuania
PL	Poland
RES	Renewable Energy Sources
SK	Slovakia
TPA	Third Parties Access
WA	Weather Adjusted
WH	Waste Heat

I. Introduction

The European Union (EU) is fully engaged in addressing the pressing challenges posed by climate change and the transition towards sustainable energy sources. In this context, district heating emerges as a key player in the energy transition, providing an efficient and sustainable solution to meet the rising demand for heating and cooling while reducing greenhouse gas emissions.

District heating (DH) is a centralised energy distribution system that delivers heat produced from a variety of sources to multiple buildings or residential areas. Unlike conventional heating methods, which often rely on individual boilers or electric heaters, district heating operates on a larger scale with the possibility to integrate multiple sources of energy (e.g., CHP, Renewables, waste heat, etc.). This approach not only enhances energy efficiency but also contributes to a significant reduction in overall carbon emissions.

EU is at the forefront of energy transition, setting ambitious targets to promote sustainable development and to achieve a carbon neutral society. EU's commitment is concretely backed-up by ambitious strategies such as the European Green Deal, the Renovation Wave Strategy, the Next Generation EU, etc.

The development of DH fits well in the EU strategy thus it is fundamental to define optimal strategies to develop this sector further and to promote its retrofitting. DH development allows to obtain notable advantages and multiple benefits such as improvement in heating (and cooling) systems energy efficiency, possibility to integrate renewables and recover waste heat, integration of decentralised energy generation, reduction of carbon emissions, promotion of sustainable urbanisation, etc.

While the benefits of district heating are evident, challenges exist in its widespread adoption. Overcoming these challenges requires a concerted effort from policymakers, industry stakeholders, and the community.

The main challenges are represented by the *capital-intensive* nature of the sector which requires substantial investment for its development, the necessary technological innovation (e.g., digitalisation) for a better integration with the existing energy system, the regulatory framework that sometimes is very complex and hampers the development of the sector and the lack of public awareness towards the benefits of DH which are often not well perceived by the society at large (e.g., avoidance of maintenance cost of individual boiler, improved comfort from the immediate availability of domestic hot water, etc.).

To support the development of DH in EU, it is mandatory a comprehensive analysis of the benefits and barriers for the development. An overall EU analysis can be developed on the status of the sector, but country specific analyses are necessary since the situation is highly jeopardised and varies from country to country especially for the regulatory aspects and the status of the network (e.g., Northern EU Countries vs. Eastern European Countries).

II. Development of DH in European Union

2.1. Introduction

DH is a well-established technology in EU and some countries have a history longer than one century in developing and operating DH. Northern, Central, and Eastern EU countries have an extensive coverage of

DH within their municipalities since the rigid winter climatic conditions elicited efficient and effective solutions to face with buildings heating.

After Second World War many Central and Eastern EU countries were under the Soviet influence and DH was considered a pivotal technology for buildings heating, thus an extensive pipe network was developed, and DH became the standard for buildings heating. DH became the standard also in Northern EU countries (e.g., Scandinavia) and quite popular in Continental Europe (e.g., Germany, Netherland, etc.).

While the network became more and more efficient in Northern and Continental EU countries, with the development of new DH generations and concepts, there was a degradation of DH network in Central, Eastern and Baltic EU countries especially after the collapse of Soviet Union. This condition was due to the severe economic crisis following the deep political change and with the *Capital-Intensive* nature of DH. The lack of investment in maintenance and renovation determined an overall worsening and inefficiency of the operating conditions as noted by (Martinot, 1997).

Soviet designed DH are based on primary distribution pipes carrying pressurised hot water at a maximum temperature of 150 °C (Martinot, 1997). Primary distribution pipes are connected to heat exchangers via substations to originate secondary distribution pipes operated at lower temperature (90-100 °C) (Martinot, 1997). Secondary distribution pipes are then connected to the buildings. The connection is built through a substation or directly to the building pipes. This approach was developed during the 50s and it did not change much till the 80s. DH systems became very complicated to accommodate the demand of growing cities and the push for urbanisation. Complicated and inflexible systems are difficult to control, and this led to the development of inefficient systems (Martinot, 1997).

The management of a complicated and inflexible DH system coupled with the lack of funds for maintenance and upgrade determined a substantial deterioration of the infrastructure which also causes an unreliable heat supply. At the same time, in most places where there is a DH network also a natural gas grid is available, thus many customers opted for switching to individual natural gas boilers for home heating and this contributed to worsen the efficiency of the system (i.e., operating load gets farer and farer from the designed load) (Büchele, et al., 2018).

Oppositely, in Northern and Continental European countries, there was a technological evolution of the DH systems with a shift from the second generation (i.e. those based on pressurised water at temperatures higher than 100 °C in the primary distribution), to the more efficient third generation from the end of the 70s where pressurised water with temperature between 80-100 °C is used. The third DH generation allowed to integrate industrial waste heat and some renewables such as biomass-based CHP (Gjoka, et al., 2023).

Now the transition to the 4th Generation of DH is in place to develop more efficient systems and to allow for the integration of low temperature renewables. This transition depends not only on the upgrade of the DH network but also from the refurbishment of the building stock. Heating equipment has been designed for a higher temperature heating fluid; therefore, the emitters surface would not be enough to provide the necessary heat if the operating temperature is reduced (IRENA and Aalborg University, 2021). To overcome this problem a reduction of the building heating demand would be beneficial as well as the substitution of the emitters to increase their surface is a solution. Another approach that would require a more radical refurbishment in existing buildings is the utilisation of radiant floors (IRENA and Aalborg University, 2021). Figure 1 illustrates a summary of the different DH generations.

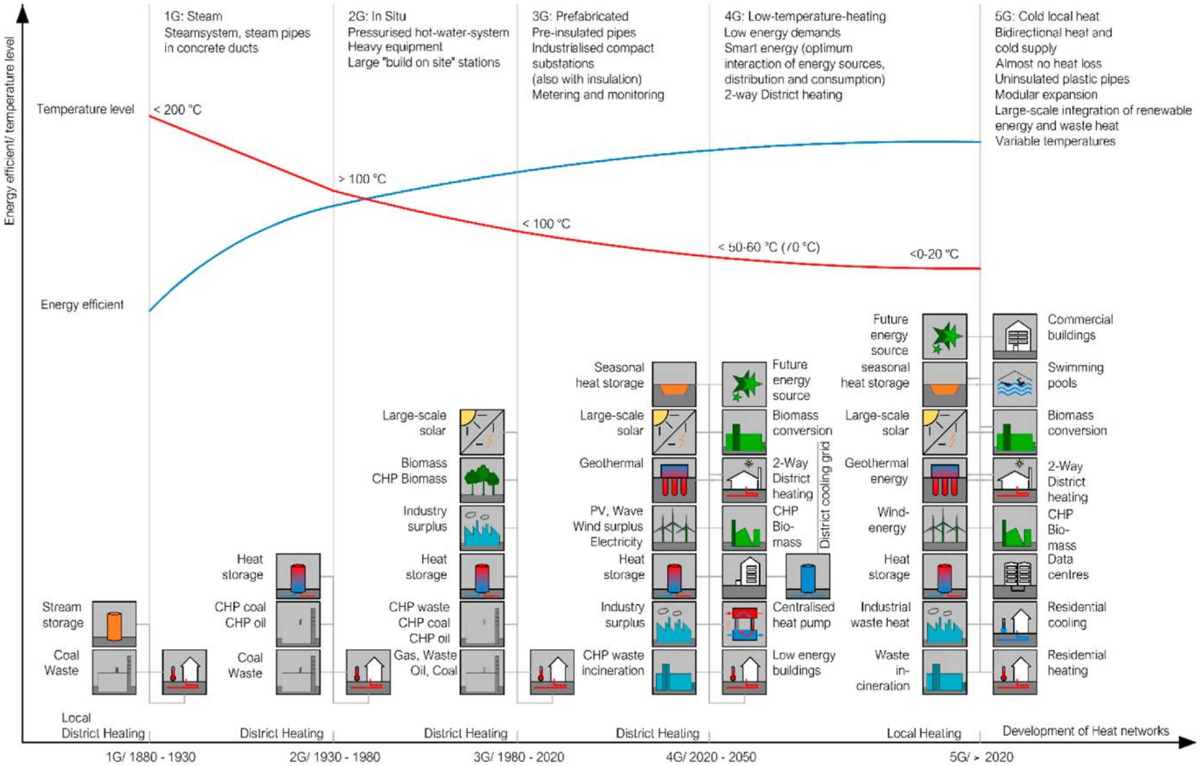

Figure 1. Main features of different DH Generation (Zeh, et al., 2023)

2.2. District Heating Generation and Consumption Trend in EU

DH generation is widespread across EU27 countries, especially those with the more severe climatic conditions, such as Scandinavian Countries, Baltic States, Continental & Western Europe. In other areas of EU, e.g., Mediterranean countries, the milder climatic conditions did not support the massive development of DH. Even tough in specific locations DH is available (e.g., some cities and towns in the Northern Part of Italy).

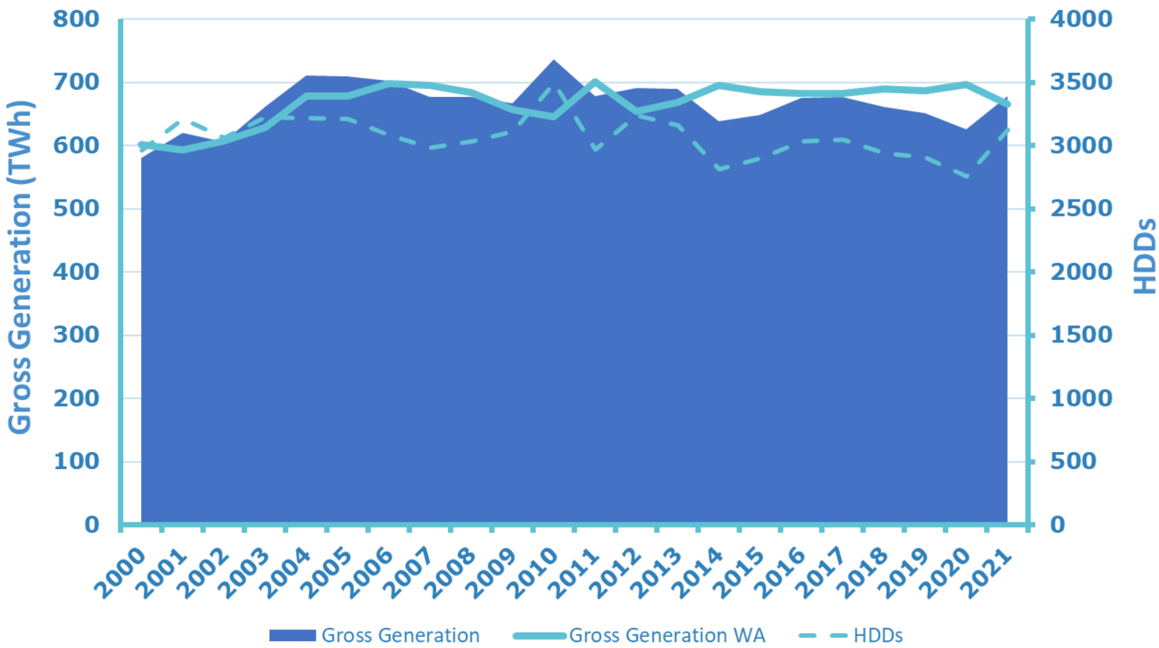

Figure 2. DH Gross Generation in EU27 (UNIPARTHENOPE elaboration based on Eurostat data).

Figure 2 reports the development of the Gross DH generation in EU27 in the period 2000-2021. An irregular pattern characterised by peaks and valleys was determined by the volatility of the climatic conditions. This is confirmed by the comparison of the trend of Gross Generation with that of the Heating Degree Days (HDDs). It can be qualitatively observed that the two trends are in phase with each other, whereas, from the quantitative point of view, a Linear Correlation Coefficient of 0.6 is estimated. This demonstrates the existence of a linear correlation between Gross Generation and HDDs (i.e., at the increase of the HDDs corresponds a linear increase of the Gross Generation).

In the period 2000-2021, Gross Generation highlights an increase of 98 TWh with a corresponding Compound Annual Growth Rate (CAGR) of 0.7%. As previously said, these values might be altered by *out of average* climatic conditions and result not meaningful. To avoid this drawback, a climate adjusting procedure is implemented (Bianco, et al., 2014). The climate adjusting procedure allows to filter the climatic effect and show the Gross Generation trend in terms of *average climatic conditions*. Namely, Gross Generation data are corrected by using the HDDs to find the Gross Generation corresponding to the average HDDs for the period 2000-2021.

As shown in Figure 2, the Weather Adjusted (WA) Gross Generation shows a more regular trend. In particular, two macro areas can be highlighted, namely the period 2000-2006 where an increase in WA Gross Generation is observed and the period 2007-2021 where the WA Gross Generation is approximately constant except for some fluctuations in the period 2009-2012.

Figure 3 represents the DH Generation Structure in EU27 both in terms of *Business Model* (Figure 3(a)) and *Technology* (Figure 3(b)). The overall situation appears quite stable with a slight increase of the Main Activity Producers which passes from a Market Share of 84% in 2000 to 87% in 2021. Also, in terms of Technology, the trend is quite stable. CHP dominates the market, even if, in the period 2000-2021, they lost some percentage points of the share decreasing from 72% of the 2000 to the 70% of the 2021.

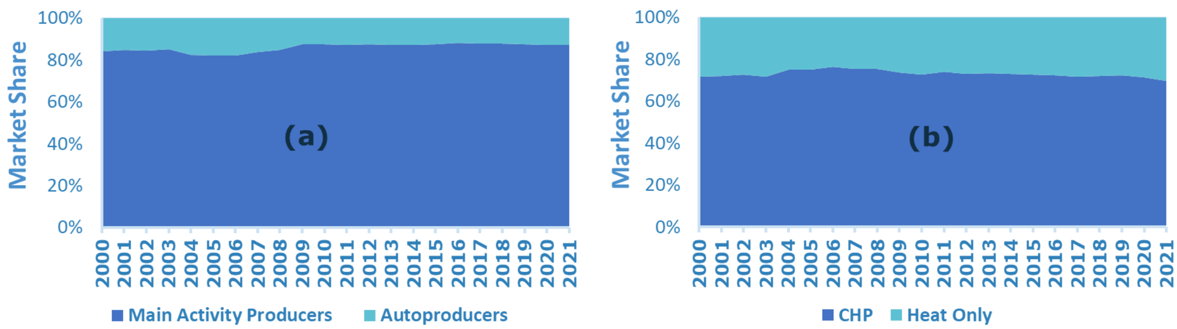

Figure 3. Market Structure of DH Generation in EU27: (a) Business models; (b) Technology (Source of data: Eurostat)

DH sector had a deep evolution in the period 2000-2021 and followed the main dynamics of the energy sector, including the relevant development of renewables. Figure 4 highlights that the share of renewables in the district heating sector increased from less than 10% in 2000 to more than 30% in 2021 with an increase of the generation of 161 TWh corresponding to a CAGR of 6.6%. At the same time fossil fuel generation decreased of 79 TWh in the same period and passed from 90% to 67% of the market share.

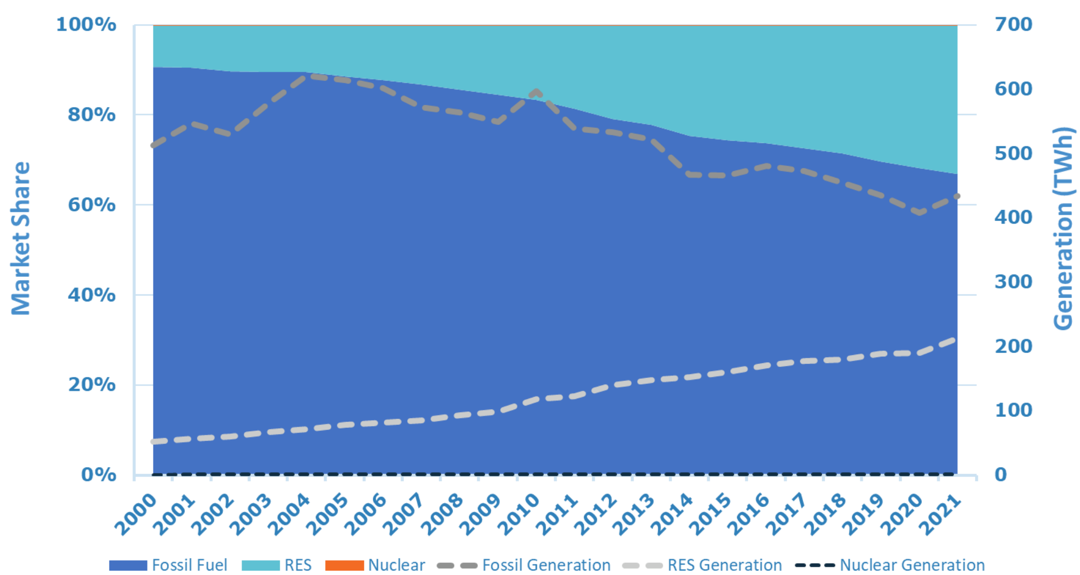

Figure 4. Fuel Market Share of DH in EU27 and corresponding amount of heat generation (UNIPARTHENOPE analysis of Eurostat data).

A small share of the DH generation, in average 0.2%/year, is covered by heat generated by nuclear power plants. This source is localised in Hungary and Slovakia. As noted in (Lipka & Rajewski, 2020), nuclear power plants have been used as a DH source since the beginning of the nuclear industry. The largest nuclear power station operated as a CHP is Zaporozhye in Ukraine, with a total power capacity of 6000 MW_{el} and heat recovery capacity of 1400 MW_{th}. Currently not much information is available about its operation since it is under illegitimate Russian control following the Russian aggression war against Ukraine. The operating nuclear power plant with the largest output for DH in EU is Bohunice plant in Slovakia, with a combined output of 240 MW_{th} (Lipka & Rajewski, 2020). This case is relevant since approximately 10% of the total CHP output is devoted to DH (Lipka & Rajewski, 2020).

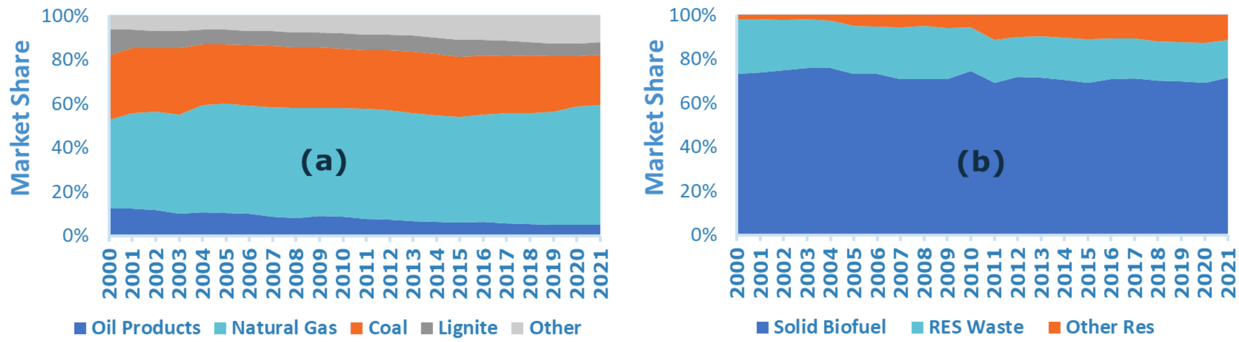

Figure 5. Primary energy share in DH in EU27: (a) fossil fuels; (b) renewables.

To gain a more in depth understanding of the primary energy used in the DH sector in EU27, Figure 5 illustrates the share in terms of primary energy use by offering a snapshot on the shares of the specific fossil fuel and renewable sources. Figure 5(a) shows the share of the fossil fuels. An increase of the share of natural gas from 40% in 2020 to 54% in 2021 is noted, whereas Oil products, coal and lignite decreased from 12% to 5%, from 29% to 23% and from 12% to 6%. This is in line with what happened in the power sector with the increase of the natural gas generation.

The increase of the utilisation of the natural gas can be ascribed to the development of new infrastructures (e.g., pipelines and LNG terminals) in the period 2000-2021, to the fully operation of the EU-ETS market which penalises carbon intensive fuels, and to the diffusion of CCGT as one of the leading CHP technologies, especially for large plants. Finally, other fuels are mainly represented by non-renewables municipal wastes which are incinerated in CHP or boilers and the corresponding heat is used in DH.

As for renewables, Figure 5(b) shows that the largest share is represented by solid biofuel, which has the average share of 72% during the considered period. It can be observed that this share is approximately constant in the considered time horizon. Furthermore, the share of RES municipal wastes reduced from 25% to 17%, whereas the share of other renewables started to become significant from 2010 onwards with a market share of 11% in 2021.

It is to be noted that, in absolute terms, all the renewables increased their generation between 2000 and 2021. In particular, solid biomass increased of 115 TWh, whereas RES Waste and other RES increased of 23 TWh each.

To have a more detailed focus on the Other RES highlighted in Figure 5(b), Figure 6 reports a detail for these sources in 2021. Distributed sources such as geothermal, solar thermal, biogases and other or technologies like heat pumps, which consent the electrification of the heating consumption, are growing.

The increasing share of these innovative technologies will lead to the transition to 4th and 5th generation DH as highlighted in (Gjoka, et al., 2023). It can be said that, currently, there is a transition in progress from 3rd to 4th generation DH. This transition poses new challenges for DH operators since different energy sources with different features should coexist in one DH network. The massive integration of new technologies such as heat pumps will be more and more important to guarantee the efficient operation of DH networks.

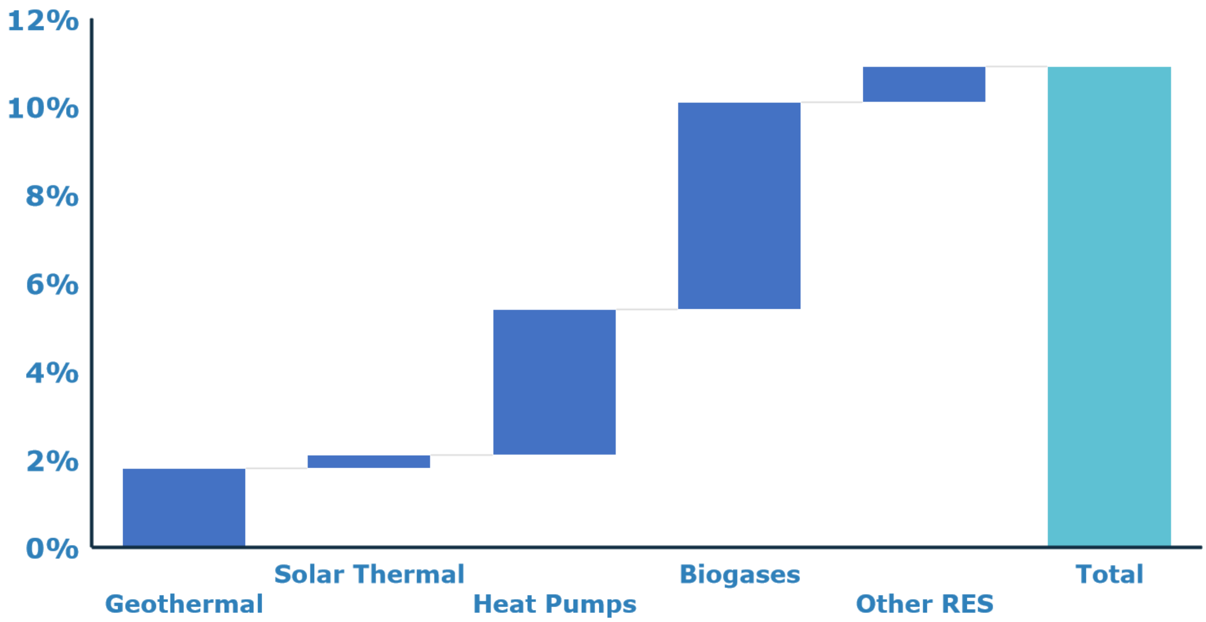

Figure 6. Share of Other RES in the year 2021.

The contribution of the different EU countries for the different renewable energy sources is different and can be dependent on many factors such as the availability of the sources or specific energy policy choices.

RES Share in Year 2021	Total RES	Geothermal	Solar Thermal	Heat Pumps	Solid Biomass	Biogases	RES Waste
Belgium	0.5%	0.5%	0.0%	0.0%	0.2%	2.5%	1.3%
Bulgaria	1.1%	0.0%	0.0%	0.0%	1.5%	0.4%	0.0%
Czechia	1.7%	0.0%	0.0%	0.5%	1.9%	2.0%	1.3%
Denmark	12.1%	0.2%	91.4%	3.9%	13.0%	5.7%	12.0%
Germany	10.3%	13.7%	2.7%	0.0%	5.0%	30.3%	29.0%
Estonia	1.9%	0.0%	0.0%	0.0%	2.6%	0.2%	0.5%
Ireland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Greece	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Spain	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
France	10.9%	50.2%	0.0%	6.9%	9.9%	10.2%	12.7%
Croatia	0.6%	0.0%	0.0%	0.0%	0.7%	1.9%	0.0%
Italy	4.7%	7.6%	0.4%	0.0%	2.9%	33.5%	3.9%
Cyprus	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Latvia	2.3%	0.0%	1.5%	0.0%	3.1%	2.2%	0.0%
Lithuania	3.3%	0.0%	0.0%	0.0%	4.3%	0.3%	1.1%
Luxembourg	0.6%	0.0%	0.0%	0.0%	0.8%	0.3%	0.0%
Hungary	1.0%	20.9%	0.0%	0.0%	0.7%	0.3%	0.6%
Malta	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Netherlands	3.4%	0.0%	0.0%	0.0%	3.0%	0.9%	6.7%
Austria	6.3%	3.9%	3.9%	2.5%	7.8%	0.5%	2.8%
Poland	3.1%	0.0%	0.0%	0.0%	3.8%	2.6%	1.2%
Portugal	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Romania	0.5%	1.9%	0.0%	0.0%	0.6%	0.5%	0.0%
Slovenia	0.3%	0.2%	0.0%	0.0%	0.3%	0.4%	0.0%
Slovakia	1.0%	1.0%	0.1%	0.1%	1.2%	2.0%	0.1%
Finland	13.3%	0.0%	0.0%	22.5%	15.8%	2.5%	6.1%
Sweden	21.2%	0.0%	0.0%	63.6%	20.9%	0.6%	20.7%

Figure 7. Share of the EU27 country for the different RES used in DH generation (Eurostat).

Figure 7 reports the contribution of the EU27 countries to RES generation in DH. In terms of total RES share for DH generation, Sweden is the first EU country having a share of 21% of the total generation. Then, Finland, Denmark and Germany follow with shares of 13%, 12% and 10% respectively. If the different sources are considered, it can be noted that France is the first EU country for Geothermal DH generation. Denmark is the first EU country for DH solar generation. Sweden is the first country for Heat Pumps utilisation (e.g., electrification of heating consumption by exploiting RES power generation via heat pumps) and solid biomass DH generation. Italy is the first country for biogas DH generation, whereas Germany is the first country for RES Waste DH generation.

The growing share of RES requires an upgrade of DH management since different operating temperatures could be necessary to accommodate different energy sources.

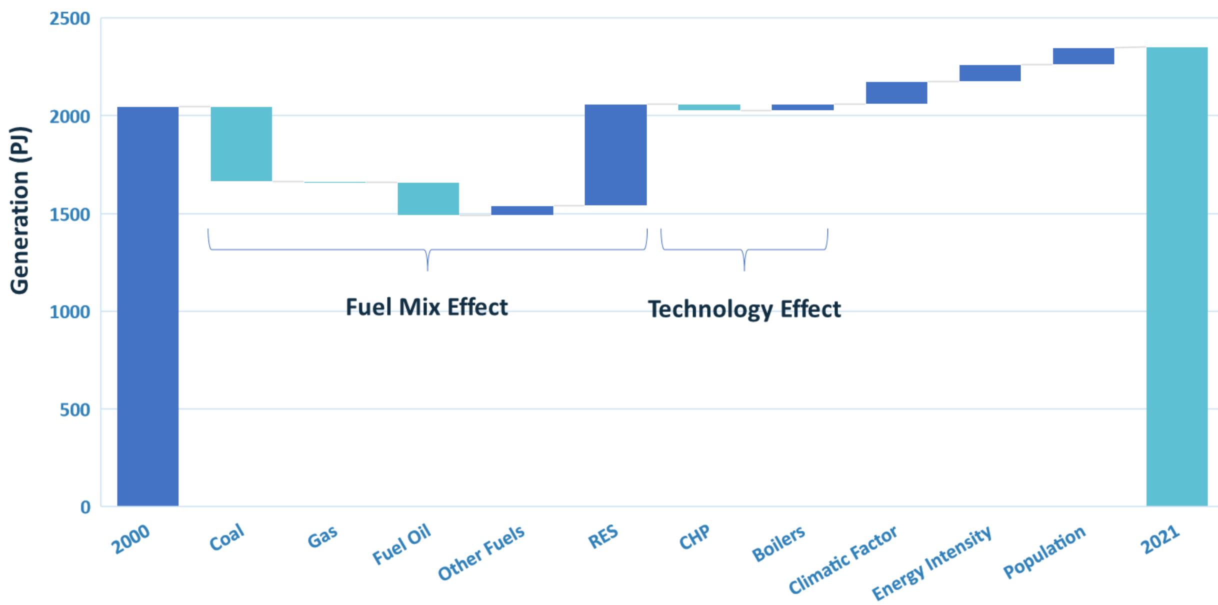

Figure 8. Decomposition analysis of Gross Generation in the period 2000-2021 (UNIPARTHENOPE analysis on Eurostat data).

To provide an overall picture of the Gross DH Generation in the period 2000-2021, a decomposition analysis based on the additive LMDI approach is developed. The analysis illustrates how selected drivers contributed to the increase or decrease of the gross generation.

Five macro-effects are considered in Figure 8, namely Fuel Mix Effect, Technology Effect, Climatic Factor, Energy Intensity, and Population. Fuel Mix Effect is further decomposed to highlight the contribution of each primary energy sources, as well as the Technology Effect to elicit the impact of each technology considered.

It can be noted that the overall impact of the Fuel Mix is limited, on the other hand, if the single sources are analysed, it is detected that the variation in the coal and fuel oil shares negatively contributed to the Gross Generation, but their impact has completely been offset by the variation in RES generation. Technology Effect is also limited, and the changes of CHP and boilers share counterbalance each other. Oppositely, Climatic Factor, Energy Intensity and Population have a positive effect. This is due to the fact that climatic conditions in 2021 were colder with respect to 2000, energy intensity increased as well as the population.

The impact of an increasing share of RES and of a decreasing of carbon intensive fossil fuels (e.g., coal and lignite) can be appreciated from the analysis of the carbon emissions trend, Figure 9. Emissions in 2021 are 30 Mt lower with respect to 2000 corresponding to a reduction of -21%.

To support and accelerate this trend more and more renewables should be integrated, thus it is fundamental to find effective ways to add RES within the existing DH systems.

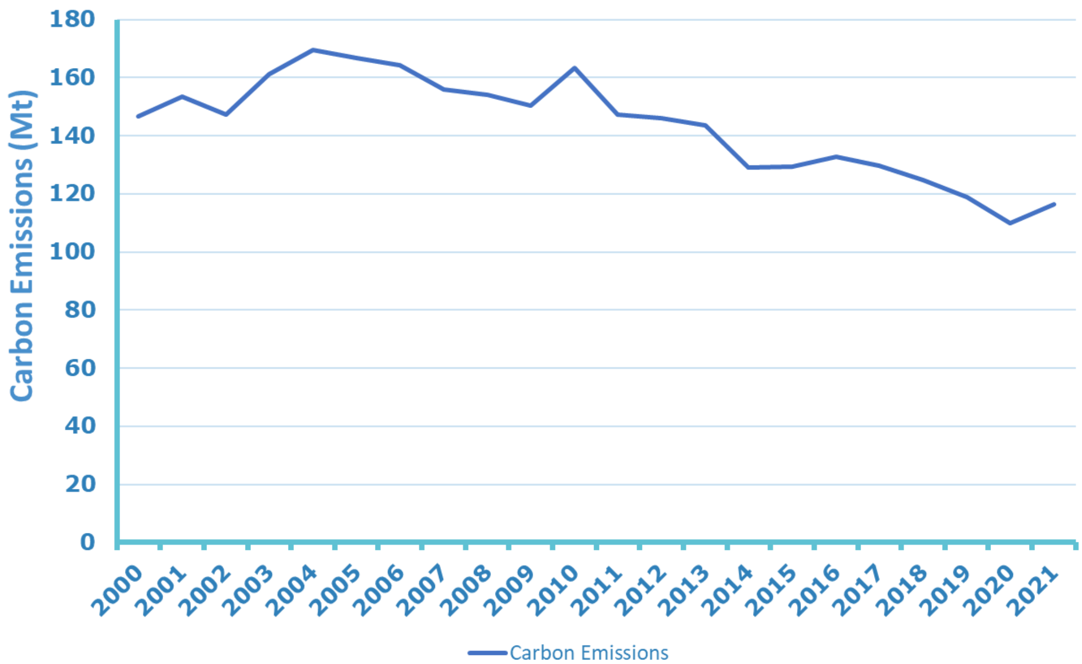

Figure 9. Carbon Emission Trend in DH Gross Generation (UNIPARTHENOPE analysis of Eurostat and EEA data).

The DH gross generation is devoted to the local consumption since the structure of the DH does not allow for other options (e.g., export). Thus, the generation serves to cover the local demand. In fact, at EU27 level, the ratio between total consumption and gross generation is about 90%. This means that network losses and possible self-consumption account for roughly 10% of the generation.

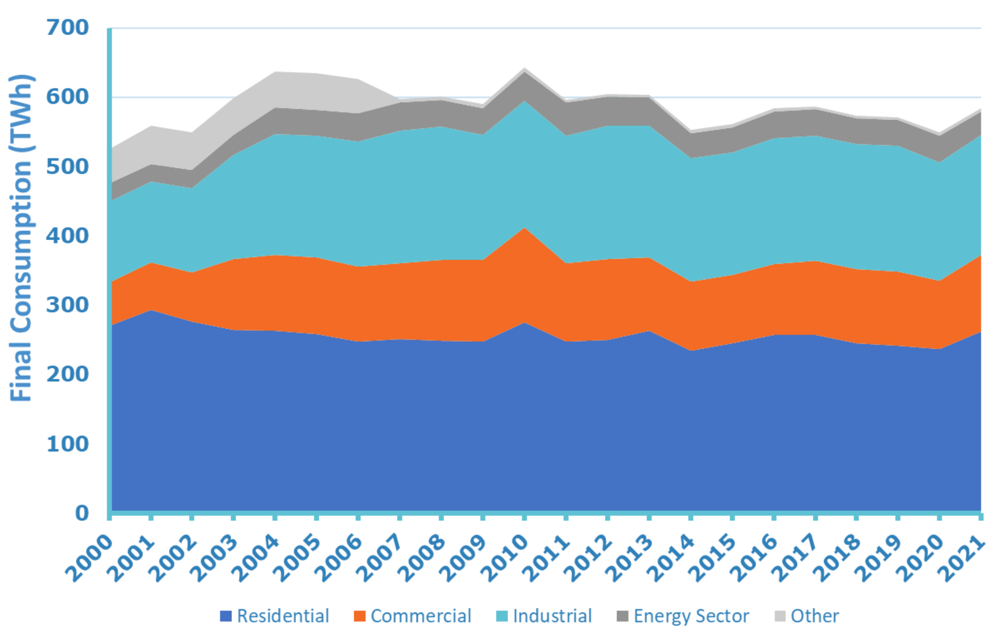

Figure 10. Evolution of DH consumption in EU27 (UNIPARTHENOPE analysis on Eurostat data).

Figure 10 illustrates the evolution of heat consumption from DH network in EU27 in the different sectors. It can be noted that the trend of the consumption is similar to that of the gross generation since DH operators only need to cover their local demand and do not have other possibilities (e.g., cross-border export) due to the physical limitations of the network.

Residential DH consumption has the largest share in EU27 which is quite stable in the considered period, and, in average, it is equal to 44% of the total. The second sector in terms of share of the consumption is the industrial one, which has an increasing trend in the considered time frame. Its share increased from 22% in 2000 to 30% in 2021.

Residential consumption is highly correlated to the HDDs trend and a linear correlation coefficient of 0.66 is found. Oppositely, there is no correlation between industrial consumption and HDDs, in fact, a linear correlation coefficient of -0.03 is found. This can be explained since the main driver for DH consumption in the residential sector is space heating which is proportional to the climatic condition proxied with HDDs. Industrial consumption is linked to the production which, in general, has a limited correlation with the climatic conditions.

2.3. Regulatory Framework

The analysis of the regulatory framework will consider three dimensions: *operational scheme, access to the network, and pricing*. These dimensions are considered relevant because they define the overall management context for DH within a country.

The main trend at EU level will be discussed per each of these dimensions with the aim to get a general context and overview.

2.3.1. Ownership and Operational Scheme

In many EU countries, DH networks are operated by vertically integrated companies. This organization is also due to the specific nature of DH business where, usually, the network is connected to one or more heating or cogeneration plants. Thus, a vertical integrated company manages all the process from the heat generation till the delivery to the final users and the corresponding billing process.

Usually, DH has a municipality dimension (e.g., a city is served by a DH network) and, in the majority of cases, municipalities own the company or have significant stakes in the company owning and managing the DH network and its infrastructure. Apart municipalities, other public or state bodies may own DH companies or stakes of them (Bacquet, et al., 2022). The public ownership/control is usually typical in countries where DH is highly regulated. According to (Bacquet, et al., 2022) this model represent the 41% of the market at EU level.

In some countries the situation can be more jeopardised and different ownership structures coexsist, such as private ownership, public ownership, public private partnership (PPP) or customes cooperative. This situation represents 31% of the EU market (Bacquet, et al., 2022). For example, customers cooperatives are very typical in Denmark (Bacquet, et al., 2022).

Another interesting case is represented by the German Stadtwerke (i.e., municipal utility) which are companies regulated by private law, but owned or controlled by local municipalities. These municipal utility companies typically build, operate, and maintain district heating systems within their respective areas of operation. They may own the infrastructure, such as pipelines and heat generation facilities, and oversee the distribution of heat to residential, commercial, and industrial customers.

The 14% of the EU market is characterised by the dominance of private operators. This is common in countries with less regulated market (including the selling price of heat) such as Belgium (Bacquet, et al., 2022).

Furthemore, in the majority of EU countries it is necessary a specific authorisation/ permission/ concession/ etc. to develop a DH network. The terms of these procedures can be highly variable from country to country.

In the following a list of possible Ownership and Operational Schemes traditionally considered in EU.

Municipal Ownership: District heating systems are owned and operated by local governments or municipal utilities (e.g., Copenhagen (Denmark) and Gothenburg (Sweden)).

Private Ownership: Private companies own and operate the district heating systems, either as independent entities or as part of larger utility corporations (i.e., Veolia (France) and E.ON (Germany)).

Public-Private Partnerships (PPP): These systems are developed and operated through collaborations between local governments and private sector companies (e.g., Bristol City Leap Project in UK).

Hybrid Models: These involve a combination of the above models, where different parts of the district heating system (such as generation, distribution, and retail) are owned or operated by different entities. An example is Helsinki (Finland), where the city owns some parts while private companies operate others.

Concession Model: A concession is a contractual agreement where a local authority grants a private company the right to build, operate, and maintain a district heating system for a specific period. The concession model is widely used in France and Italy.

Service Contract Model: The local authority contracts a private company to manage specific aspects of the district heating system, such as maintenance or customer service.

Build-Operate-Transfer (BOT): A private company finances, builds, and operates a district heating system for a defined period before transferring ownership to the public authority.

Joint Ventures: A partnership between public and private entities to jointly own and operate a district heating system.

Cooperative Models: These systems are owned and managed by cooperatives, which are organisations owned and operated by their members (who can be consumers, employees, or other stakeholders). Some examples available in Germany and Denmark.

Regional or National Ownership: District heating systems are owned and managed by regional or national government entities.

Community-Based Models: Small-scale district heating systems owned and operated by local communities, often in rural or remote areas.

2.3.2. Access to the Network

The rules for the connection of the consumer to the network are variable in the different EU countries. A main challenge for DH networks is that not enough customers are connected. This is a relevant issue for the financial sustainability and technical operation of the network.

To limit this problem, some countries have introduced mandatory connections (Billerbeck, et al., 2023). Usually consumers are obliged to connect to their local network under specific conditions. The mandatory connection exist in France, Denmark, Germany and Norway. It is an option that can be considere by the local authority and it needs to be justified, e.g. cots-efficiency, energy efficiency, etc. In most countries the connection to the network is not mandatory, but specific regulation for the connection could be in place.

The accession to the network for other heat producers is a topic of great interest, especially for the growing impact of distributed generation. This problem has the name of ”Third Parties Access“ (TPA) when it is referred to the electricity or natural gas distribution grid. Differently from natural gas and electricity market, unbundling of DH systems is not required by EU legislation. Thus, in many countries, DH is a vertically integrated service, namely one company generates heat, operates the grid, and serves the final users.

There are different conceptual options to implement the TPA to DH networks. Three main frameworks are generally considered: *network access model*, *extended producer market* and *single buyer model*.

In the *network access model*, producers are granted access to networks and supply the heat they produce directly to their end customers (Billerbeck, et al., 2023). Conversely, in the *single buyer model*, producers have the right to inject heat into the network, while the grid operator is obligated to accept and compensate for the heat. Under this model, consumers lack the option to choose between multiple suppliers; instead, they are all serviced by the single buyer, namely the grid operator (Billerbeck, et al., 2023). The *extended producer market* is based on the single buyer model but with more transparent rules for all the market actors (Billerbeck, et al., 2023).

In practical terms, the TPA to DH is mentioned at some extent in EU directives. The RED II Directive mention the TPA in Art 24(4) in relation to the increase of the share of renewables in District Heating and Cooling (DHC) networks. In particular the Directive introduces two options to reach its goal: *(i)* to adopt measures which allows to increase the share of renewables by 1% per year; *(ii)* to oblige DH operator to connect to the network suppliers of energy from renewable sources and from waste heat and cold (Billerbeck, et al., 2023). Based on this, about half of the EU countries introduced a kind of regulation for TPA in DH (Bacquet, et al., 2022)

2.3.3. Pricing

The heat selling price from DH networks is a complicated matter and very veriable within the different EU countries. Differently from electricity and natural gas, the price of heat is not published in Eurostat since it is not subjected to the European regulation on price transparency (Billerbeck, et al., 2023).

Prices are usually subjected to *ex-ante* or *ex-post* price control. In *ex-ante* price control it is necessary to get an approval by relevant authorities before applying the price to final consumers. Whereas on *ex-post* price control, prices are monitored and controls implemented if suspicious situations are detected. In countries with very high level of regulation, heat price can be administrated and set-up by relevant authorities.

The criteria to determine the heat price are usually cost-driven. This means that the price is determined in order to cover the costs and ensure a fair margin to the operator. Since this price can be variable due to the volatily of the energy markets, adjustment clauses are usually included in the contracts. On the other hand, some countries include in their regulations price caps which set upper limits to the heat price. For example in Norway the heat price from DH cannot be higher than an alternative source for heating in that area (Billerbeck, et al., 2023). In Germany the heat price is linked to the natural gas and coal price through an adjustment clause as reported in the Ordinance on General Terms and Conditions for the Supply of District Heating (Billerbeck, et al., 2023). In Denmark the price of heat is based on a no-profit rule and it can only cover the costs (Billerbeck, et al., 2023).

III. DEVELOPMENT OF DH IN POLAND

3.1. INTRODUCTION

The roots of district heating in Poland trace back to the mid-20th century when the country began modernising its urban infrastructure. The rapid industrialisation and urbanisation during the communist era led to the widespread adoption of district heating systems, primarily fueled by coal and other fossil fuels. These systems were instrumental in providing centralised heating to residential, commercial, and industrial buildings, thereby improving living standards and supporting economic growth.

During the past decades, Poland dedicated impressive efforts in the achieving of the *decoupling*, namely the disconnection betwen energy consumption and economic growth. All this happened during its transition from a command-and-control to market economy in the period 1990-2016 (World Bank, 2018). In that period the country was able to increase its Gross Domestic Product (GDP) by seven-fold with only a slight increase in total final energy consumption and a slight decrease in total primary energy consumption. Poland reduced its energy intensity by 30% from the peak level of 1987 with respect to 2016 (World Bank, 2018).

However, despite all these impressive achievements, Polish energy sector is one of the most carbon-intensive in EU due to its high dependance on the use of local coal for electricity and heat generation.

Decarbonisation of the DH sector is pivotal to support the energy transition in countries and cities where DH plays a significant role in terms of infrastructure and energy supplied. The decarbonisation of the DH sector offers important opportunities for example for the utilisation of more sustainable or renewable heat sources. The flexibility of DH systems allows to use and integrate different heat sources and conversion technologies to generate heat.

The strategic transformation of Poland's heating sector is underscored by two key documents shaping the country's energy future: the National Energy and Climate Plan for 2021–2030 (KPEiK) and Poland's Energy Policy until 2040 (PEP2040) (Talarek, et al., 2023). PEP2040 outlines a tripartite approach to guide these transformational efforts. Firstly, it advocates for a transition focused on the eradication of energy poverty and the phased-out dependency on fossil fuels, while simultaneously fostering the growth of new industries, particularly in renewable energy sources (RES), including heating, and nuclear energy (Talarek, et al., 2023).

Secondly, PEP2040 emphasises the establishment of a zero-emission energy system, highlighting the pivotal roles of offshore wind energy, nuclear energy, and the growing potential of local and community energy initiatives. This latter aspect is anticipated to spur a resurgence in prosumer engagement similarly to recent trends observed in electricity generation (Talarek, et al., 2023).

Lastly, the policy prioritises the improvement of air quality, necessitating a comprehensive revision of heating practices, particularly at the local level, and consequently addressing the heat generated in domestic furnaces (Talarek, et al., 2023).

3.2. District Heating Generation and Consumption Trend in PL

In 2022, Poland, with a generation of heat of 81 TWh, represented the second largest DH market in EU after Germany. Figure 11 illustrates the trend in DH gross generation in PL in the period 2000-2021. Two main characteristics can be noticed: *(i)* volatility in the gross generation from one year to the other; *(ii)* an overall decreasing trend.

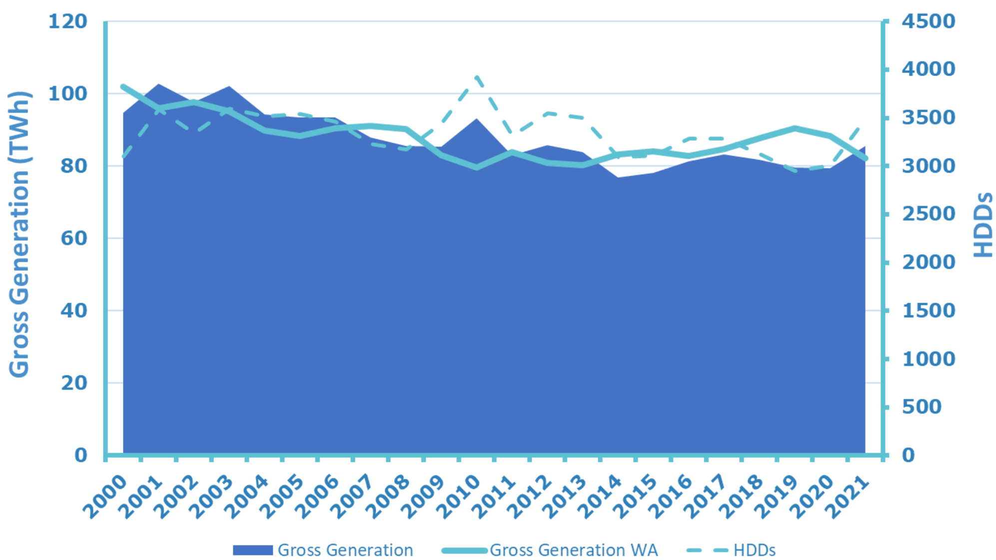

Figure 11. Gross DH Generation in Poland (Data: Eurostat)

The volatility is well explained by weather fluctuations proxied by HDDs. It can be observed that at an increase in HDDs (i.e., colder climatic conditions) corresponds an increase in generation. A decrease in generation of 20 TWh (with reference to WA data) can be observed with a CAGR of -0.98% (-0.45% if level data are considered). This decrease can be explained partially with an increase of the energy efficiency in the building stock and partially with a transition to individual heating which determined a decrease of the residential demand. On the other hand, it should be highlighted that 58% of households were connected in 2018 to the DH network and this represented the highest share in Europe (IEA, 2022).

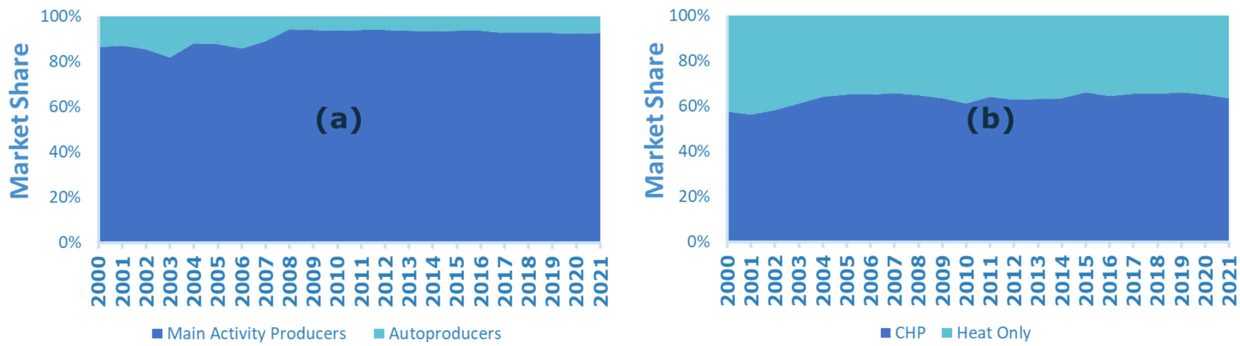

Figure 12. Market Structure of DH Generation in Poland: (a) Business models; (b) Technology (Source of data: Eurostat)

A snapshot of the market structure is displayed in Figure 12, which reports the ownership structure in Figure 12(a), whereas the technology share is reported in Figure 11(b). The ownership structure illustrates that the large majority of the generation (94% in average) is developed by Main Activity Producers, whereas in terms of technology CHP has approximately 60% of the market share. Poland is strongly engaged in expanding high efficiency cogeneration in DH sector (IEA, 2022).

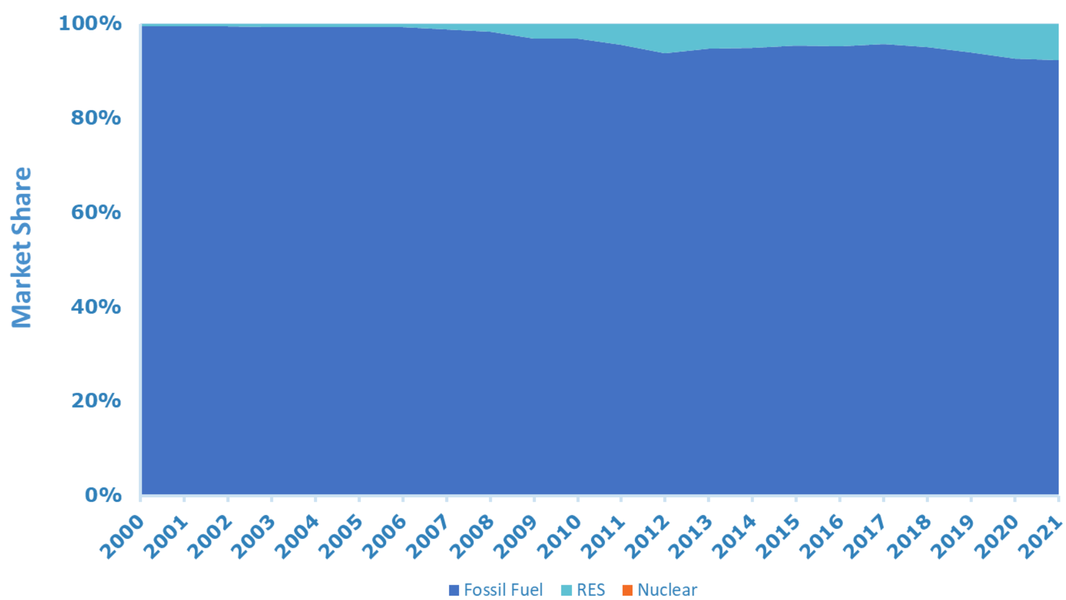

Figure 13. Generation shares of DH in Poland

The generation shares, Figure 13, show a market dominated by fossil fuel generation. Renewables appeared around 2010 and in 2021 they had a share of 8% and 15% in 2022. Thus, much effort is needed to decarbonize the Polish DH sector. To this aim the Polish Government launched a program called "Local District Heating Programme" to provide funding to DH companies for modernising their facilities in terms of energy efficiency or increase in the share of renewables (IEA, 2022). On the other hand, it must be added that, at moment, there is not a clear strategy on the role of renewables in DH sector (IEA, 2022).

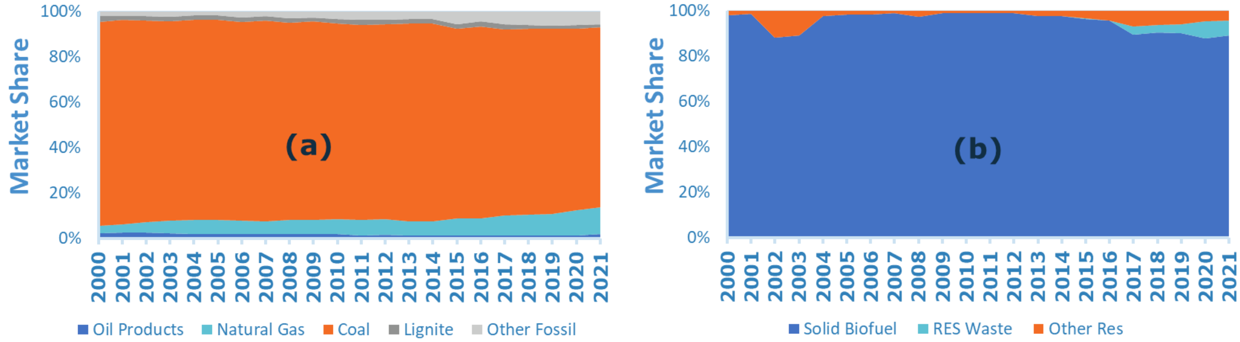

Figure 14. Breakdown of the market share for: (a) fossil fuels; (b) renewables

The breakdown of the fuel consumption is reported in Figure 14. The dominant role in the fossil fuel share is taken by coal. Most of the DH plants are operated by using locally extracted coal. Minor shares are covered by natural gas and fuel oil. Coal fired CHP units and boilers represent the main source of energy for Polish DH sector.

In terms of RES generation, whose total share is 15%, biomass represents the main source with the 90% of the share in 2021, whereas RES waste has a share of 6% and other RES account for 4%. The potential for expanding the global RES share is high. The utilisation of biomass may increase, as happened in other developed DH markets (e.g., Sweden), also considering the importance of the forestry sector in PL, which approximately accounts for the 2% of the yearly GDP.

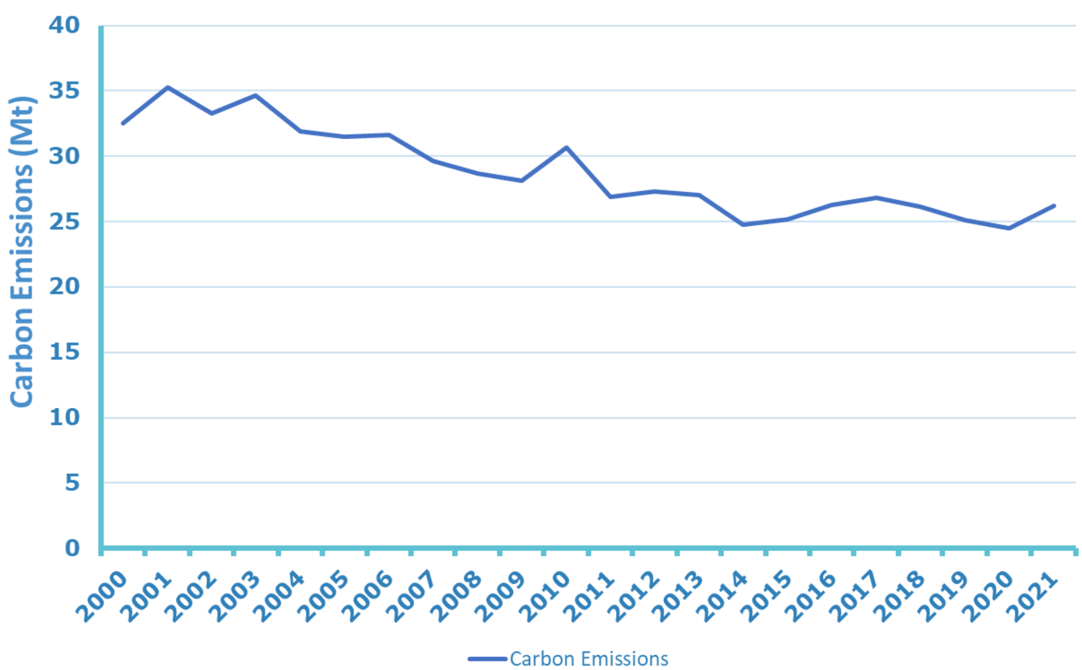

Figure 15. Carbon Emissions trend in Polish DH generation.

Carbon emissions, Figure 15, shows a decreasing trend which is in line with the decrease of the Gross Generation showed in Figure 11. This happens since most of the generation is based on coal which has a high carbon intensity. Thus, a reduction in Gross Generation means a corresponding reduction in Carbon Emissions.

Consumption trends are reported in Figure 16. The main sector in terms of consumption is represented by the residential one. The sector highlights a constant decrease in the consumption, which can be partially explained with the increased energy efficiency of the Polish building stock. On the other hand, it is likely that disconnections from DH in favor of individual heating solutions played a role in the reduction of the consumption.

An opposite trend is shown by the commercial sector which increased its consumption by 5 TWh in the period 2000-2021.

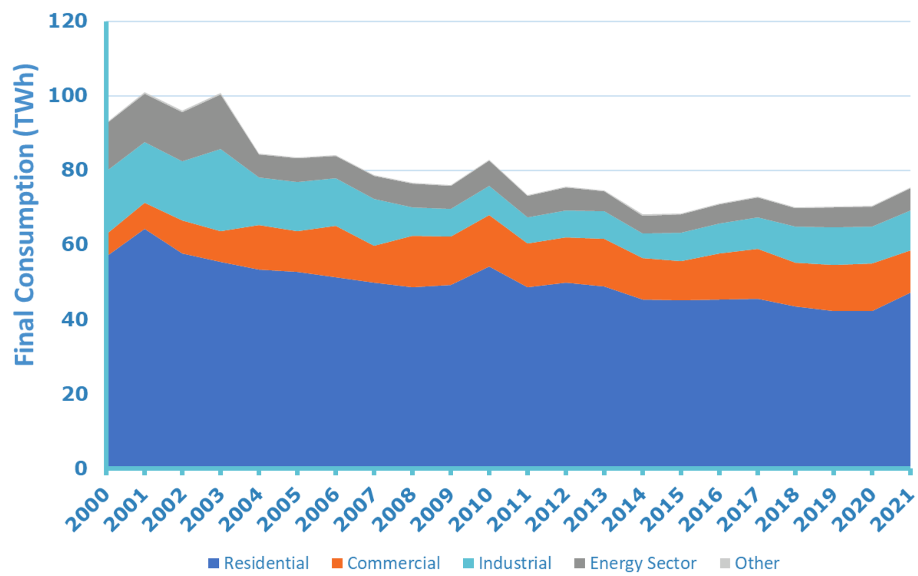

Figure 16. Final consumption in PL end use sectors.

Industry and energy sector also show a decrease in heat consumption in the considered period. In particular, consumption in the energy sector decreased by more than half.

DH Operating Temperature [°C]	120/80 °C[1]
DH Operating Pressure [Mpa]	0.6/1.2 MPa[1]
Length of the Trench [km]	21.000
Number of DH Companies	392
Number of Cities Served by DH	600

Table 1. Main Parameters for DH in Poland.

[1] https://www.sciencedirect.com/science/article/pii/S187661021732266X/pdf?md5=7ca5c52f185e4db39ce3bf4c05daae60&pid=1-s2.0-S187661021732266X-main.pdf

3.3. Regulatory and Financial Framework

Main Legislative Framework

The Energy Law (Prawo energetyczne) provides the primary legal framework for the energy sector in Poland, including district heating. The Energy Law establishes the basic principles of energy policy, regulatory oversight, licensing requirements, and consumer protection in the district heating sector. Furthermore, there are a number of laws and regulations governing the district heating sector in Poland. They set out rules and procedures for the organisation, operation, and management of district heating systems. The regulatory authority responsible for overseeing the district heating sector in Poland is the Energy Regulatory Office (Prezes Urzędu Regulacji Energetyki). The Energy Regulatory Office (URE) is tasked with regulating tariffs, issuing licenses, monitoring compliance with regulatory requirements, and resolving disputes in the district heating market.

Ownership and Operational Scheme

Polish District Heating network is evenly distributed within the country serving both large and small cities. The ownership of the network is mixed, thus public, private, PPP (Public Private Partnership), etc. are present, including the presence of international companies (Bacquet, et al., 2022).

This means that different ownership models are available without a single dominant operating framework, thus the market can develop in a very dynamic way. Most often, in the same city, one heating company manages both the sources and the heat network system. Sometimes the DH network is owned by a municipal company (or another owner), and the heat sources are owned by completely different companies. Generally, the concession model is used very rarely.

The dimension of the companies is operating in the Polish market is mixed, namely both large and small companies operate on the market (Bacquet, et al., 2022).

Metering

The companies operating the DH distributes the heat to final customers, thus, according to the Energy Efficiency Directive and subsequent updates, customers should be guaranteed that the heat they consume is accurately metered and that their bill is the result of an accurate metering. The heat metering at the point of delivery (e.g., the connection interface between supplier and customer) is regulated in the Polish market (Bacquet, et al., 2022). DH companies are obliged to measure the heat they deliver and to sell it accordingly. The detailed procedure is described in the Polish Energy Law. The location of the metering systems for a whole building are usually specified in the contract signed by the supplier and customer.

Often the whole buiding is intended for „customer“, therefore there is the issue to split the total consumption of the building among the individual users. Also this accounting procedure is regulated by Article 45a of the Energy Law (Bacquet, et al., 2022). According to this, owners or adminstrator of these building must equip the different dwellings with meters and each user must pay is share in accordance (e.g., in proportion) with the executed measurements. The total of the sum of the individual metering system and the value measured by the point of delivery metering system can differ because thermal dispersions usually occur within the distribution system of the building.

Smart heat meters are not yet obligatory in Polish market, but they are generally widely used, thus remote reading is usually implemented.

Pricing

Heat pricing is a highly sensitive topic in DH management since the level of the pricing determines the profitability of the business, but also the satisfaction of the customers. If DH price is not competitive versus individual heating, users are likely to opt for individual solutions.

DH prices on the Polish market are regulated based on a cost-plus logic. The cost-plus approach determines the price based on the real costs incurred by the DH company for the delivery of the service (e.g., fuel, maintenance, personnel, etc.) plus a mark-up to secure its own remuneration (Bacquet, et al., 2022). Also costs incurred for modernisation of the network, reduction of environmental impact, etc. are included in the calculation. Detailed rule for the calculation of the tariff are included in the Polish Energy Law.

Polish DH companies send their tariff calculation to the Energy Regulatory Office (URE) which will review and approve the proposed tariffs (Bacquet, et al., 2022). This process is repeated every year, thus there are yearly reviews of DH pricing for final users.

Third Party Access

Third Party Access (TPA) is the right for other operators to have access to the network, e.g., for injecting heat or for retailing purposes. According to the Polish law, full TPA is implemented in Poland (Bacquet, et al., 2022), thus third operators are entitled to access the network provided that they fulfill the connected procedures.

To this aim, the grid operator, before accepting TPA, must develop an assessment to check that all the requirements are fullfilled. The producer requesting the grid connection can appeal to the Energy Regulatory Office if it is not convinved by the assessment developed by the grid operator which will double check the calculation of the tariff (Bacquet, et al., 2022).

From the practical point of view, TPA is applicable only in large cities where there is market space for different producers (Bacquet, et al., 2022). Theoretically, consumers may choose among the different producers operating in the network. On the other hand, the maket is configured with a larger producer which supply most of the final users and small producers which are often interested in acquiring only large consumers. Thus, the competition is limited to large consumers which may choose among different suppliers.

IV. DEVELOPMENT OF DH IN SLOVAKIA

4.1. INTRODUCTION

District heating systems have a prominent role in the Slovakian energy sector. They offer efficient and sustainable solutions for heating residential, commercial, and industrial spaces. District Heating network is a relevant infrastructure for the country and contributed to the economic development, environmental sustainability, and societal well-being.

The initial development of DH in Slovakia is dated back to the post-World War II period when rapid industrialisation and urbanisation demanded efficient heating solutions. The establishment of an evenly DH network had a massive development during the socialist era, which was characterised by the construction of large-scale infrastructures aiming at meeting the energy needs deriving by the rapid urbanisation. The infrastructures developed in that period are still in use today.

Slovakia's district heating infrastructure comprises a network of interconnected heat generation facilities, distribution pipelines, and end-user connections. The heat generation infrastructure is represented by a mix of cogeneration and heat only plants mainly fuelled with a mix of fossil fuels, nuclear energy and biomass. The distribution network, consisting of pipelines ranging from large trunk lines to smaller branches, delivers heat to residential, commercial, and industrial consumers, ensuring reliable and affordable heating services throughout the year.

The district heating sector in Slovakia is characterised by a diverse mix of stakeholders, including public utilities, private companies, and municipal entities. Publicly-owned utilities traditionally dominate the market, operating and maintaining the majority of district heating infrastructure across various cities and towns. However, in recent years, there has been a growing trend towards privatisation (e.g., through concessions) and public-private partnerships, as Slovakia seeks to leverage private sector expertise and investment to modernize and optimise its district heating systems.

The regulatory framework governing the district heating sector in Slovakia is shaped by both national legislation and European Union directives aimed at promoting energy efficiency, decarbonization, and competition.

Despite the role of Slovakia's DH network, the district heating sector faces several challenges that warrant attention and strategic intervention. Aging infrastructure, inefficient heat generation technologies, and reliance on fossil fuels pose operational and environmental risks, necessitating investments in modernisation and diversification of energy sources. Moreover, fluctuating energy prices and regulatory uncertainties add complexity to the economic viability of district heating projects, requiring innovative financing mechanisms and business models to ensure long-term sustainability.

However, despite these challenges, the sector offers relevant opportunities for innovation, collaboration, and transformation. The transition towards renewable energy sources, coupled with advancements in energy efficiency technologies, presents an opportunity to reduce carbon emissions and enhance the environmental sustainability of district heating systems. Furthermore, digitalisation and smart grid technologies offer the potential to optimise energy distribution, improve system resilience, and enhance customer engagement.

4.2. Historical Evolution of District Heating in Slovakia

The initial development of DH in Slovakia is dated back to the post-World War II period when rapid industrialisation and urbanisation demanded efficient heating solutions. From 1928 to 1945, efforts were made in the territory of Bratislava to use residual heat from power generation in DH systems. In 1930, the Škoda company developed a project for an independent DH plant for Bratislava, but it was not implemented. A year later, Západoslovenské elektrárne (Western Slovakia Power Plants) leased and later bought the power plant of the textile company Klinger, which became a central DH source. The construction of the DH network was postponed due to the Great Depression. The newly built heating plant of the Apollo oil refinery was used as a DH source in the next heat supply project, which was built between 1938 and 1944. The destruction of the refinery by Allied air raids in June 1944 meant that this project was not realised either. Until 1948, DH was used as a system for heating buildings on the premises of industrial enterprises, hospitals, and schools.

The establishment of an evenly DH network had a massive development during the socialist era, which was characterised by the construction of large-scale infrastructures aiming at meeting the energy needs deriving by the rapid urbanisation. The infrastructures developed in that period are still in use today. As in neighbouring countries, the post-war 1950s in Slovakia were a period of implementation of plans to supply several buildings from a DH source. For this purpose, older thermal power plants were used in larger towns, which were modified to meet new requirements, and it was the inhabitants of these towns who were the first to benefit from the distribution of heat and hot water from a DH source. In Bratislava, for the first time, the Vistra chemical plant was adapted for this purpose, as was the Apollo refinery's thermal power plant in 1953. Initially, the heat transfer medium in the DH network was steam. Due to operational and economic advantages, in 1959 a change was made to a new heat transfer medium, hot water.

Location	Start of construction of DH systems
Bratislava – southern part	1942
Nováky	1954
Martin	1955
Zvolen	1955
Košice	1962
Trnava	1966
Žilina	1966
Komárno	1966
Bratislava – western part	1973

Table 2. Starting year of construction of DH systems in some cities in Slovakia (CHVALKOVSKÁ, et al., 2011)

The years 1948-1989 were a period of dynamic development of DH systems, when their development was preferred, and new buildings added in zones with available DH systems were compulsorily connected to them (Slovak Innovation and Energy Agency, 2014). An example is the construction of the largest housing estate in Central Europe - Petržalka in the city of Bratislava. Its construction started in 1973 and after positive experience from practical operation of DH in other cities, this method of heat supply was also chosen for this housing estate (CIKHART, et al., 1989). As the Slovak Republic is a transit country in terms of fuel base, natural gas dominates, but also coal and municipal waste combustion (CHVALKOVSKÁ, et al., 2011). Table 2 shows the start of the construction of DH systems in cities where there are large heat withdrawals from the DH source for both residential and non-residential buildings.

4.3. District Heating Generation and Consumption Trend in SK

In 2021, the Gross Generation of heat in Slovakia DH was 9 TWh which is 44% less with respect to the 2001. Figure 17 shows the Gross Generation of the SK DH sector and a marked downward trend is highlighted. Peaks and valleys in the generation profile are observerd, but they are well correlated with the climatic conditions proxied by HDDs. When the Weather Adjusting Procedure is implemented, the WA Gross Generation shows a decreasing straight line trend. The CAGR in the period 2001-2021 is about -3%/year.

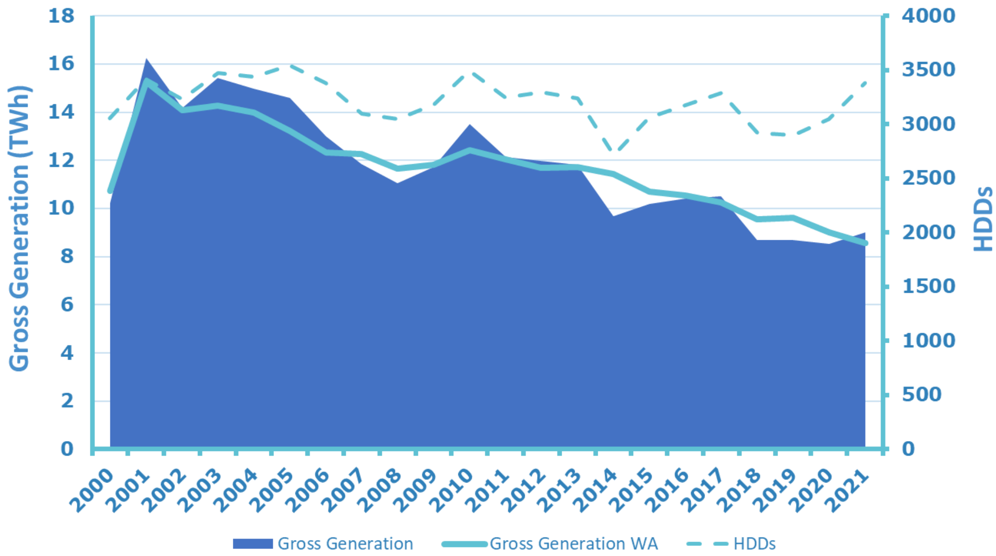

Figure 17. Gross DH Generation in Slovakia (Data: Eurostat).

The decrease in gross generation can be mainly explained by two trends: (i) increase of the energy efficiency in buildings due to substantial renovation programs; (ii) disconnection of customers from the network (Mataszsz, 2020). Customer disconnection is usually due to unsatisfactory service and for the willingness to be more flexible by having an indipendent heating system.

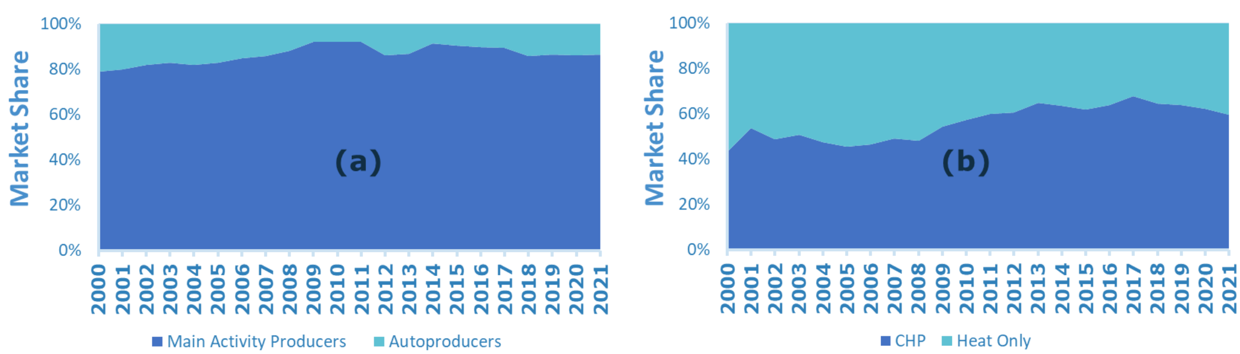

Figure 18. Market Structure of DH Generation in Slovakia: (a) Business models; (b) Technology (Source of data: Eurostat).

The market structure is illustrated in Figure 18, where ownership and technology structures are reported. In terms of ownership, it can be noticed that Main Activity Producers dominate the markent having a market share which raised from the 80% of 2000 to the 86% of 2021. The Main Activity Producers are often vertically integrated companies with a municipal scope, i.e. their goal is to supply heat to a specific municipality and to manage the corresponding DH network.

In terms of technologies, CHPs approximately represent 60% of the market and the remaining part is represented by central boilers. Thus, in most cases, the generation of heat is coupled to the generation of electricity.

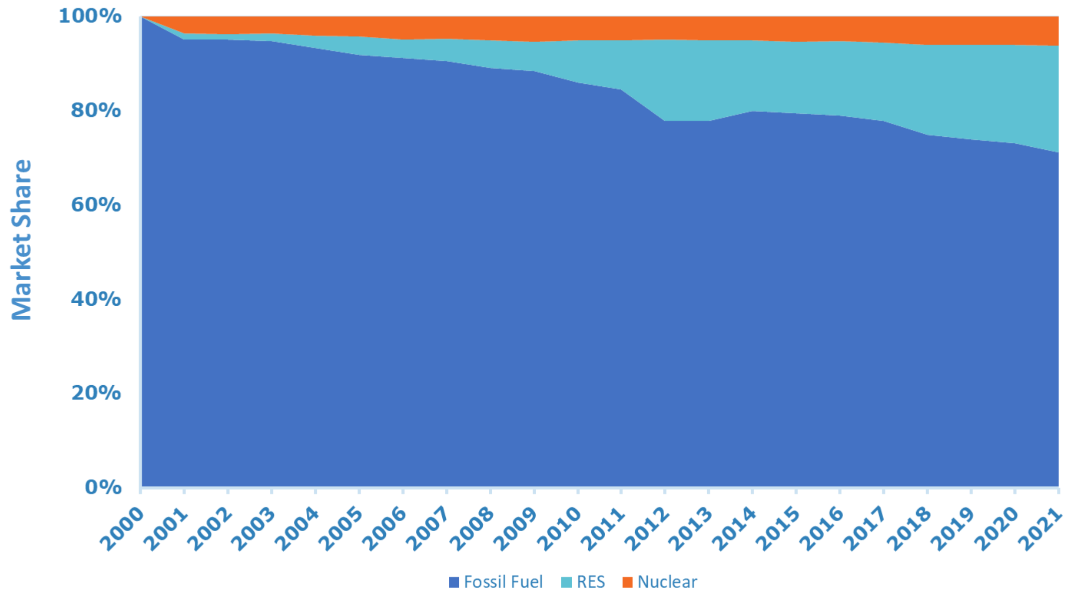

Figure 19. Fuel generation shares of DH in Slovakia.

Figure 19 shows the market share in terms of primary energy. It can be observed that most of the generation is linked to fossil fuel, but the share of renewables is expanding. Furthermore, nuclear heat (e.g., heat cogenerated in Nuclear Power Plants) accounts for 6% of the total with a stable share from 2001 onward. This heat comes from the Bohunice nuclear power plant which supplies the nearby towns (Oravcova, 2022).

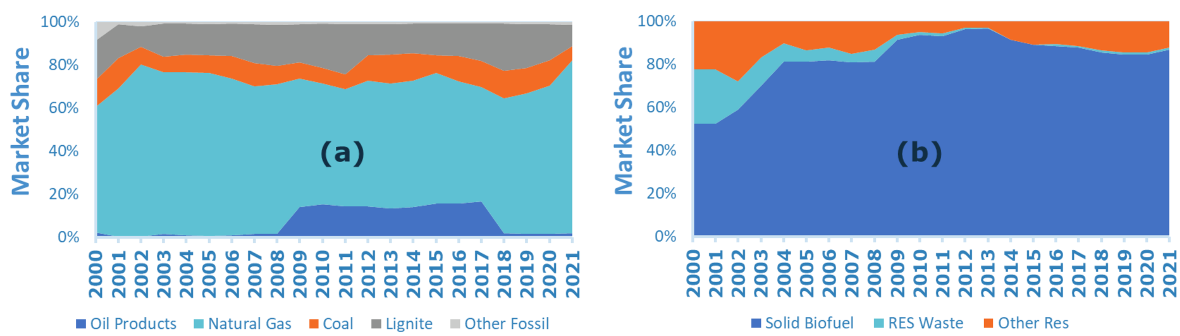

Figure 20. Breakdown of the market share for: (a) fossil fuels; (b) renewables.

Figure 20 shows the breakdown of the used primary energy sources. The dominant fossil fuel source is natural gas followed by lignite and local coal. These sources cover more than 90% of the fossil fuel sources. Minor shares are covered by fuel oil or other fuels. In terms of renewable the most used source is solid biomass which covers the 80% of total. The increased share of biomass between 2012 and 2015 was due to a legislative adjustment that supported electricity production from renewable energy source if it is linked to usable heat. In 2016, there was a certain decrease in biomass consumption due to a change in the heat costing structure in some industrial enterprises (URSO, 2022).

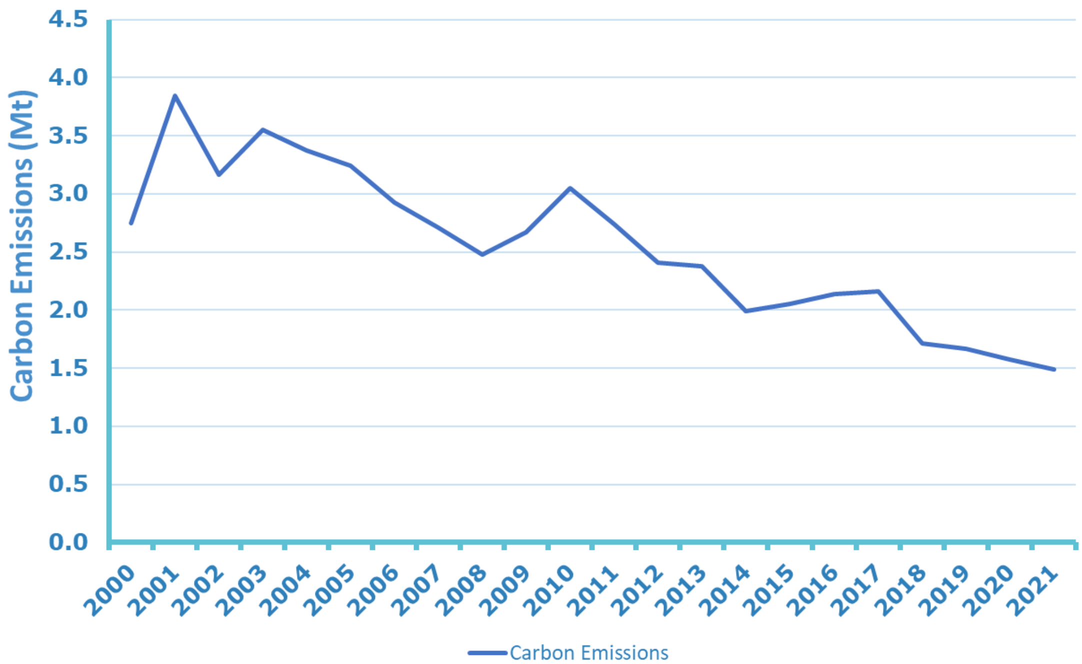

Figure 21. Carbon Emissions trend in Slovak DH generation.

The carbon emission trend highlighted in Figure 21 is proportional to the Gross Generation. A decreasing trend in the emission level is observed. The trend is characterised by peaks and valleys which are linked to the volatility of climatic conditions.

Heat consumption in the different end use sectors are shown in Figure 22. Most of the consumption is represented by the residential sector followed by the commercial one. However, both of them highlight a decreasing trend. Heat consumption from DH network in industrial and energy sector is much lower but with a more stable trend.

Decrease in consumption for residential and commercial sector is linked to increased energy efficiency of the building stock, but also to disconnection from the DH network determined by the willingness of final users to use individual heating systems in order to exploit more flexibility and by the dissatisfaction of end-users with prices and quality of the heat supplied (Slovak Innovation and Energy Agency, 2014). This trend is detected in many countries.

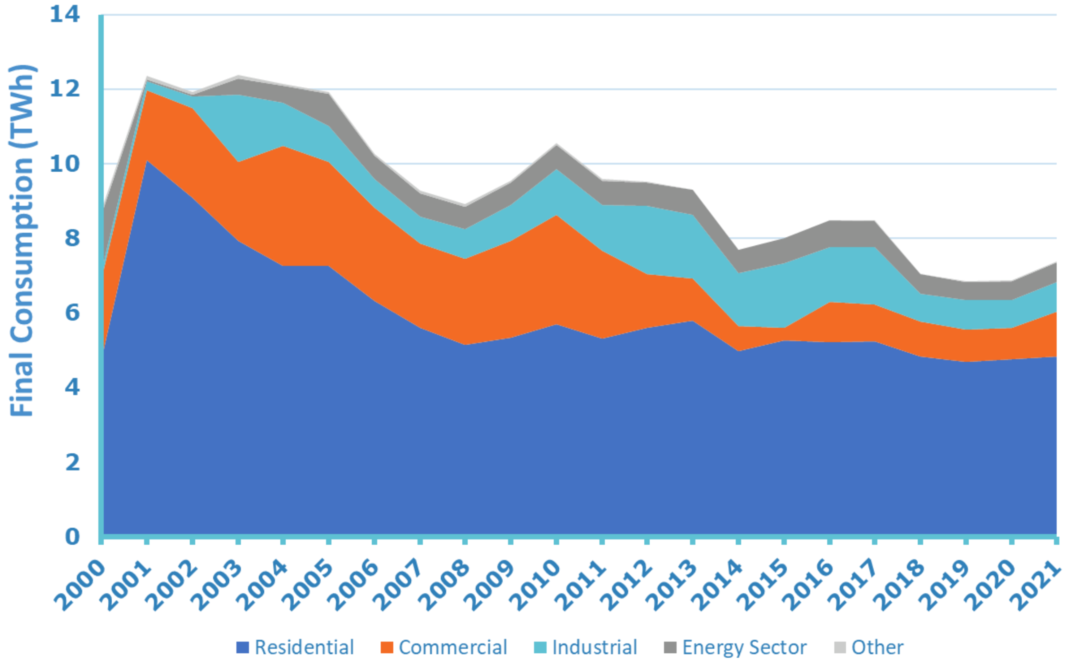

Figure 22. Final consumption in SK end use sectors.

DH Operating Temperature [°C]	80/60 °C
DH Operating Pressure [Mpa]	0.6 Mpa
Length of the Trench [km]	1000
Number of DH Companies	333
Number of Cities Served by DH	42

Table 3. Main Parameters for DH in Slovakia.

4.4. Regulatory and Financial Framework

Main Legislative Framework

District heating in Slovakia is regulated primarily by the Act No. 657/2004 Coll. on Thermal Energy. In addition to the basic provisions, this Act regulates the conditions of doing business in the thermal energy sector, the rights and obligations of participants in the heat market, transition to efficient district heating and the conditions for compulsory heat abstraction.

Other parts of this Act are restrictive measures in the thermal energy sector; competence of state administration bodies and municipalities and the exercise of state supervision; rights and obligations of natural persons and legal entities whose rights, legally protected interests or obligations may be affected by the exercise of rights and obligations of participants in the heat market; administrative offences; protection zones; common and transitional provisions.

The regulatory authority responsible for overseeing the district heating sector in Slovakia is the Regulatory Office for Network Industries (ÚRSO - Úrad pre reguláciu sieťových odvetví). ÚRSO is tasked with ensuring fair competition, consumer protection, and setting tariffs for district heating services.

District heating operators in Slovakia are required to obtain a license from the Regulatory Office for Network Industries (ÚRSO) to legally operate their facilities. The licensing process typically involves submitting an application to ÚRSO, which assesses the applicant's technical and financial capabilities, compliance with regulatory requirements, and other relevant factors. Upon successful review, ÚRSO grants the operator a license to provide district heating services within a specified geographic area.

Currently there is a relevant focus on DH within the Integrated National Energy and Climate Plan (INECP) 2021-2030 of Slovak Republic. Existing district heating systems, which supply several buildings at the same time, are one way to decarbonize heat supply in buildings by using environmentally friendly and highly efficient equipment and technologies that save primary energy. According to the INECP, the existing DH infrastructure has all the prerequisites to fulfil the role of integrator of individual RES solutions in cities. According to the INECP, within 2030 Slovak aims to achieve the 20% renewable generation within the DH sector.

Ownership and Operational Schemes

In Slovakia, the district heating market is open to private companies, and both public and private entities operate district heating systems. Private companies can participate in the district heating market through various models, including concessions, public-private partnerships (PPPs), and outright ownership of infrastructure.

- **Concessions.** Concessions are one of the models through which private companies can participate in the district heating market in Slovakia. Under a concession agreement, a private entity is granted the right to operate and maintain a district heating system for a specified period, typically under certain regulatory conditions set by the government or regulatory authority. Concession agreements may involve the private company making investments in infrastructure and sharing revenue with the public authority.
- **Public-Private Partnerships (PPPs)**. PPPs are another common model for private involvement in district heating projects in Slovakia. PPPs involve collaboration between public and private entities to develop, finance, operate, and maintain district heating infrastructure. PPPs may be structured in various ways, such as joint ventures, long-term contracts, or build-operate-transfer (BOT) arrangements, depending on the specific project requirements and regulatory framework.
- **Outright Ownership.** Private companies may also own district heating infrastructure outright, either through acquisition or greenfield development. In such cases, private owners are responsible for the investment, operation, and maintenance of the district heating system. Private ownership allows companies to have greater control over operations and decision-making, but they must still comply with regulatory requirements and standards.
- **Mixed Ownership**. Some district heating systems in Slovakia may have mixed ownership structures, where both public and private entities have ownership stakes or participate in the operation of the system. This arrangement can combine the expertise and resources of both sectors to improve efficiency and service quality.

Regardless of ownership structure, all district heating operators in Slovakia are subject to regulatory oversight by ÚRSO and must comply with applicable laws, regulations, and standards. The regulatory framework aims to ensure fair competition, consumer protection, and the efficient and sustainable provision of district heating services.

There is not a dominant onwership model in Slovakia and the different forms may be present also depending on historical development in the local regions/provinces/municipalities.

District heating companies in Slovakia range from small-scale operators serving local communities to larger entities providing heating services to multiple municipalities or regions. However, an industry consolidation trend has been observed in the last years with the merging and acquisition of smaller companies by larger entities.

Metering

DH companies deliver heat to final customers and, according to the EU Energy Efficiency directive, the billing process must accurately reflect the heat consumed, hence metering assumes a relevant role. In Slovakia heat metering at the Point of Delivery (POD) of the customer is regulated through the Act 657/2004 Coll. First of all, the legislation prescribes that all the customers must be metered and technical prescriptions on how the metering is to be performed are also provided (Bacquet, et al., 2022). Detailed indications on obligations related to the supply of domestic hot water, temperature assurance, measuring heat amount, etc. are provided (Bacquet, et al., 2022). If buildings have a floor area lower than 500 m^2, the rules reported in Act 657/2004 Coll. do not apply and simplified procedures can be implemented.

Slovak regulations do not foresee mandatory „smart meters“, which currently cover about 5% of the delivered DH heat (Bacquet, et al., 2022).

Pricing

Slovak market works on the basis of a regulated heat price as prescribed by the Act on Regulation in Network Industries (Act 25/212 Coll.) and the Decree 248/216 Coll. (Bacquet, et al., 2022). URSO develops an ex-post control on the applied tariffs to final users. The logic implemented for the definition of the tariffs is the "cost-plus method". The tariff includes costs of heat production, distribution, and administration, as well as a reasonable rate of return for operators.

District heating operators are required to submit detailed cost data to ÚRSO, including information on operating expenses, capital investments, maintenance costs, and other relevant expenditures. ÚRSO evaluates these cost submissions to ensure transparency and accuracy in tariff calculations. Based on the cost analysis and other relevant factors, ÚRSO determines the revenue requirements necessary for district heating operators to cover their costs and earn a reasonable return on investment. This may involve considering factors such as inflation, interest rates, depreciation, and changes in market conditions. URSO reviews all the received information and approve (or request modifications) to the proposed tariff. Decisions are issued in the form of regulatory orders or decisions, which specify the approved tariff rates, effective dates, and any applicable terms and conditions.

The structure of the DH tariffs in Slovakia may have a complex form, which includes fixed charges (e.g., for contractualised heating power), variable charges depending on the heat consumption, seasonal adjustment (e.g., different price levels for winter and summer), and other components. Tariff structures and levels are variable among the different DH operators, since different conditions may apply (e.g., different fuels used in the DH plant, different operating conditions, etc.).

ÚRSO typically conducts public consultations to gather input from stakeholders, including district heating operators, consumers, industry associations, and other interested parties. Public consultations provide an opportunity for stakeholders to express their views on proposed tariff adjustments and contribute to the decision-making process. At the same time, for URSO, it represents a unique occasion to gather information which may support the approval procedures of DH tariffs.

Third Parties Access

Third Parties Access (TPA) refers to the regulatory framework which allows independent operators to access and utilise district heating infrastructure owned and operated by incumbent heating companies. TPA is conceived to promote competition, improve market efficiency, and facilitate the entry of new players into the district heating market. Furthermore, it may result relevant for supporting the uptake of RES in the Slovak DH sector.

TPA is regulated by the Slovak law on ”Thermal Energy“, but it applies only to the case of heat generated through renewable resources or CHP plants (Bacquet, et al., 2022). In such cases, grid operators are obliged to offtake, at an approved price, heat generated by RES or high efficient cogeneration. The offtake is conditioned to the fullfillment of technical requirements (e.g., in terms of temperature and pressure of injection). The offtake obligation does not apply if it determines an increase in price for final users or if this generation displaces production from high efficient CHP already connected to the DH grid (Bacquet, et al., 2022).

ÚRSO monitors compliance with TPA regulations and may take enforcement actions against incumbent heating companies or third parties found to be in violation of regulatory requirements.

V. DEVELOPMENT OF DH IN LITHUANIA

5.1. INTRODUCTION

In Lithuania, district heating serves as a fundamental energy infrastructure, providing efficient and reliable heating solutions to residential, commercial, and industrial consumers. DH sector plays a vital role in meeting the country's heating needs, promoting energy security, and advancing sustainability goals.

DH in Lithuania was massively developed during the Soviet period, where centralised heating network represented a standard. This was due to the need for a rapid urbanisation, which determined an increasing energy demand to cover quickly. During this period, large-scale heat generation plants were constructed, primarily fuelled by natural gas and coal to supply heat to densely populated cities and towns. While the legacy of Soviet-era infrastructure still influences the sector, Lithuania has undergone significant transformations since gaining independence in 1990, with a focus on modernisation, efficiency, and sustainability. In particular, a relevant switch from fossil fuels to local renewables (e.g., biomass) has been implemented for both environmental and energy security issues.

Lithuania's district heating infrastructure comprises a network of interconnected heat generation facilities, distribution pipelines, and consumer connections. The heat generation plants, ranging from combined heat and power (CHP) plants to biomass-fired boilers, serve as the backbone of the system, producing heat for distribution. A network of underground pipelines transports hot water or steam from the generation plants to residential, commercial, and industrial consumers, ensuring a reliable supply of heat even during harsh Baltic winters.

The DH sector in Lithuania is characterised by a diverse mix of stakeholders, including state-owned utilities, private companies, and municipal authorities. Historically, municipalities-owned enterprises have played a dominant role in operating and maintaining district heating infrastructure, particularly in major cities like

Vilnius, Kaunas, and Klaipėda. However, in recent years, there has been a growing trend towards privatisation and liberalisation of the sector, with private investors and international companies entering the market, bringing new technologies and expertise.

Lithuania's DH sector operates within a regulatory framework governed by national legislation and European Union directives aimed at promoting energy efficiency, decarbonization, and competition.

The future of the DH sector in Lithuania is based on its ability to innovate, adapt to changing market dynamics, and align with broader energy transition objectives. Strategic investments in infrastructure upgrades, renewable energy integration, and regulatory reforms will be essential to unlock the sector's full potential in driving economic growth, reducing greenhouse gas emissions, and enhancing energy security. Collaboration among stakeholders, including government agencies, utilities, investors, and civil society, will be critical in navigating the complexities and seizing the opportunities that lie ahead for the DH sector in Lithuania.

5.2. District Heating Generation and Consumption Trend in LT

Gross Heat generation from DH network in Lithuania was 12 TWh in 2021. Figure 23 shows the generation trend in the period 2000-2021. Differently from what was observed for Poland and Slovakia, Lithuania does not show a marked decrease in DH generation. Only a slight decreasing trend is highlighted with a CAGR of -0.4%. The generation pattern is very volatile since it is closely linked to the climatic conditions as highlighted by the trend of HDDs and gross generation. In fact, a correlation index of 0.61 is estimated which means that approximately 61% of the variation in consumption can be explained by the variability of the climatic conditions.

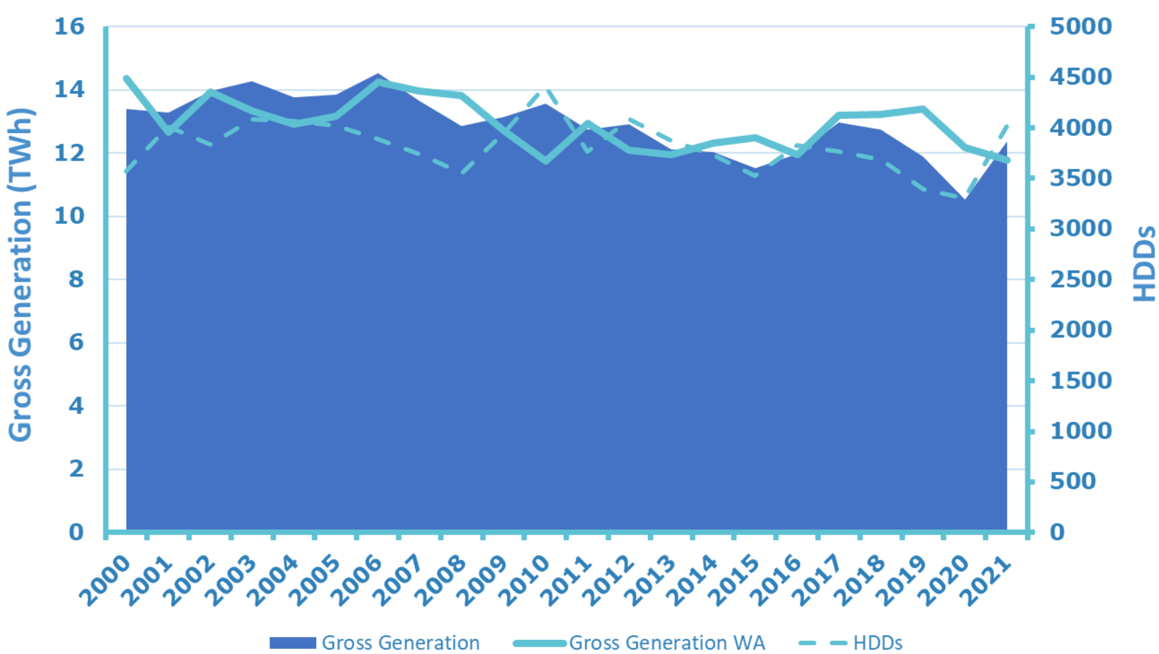

Figure 23. Gross DH Generation in Lithuania (Data: Eurostat).

The weather adjusted generation is also reported in Figure 23. Despite the weather adjusting procedure, the generation pattern still present a substantial level of volatility. Anyhow, two levels of consumption can be highlighted, namely about 14 TWh/year in the period 2000-2010 and 12 TWh/year in the period 2011-2021.

The market structure is reported in Figure 24. In terms of ownership, the LT DH sector is dominated by Main Activity Producers which have the 95% of the market share. Main Activity Producers generally consist in vertically integrated municipal utilities. These companies usually own CHP/boilers plant connetected to the municipal DH network, manage the DH network and sell the heat to the final users.

In terms of technology, CHP units represent 40% of the total in terms of generation and the remaining part is covered with boilers. This technology mix can be explained by the seasonality of the heat consumption and the matching with power generation. If the majority of the heat demand is covered by CHPs two issues could arise, namely an excess of electricity generation and an excess of heat generation in a period of low demand.

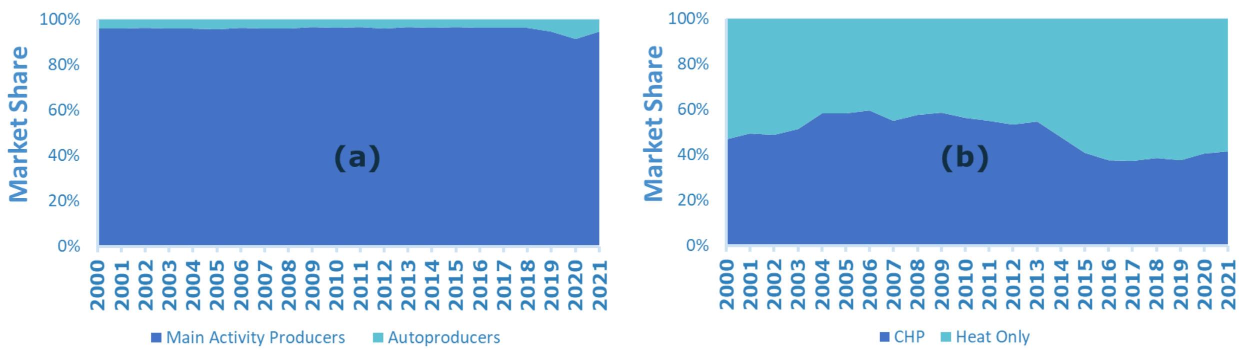

Figure 24. Market Structure of DH Generation in Lithuania: (a) Business models; (b) Technology (Source of data: Eurostat).

According to the data, the current structure of the system is based on CHP generation in order to cover the power demand and part of the heat demand. The remaining part of the heat demand is covered by boilers which are activated mainly during the heating season.

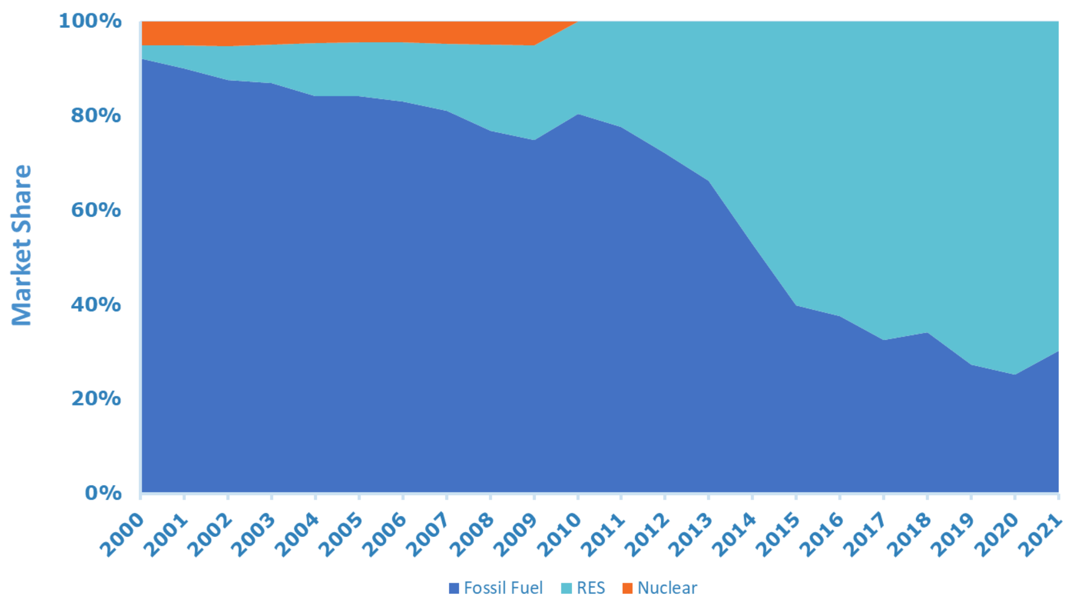

Figure 25. Fuel generation shares of DH in Lithuania.

Figure 25 shows the market share in terms of primary energy. A radical transformation of the primary energy shares can be observed. A marked switch from fossil fuel to RES has been implemented starting from 2000. In 2021, RES generation has 70% of the share. In some DH networks, e.g., Kaunas, the DH generation is based on RES for over 90% of the total. A mix of biomass-based boilers and CHP are used in Kaunas DH network. Oppositely, the usage of natural gas in Kaunas DH reduced radically from 95% to 10%.

Apart the environmental issues, this radical switch has also energy security implications, since Lithuania, in the past years, pursued a policy of energy independence, especially from natural gas import coming from Russian Federation.

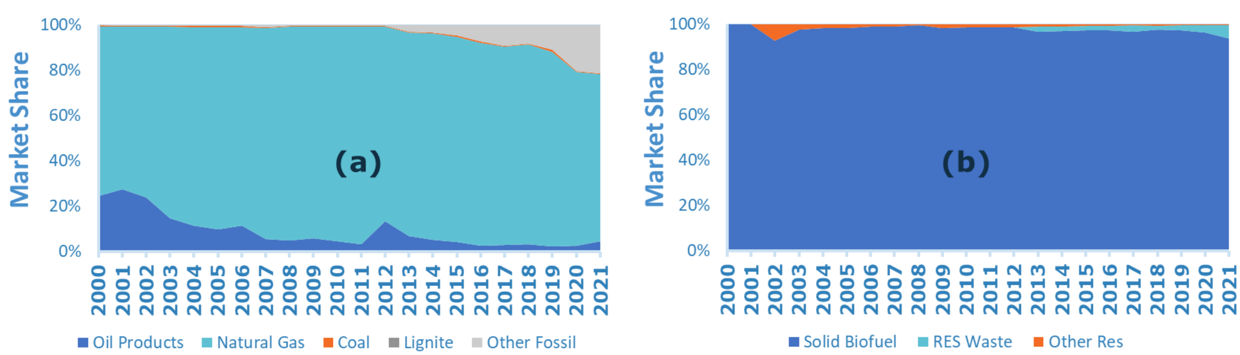

Figure 26. Breakdown of the market share for: (a) fossil fuels; (b) renewables.

Figure 26 shows the breakdown of the primary energy sources used. The dominant fossil fuel source is natural gas which approximately covers 80% of the market and then other fuels cover (e.g., non-renewable waste) the remaining 20%. A very minor share is covered by fuel oil. As for the renewables, solid biomass covers 95% of the generation, whereas the remaining 5% is covered by renewable waste. In future solar solutions for hot water supply during summer can be considered to complement biomass in order to reduce its consumption during the summer to have more availability in winter when there is higher demand. However, such a kind of solution poses problems in terms of temperature levels since solar thermal energy could be ideally used with a network operated at 60 °C while the Lithuanian one is operated at higher values (i.e., around 100 °C). The utilisation of heat pumps can help in overcoming this issue.

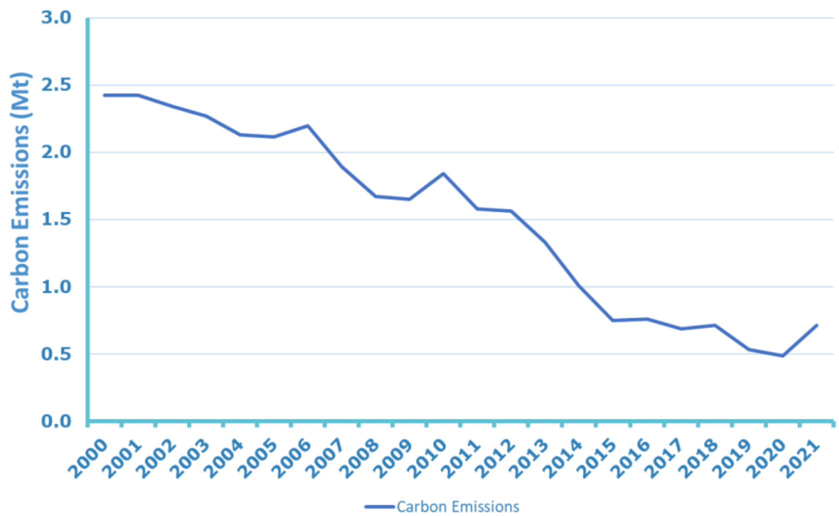

Figure 27. Carbon Emissions trend in Lithuanian DH generation.

Figure 27 illustrates the carbon emissions trend in LT DH generation. A sharp reduction of the emissions can be noticed resulting from the massive penetration of renewables. Differently from SK and PL, the decrease in DH generation is much more limited, thus the reduction of carbon emissions can be completely ascribed to the efforts for the transition from fossil fuels to renewable energy.

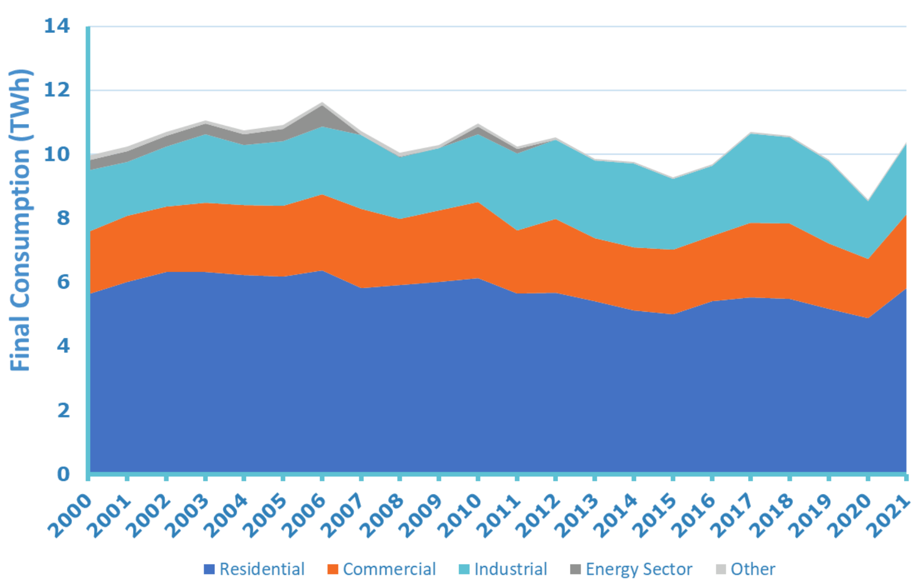

Figure 28. Final consumption in LT end use sectors.

Heat consumption in the different end use sectors are shown in Figure 28. Most of the consumption is represented by the residential sector followed by the commercial and industrial sectors. A slight decrease in consumption is observed in the residential sector, whereas a slight increase can be observed in the industrial sector.

DH Operating Temperature [°C]	70 - 110 °C
DH Operating Pressure [MPa]	0.3 - 07 MPa
Length of the Trench [km]	2840
Number of DH Companies	55
Number of Cities Served by DH	103

Table 4. Main parameters for DH in Lithuania.

5.3. Regulatory and Financial Framework

Main Legislative Framework

The Lithuanian DH market is strongly regulated. The background legislation is represented by the Law on Energy of the Republic of Lithuania, which provides the general provisions for the energy sector, and the Law on Heating Sector, which provides more specific sectoral prescriptions. DH market is overseen by the National Energy Regulatory Council (VERT).

The main activities of VERT related to the district heating sector are: approval of heat supply tariffs, issuing of heat supply licences, monitoring of correct tariff applications, dispute resolutions, etc.

The Law on Heating Sector has been updated in 2023. The most important changes refer to the:
- Planning of investments for 3-10 years;
- Auctions for heat production capacities;
- Priority for using waste heat;
- Simplified and more reasonable pricing system.

Ownership and Operational Schemes

The heat supply is a monopoly in each municipality, namely in each municipal network only one company can supply heat. If the supply is greater than 10 GWh/year a license issued by VERT is necessary, if the supply is lower than 10 GWh/year a local license issued by the municipality is necessary (GALINDO FERNÁNDEZ, et al., 2021). 55 licensed DH companies with annual sales of more than 10 GWh are regulated by the National Energy Regulation Council. Smaller companies (up to 10 GWh/year) are regulated by municipalities. While the heat supply is a monopoly within a municipality, heat generation is market-based and monthly auctions are organised where both private independent producers and public companies compete against each other.

Heat supply ownership works in the following way: usually the infrastructure (e.g., pipes) is public and it can be operated by municipal companies themselves or given in concession (through public procedures) to private companies with specific conditions to respect (e.g., renovations to implement, etc.). The duration of the concession is usually in the range of 10-20 years. Municipalities owned about 93% of DH companies, while 7% are leased (status in 2022).

The concession model was popular in Lithuania in 2000s years, but at the end of the concession period (e.g., from 2010 onward) many municipalities decided to retrieve the operatorship and to create municipal DH utility (e.g., following the well known German example) (GALINDO FERNÁNDEZ, et al., 2021). The reason for such an approach was a lack of efficiency of the private operators which managed the DH network.

Following this experience, very strict rules have been set for heat supply operators with a specific attention to cost efficiency (GALINDO FERNÁNDEZ, et al., 2021). If the IRR of heat suppliers exceeds the regulated WACC (currently about 3%), the excess must be returned (GALINDO FERNÁNDEZ, et al., 2021).

In contrast to a strict regulation on heat supply companies, which are basically owned and managed by municipalities, the heat generation is a free market business, thus both private and public companies can compete in auction for the provision of heat to inject in the network, provided that technical constraints are respected. The auction is based on the merit order, thus the offers are accepted in order of increasing price until meeting the expected (forecasted) heat demand of next month (Bacquet, et al., 2022). Adjustment for matching the differences bewteen forecasted and actual demand is responsibility of the heat supply operator (Bacquet, et al., 2022). Furthermore, the heat producer is responsible for the necessary investment to connect its facility to the DH network including the heat exchanger.

Metering

Heat metering at the point of delivery of heat for billing purposes is a regulated process. The Heat Law IX-1565 from 2003 reports this regulation and prescribes the obligatoriety of installing heat meters at the supply interface (Bacquet, et al., 2022). On the contrary, metering at individual consumption level is not regulated (e.g., for a building connected with the DH network it is mandatory and regulated to have a metering device, whereas for the dwellings present in the building the metering is not regulated) (Bacquet, et al., 2022).

However, there are some specific rules for the allocation of the metered heat quantities at individual level. Specifically, the Law on Heat of 20th May 2003 makes reference to methodologies recommended by the National Commission for Energy Control and Prices (Bacquet, et al., 2022).

Smart heat meters are mandatory in Lithuania (Bacquet, et al., 2022). This allows to have updated and precise information on the level of consumption, which is fundamental also to manage the heat generation auctions which are based on monthly forecasts.

Pricing

Prices for heat supply are strictly regulated bu the Lithuanian Law on Heat. The tariff is split in two parts: heat price and domestic hot water price. Domestic hot water price has only one component, whereas the heat price has three components: fixed, variable and additional components (GALINDO FERNÁNDEZ, et al., 2021). The tariff is usually established for a period of 3-5 years and necessitates to be approved ex-ante by VERT. However, some components are updated every month or every year depending on the calculation procedure applied by VERT.

The variable component, which includes the fuel cost, is updated every month according to fuel market variation and to the result of the monthly auctions for heat generation.

The fixed components which includes depreciation, personnel cost of the heat supply company, etc. is updated every year. Furthermore, for new clients, some connection fees can be also due.

Third Parties Access

Third Parties Access (TPA) is regulated by the Law on Heat. In the Lithuanian market there is the obligation to implement the TPA by the grid operators , mainly represented by municipalities. Thus, third parties (e.g., independent heat producers) must have access to the heat supply network provided that they meet technical requirements (e.g., in terms of temperature and pressure of injection within the DH network).

The connection is guaranteed at the closest technical suitable point (or to other technical feasible and less expensive point of connection) and the connection costs are charged to the independent heat producer. Once connected to the heat supply network, the independent heat producer can participate in the monthly auctions to sell heat to the network.

Boiler and CHP plants operated by heat supply companies accounted for around 60% of the total heat supplied to DH systems. A further 40% is purchased from independent heat producers (IHP). There are 23 unregulated and 20 regulated independent heat producers in the DH production market.

DH Demand Evolution

The number of new users is growing in larger cities. In Kaunas alone, six large-scale businesses were connected to the city's heat network in 2022, and the implementation of eight more projects has started. In total, applications for connection of about 300.000 m^2 of multi-family and commercial buildings have been received for the period 2021-2022. The latest project to be connected to the city's DH is the heated lawn of the football stadium. This is the first such project in Lithuania. Another example is Klaipėda, where more than 50 new customers – new and old apartment buildings, shopping centres, office buildings, port companies - have requested heating services in 2022. The trend is that not only new customers are joining, but also those who have previously disconnected are coming back. The total number of consumers has increased by almost 10% over the last decade, from 658.000 to 727.000.

In the small town of Mažeikiai, the interest of individual house owners in connecting to the district heating network is exceptional. With the support of the Structural Funds, the company has implemented three low-temperature heat network expansion projects, constructed 14.3 kilometres of new low-temperature heat flow lines and connected 131 new customers. Air pollution in the connected neighbourhoods has significantly decreased.

Lithuanian DH systems meet the efficiency criteria set by the European Union and are therefore considered energy efficient. Connecting to DH systems from 2021 onwards is also encouraged by the new building requirements that have come into force, whereby central heating in Lithuania is recognised as suitable for A++ class buildings, as the majority of district heat is produced from renewable sources.

The average annual heat consumption in residential buildings is around 130 kWh/m^2. The average owner of an average statistical flat spends on average about 1.8 Eur/m^2 on heating in typical old poorly insulated apartment blocks, where the majority of the population lives, 0.75 Eur/m^2 in quality apartment blocks and 2.6 Eur/m^2 in very poor condition apartment blocks. Obviously, these figures vary with different average outdoor temperatures.

In order to encourage managers and residents of multi-apartment buildings to take all necessary measures to ensure the efficient use of heat energy, amendments to the Laws on Heat Management and Modernisation of Multi-apartment Houses have been implemented in the summer of 2022. The law requires that by 1st July 2026, the heating and hot water supply systems of all Lithuanian multi-apartment buildings must comply with the new mandatory requirements. Systems not compliant with the new standard must be upgraded. A period of 4 years is given for the implementation of the upgrading processes.

VI. Barriers and Best Practices to the Integration of LOW-GRADE RES in High Temperature DH

The integration of “low graded“ energy sources in high temperature District Heating is a challenging effort characterised by barriers and best practices which will be illustrated in the following. The proposed analysis is based on different data sources, namely a desk research, a online survey among 109 experts in the field, and one to one experts interview.

6. 1. Barriers

Regulatory. Regulatory barriers to the integration of distributed RES-heat or waste heat in DH networks may have a substantial role. A correct and transparent implementation of the TPA is necessary or it will be impossible the access of third parties generators to the network. In some countries this process is well-developed (e.g., Lithuania), whereas in others (e.g., Poland) is less smooth. According to the online survey developed withing the Low2HighDH project, for 28% of the answers, regulatory barries represent the primary factor which hampers the integration of low graded RES in high temperature DH network. Furthermore, a policy support to develop appropriate regulatory measures to support the integration process is considered to have a high impact in 44% of the answers.

Technical. For 47% of the answers to the Low2HighDH survey, technical barriers are the most relevant for the integration of low graded renewables. The main issues is represented by the possible temperature difference of the heat in the network and the heat injected by distributed generators. In case of differences, the extra cost for balancing can be relevant. More complex solutions could be adopted such as the utilisation of a decoupling energy storage units which serve as an interface for the connection to the network. Thus the distributed generation supplies the storage which is then connected to the network (e.g., via a heat-pump) and managed by the DH company. More complex solutions require extra effort and higher investments. As resulted from L2H survery, for 45% of the answer, the intermittency of RES can represent a technical issues since back-up units could be necessary in any case.

Financial. Financial barriers are considered the most important barriers by 45% of the answers collected by the Low2HighDH survey. Lack of funding & investment and high upfront cost are considered the main factors hampering the development of the integration of distributed heat generation from RES/WH in high temperature DH network. The financial barriers are relevant for both DH operators and thrid parties generators. DH operators may incur in higher costs for the operation of the network due to balancing issues and controlling of all the distributed source of generation. Third parties generators have high investment cost for developing the heat generation facility (this is not the case for WH) and for the connection to the main DH network. Furthermore, they have operating costs since they have technical committment to fulfill (e.g., temperature and pressure of injection). This may lead to the conclusion that only operators with adequate know-how (e.g., industrial complex, energy utilities, etc.) can act as third parties generators. This is different from what happens in the power market where even households can be producers connected to the network.

6.2. Best Practices & Drivers

The integration of low graded renewables in high temperature DH includes multiple best practice actions and drivers to push for the opening of the network to the injection of heat coming from distributed generation. Some relevant aspects are highlighted by (Selvakkumaran, et al., 2021), who illustrates that a set of best practices can be achieved by integrated distributed RES heat generation in the network, in particular:

- **Cost Saving.** The marginal cost of heat coming from distributed generation may result lower than the marginal cost of heat provided by the main heat plants (Selvakkumaran, et al., 2021). Thus, the integration of distributed generation may determine cost savings. Furthermore, the reliance on distributed generation leads to the avoidance or delaying of investments in marginal heat technologies for the DH company, determining a further cost saving (Selvakkumaran, et al., 2021).
- **Enhancing the environmental and commercial profile of DH companies.** The inclusions of distributed RES-heat generation in the network enhances the environmental profile and commercial status of DH companies (Selvakkumaran, et al., 2021). This can attract commercial customers since, if they use renewable heat, this can be claimed in their environmental report or used for satysfing obligations in terms of reduction emissions or to obtain voluntary certification on sustainability issues. Furthermore, the integration of waste-heat in the DH network leads to an increase of the circularity (Selvakkumaran, et al., 2021).
- **Overall increase of DH network energy efficiency.** The integration of distributed heat generation from RES or excess heat represents a global increase in energy efficiency and a reduction of the primary energy use. In particular, the integration of excess heat supports the increase of the efficiency since energy waste is reduced. The use of RES permits the reduction of primary energy use in the DH operation, the exploitation of local resources (e.g., the case of Lithuania with biomass is exemplary), and the reduction of the emissions. The reduction and more efficient use of energy sources is considered to have an impact also on energy security issues. The 28% of the answers of our survey state that the integration of RES/WH in DH network contributes to the improvement of the energy security.

VII. Conclusions

The present report illustrates a general overview of the market dynamics of the DH sectors in EU, with a specific focus on PL, SK, and LT. The market context in terms of generation and consumption is analyzed, as well as the main regulatory framework.

The analysis shows that the situation in PL and SK is similar with the market dominated by fossil fuel generation, e.g., coal in PL and natural gas in SK. The situation in LT is different since the market is dominated by RES generation, specifically by local sourced biomass which represent the 80% of the market in terms of generation.

The model developed in LT could be applicable to SK since the two markets have comparable dimensions (e.g., about 10 TWh/year) and are based on similar technologies (e.g., those developed during the Soviet/Socialist period). Slovakia could source biomass locally as well and substitute natural gas import. This would be a relevant step in the enhancement of energy security (i.e., energy independence is one of the dimensions of the energy security), especially in the current period characterised by high geopolitical instability polarised by the Russian-Ukraine war. Russia was the main EU natural gas supplier, thus to reduce the utilisation of natural gas is a strategic period.

As for Poland the situation is different, since the market is much larger (80 TWh/year), thus different solutions should be implemented. In particular, a mix of solutions should be considered to reduce the utilisation of coal and improve the carbon footprint of the sector. PL could also massively rely on biomass generation, but this solution alone is probably not enough given the extension of the market. Integration of industrial heat, modernisation of CHP plants, improved efficiency of buildings, introduction of DH subnetworks operated at lower temperature, etc. are possible solutions to integrate alltogether to achieve tangible results at country level in terms of carbon emissions reduction.

Also in terms of market rules it can be said that Lithuania presents a more advanced and sophisticated framework since heat generation is completely based on free market. Namely, monthly auctions are organised and heat generators participate with their offers and a merit order is then built. The mechanism is similar to that of the power market. The offers are accepted in order of increasing price up to the complete covering of the demand.

The market framework used in Lithuania could be exported to other countries, primarily to Slovakia due to the context similarities discussed above. However, it could be also implemented on larger markets since DH network are usually municipality based, thus a larger market means more municipalities so it is no envisaged an increase in complexity due to market scale. The implementation of a free market on the generation side would support the diffusion of renewables or integration of waste-heat since the operators know that they can work under a transparent and fair mechanims as it happens for the power market.

The analysis of PL, SK and LT market shows that the DH sector offers relevant opportunity for increasing its sustainability and for the modernisation of its business models. LT has demonstrated that, despite the technical constraints, it is possible to restructure this sector in order to meet the decarbonization requirements.

VIII. References

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