

Integrating Geothermal Resources and Energy Geostructures in Heating Systems: Market Potential, Challenges, and Strategic Pathways in Lithuania

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Keywords: geothermal energy, energy geostructures, heat pumps, district heating.

ABSTRACT

Currently, a district heating (DH) covers over 55% of Lithuania's heat demand supplying combined heat from power plants (CHPs) and boilers using biomass, waste incineration, and fossil fuels for peak demand. Lithuania ranks second among the EU Member States in terms of the share of DH from renewable energy sources in urban areas (73% in 2022). Increasing demand for diversification and the share of heat produced from renewable sources, including geothermal energy and energy geostructures, presents an important opportunity and challenge for district heating and other heating systems.

The aim of this review paper is to assess and consolidate the potential of Lithuania's shallow and medium-depth geothermal energy and energy geostructures in building heating systems, identify both technical and non-technical barriers, and propose strategic pathways for its further integration in alignment with national energy goals.

1. INTRODUCTION

Lithuania is considered a cold-climate country and its well-developed district heating (DH) network covers over 55% of heat demand. After the decommissioning of the Ignalina Nuclear Power Plant in 2009, Lithuania's energy dependence on fuel imports increased from 50 - 62% to approximately 80–82% (Gaigalis et al., 2016). Lithuania has changed from being a net electricity exporter to a net electricity importer. In response to the war in Ukraine, in June 2022 Lithuania passed a law banning Russian natural gas imports and in May 2022 import of Russian electricity. The government is developing plans for Lithuania to generate 80% of its domestic energy needs by 2025 (International Trade Administration, 2024).

Lithuania DH networks can be classified as the 3rd or the 4th generation (3G or 4G) networks, with supply temperatures below 100°C and return temperatures below 60°C, as well as traditional heating systems with supply temperatures up to 80°C.

In 2022, 8.6 TWh of thermal energy was supplied to the networks. Approximately 60% of the total heat supplied to DH systems was produced in boiler houses and cogeneration plants managed by heat supply companies. The remaining 40% (2% more than the previous year) was purchased from independent heat producers (IHPs). The DH production market included 23 unregulated and 20 regulated independent heat producers (The Lithuanian District Heating Association, 2022). No up-to-date information has been officially provided by the Lithuanian District Heating Association as of the end of 2024.

Different types of heat pumps (HP) and geothermal energy for both direct and indirect use have been well-known technologies for many years. However, they have not received sufficient attention compared to traditional energy sources that were cheap and easily accessible. On the other hand, the efficiency of HPs has increased in the last decade (Fischer & Madani, 2017; Valančius, Singh, et al., 2019), along with better large-scale HPs integration and advancements in drilling and exploitation technologies for geothermal energy usage (Allahvirdizadeh, 2020; Romanov & Leiss, 2022; Song et al., 2023; Valančius et al., 2023).

At the end of 2023, the amount of HP installed in buildings across Europe was 23.96 million, the most dominant types were "air-to-air" and "air-to-water". However, the sales of heat pumps declined by 47% in the first six months of 2024 compared to the same period in 2023. A key reason for this slowdown is changes in policies and support schemes (The European Heat Pump Association, 2024).

As of the end of 2022, there were 395 operational geothermal DH and cooling systems in Europe, with 14 new systems launched that year. Within the EU, 261 systems were in operation, including 12 commissioned in 2022. This growth trend is expected to continue, with 316 projects currently under development, potentially adding over 700 MW to the existing 5,608 MW of capacity. Additionally, by the end of 2022, 16 projects were in the initial drilling phase, supporting large-scale heating and cooling production. Geothermal heating and cooling systems have been installed in 29 European countries, including 21 EU Member States, and this number is expected to increase to 34 as projects progress in Bosnia, Ireland, Latvia, Luxembourg, and Malta. (The European Geothermal Energy Council, 2023).

Many case studies have provided promising results in transition from traditional heating systems to HP and combining various renewable energy sources, including HP, solar energy, common storage facilities, and similar synergies. These efforts aim to improve heating efficiency in both individual and DH solutions (Ancona et al., 2022; Eslami et al., 2023; Guelpa & Verda, 2019; Pelda et al., 2020; Rose et al., 2022; Soloha et al., 2017; Valančius, Černeckiene, et al., 2019; Vonžudaitė et al., 2023).

New technologies, such as energy geostructures, a special type of ground heat exchanger integrated into ground-contact structures like retaining walls, piles, tunnels, and other buried infrastructures, are emerging in the market and hold great promises. However, technical, and non-technical obstacles still prevent their large-scale implementation (Aresti et al., 2024; Bourne-Webb et al., 2016; Loveridge et al., 2020; Meibodi & Loveridge, 2022;).

2. GEOTHERMAL ENERGY APPLICATIONS IN LITHUANIA

The Baltic Artesian Basin is characterized by a low geothermal gradient, with certain anomalies at greater depths, particularly within the Cambrian Formation sandstone reservoir in central and western Lithuania.

The research on geothermal energy in Lithuania has begun more than 30 years ago. It revealed the high energy potential geothermal anomaly at the greater depths in western Lithuania. In comparison to the background geothermal field intensity of 40–50 mW/m², the intensity of the anomalous field in western Lithuania measures 90–100 mW/m². Surveys conducted at the end of the 20th century indicated that geothermal waters in the southwestern part of Lithuania are located at a depth of about 1200 m, with temperatures reaching approximately 50°C. (Šliaupa et al., 2019; Valančius et al., 2023; Zinevičius et al., 2015).

The main legislative document for shallow geothermal applications is the Decree of Minister of Environment of the Republic of Lithuania entitled “Design, Installation and Liquidation of Geothermal Boreholes”

(Concerning the Approval of the Procedure of the Design, Installation and Elimination of Geothermal Boreholes (In Lithuanian), 2015). According to the description of procedures, a technical design must be prepared for any geothermal boreholes, irrespective of the installed heating capacity. Higher engineering education in hydrogeology or geology is required for designers and planners, as well as the permit issued by the Lithuanian Geology Survey to investigate the depths of the earth. For installations with a nominal heating capacity exceeding 30 kWt, the geological structure and the thermal conductivity must be tested in at least one borehole. The results are added to the national registry (Concerning the Approval of the Procedure of the Design, Installation and Elimination of Geothermal Boreholes (In Lithuanian), 2015). The special permit must be obtained from the Lithuanian Geology Survey in cases when boreholes are installed within the area of public water supply or mineral water supply sites. No permit is required for closed horizontal shallow geothermal systems.

The total capacity of installed small-scale ground source HP systems progressed from 0.09 MW in 2008 to 125.5 MW in 2020 (Šliaupa et al., 2019). The annual growth of the capacity of geothermal installations is 7.7 MW, indicating the stable growth of the geothermal market. The registration of geothermal installations started in 2009, currently the total of 532 geothermal applications with boreholes recorded by the Lithuanian Geological Survey. The share of geothermal energy in the national energy balance is approximately 1% (Marčiukaitis et al., 2016). Closed-loop systems with “U” shaped heat exchangers are the most common in Lithuania (Palaitis & Satkūnas, 2016).



Figure 1: Geothermal studies in Lithuania

Since some of the preliminary investigation has been already done there are four sites (Fig. 1) in Lithuania highlighted as perspective for the development of the DH network: Šilutė town (2170 m depth, temperature of the aquifer ~93°C, heat potential of the geothermal duplet is assessed at 1.5 MWh); Vilkaviškis town (1150 m depth, temperature of the aquifer ~45°C, heat potential of the geothermal duplet is assessed at 2,5 MWh) (Šliaupa S & Kežun J, 2011); Vydmantai village with some technical limitations (2000 m depth,

temperature of the aquifer $\sim 70^{\circ}\text{C}$) and well known Klaipėda Geothermal Demonstration Plant.

The construction of demonstrative Klaipėda City Geothermal Plant was launched in 1997, marking the inception of the first geothermal heating plant in the Baltic countries. In the Klaipėda Geothermal Plant, circulation pumps pumped 38°C heat geothermal water through 4 wells from the Devonian layer at a depth of 1135 meters. The capacity of the geothermal plant ranged from 10 to 35 MW with a geothermal loop flow rate varying between 160–210 m^3/h . In summer, the plant supplied heat for approximately half of Klaipėda City. In winter it generated enough energy to satisfy the demands of about 10% of the city (Radeckas & Lukoševičius, 2000; Šliaupa et al., 2019; Memon et al., 2024).

Primarily due to high liabilities, operation of the geothermal plant was suspended in 2017. Additionally, the cost of energy production using traditional sources such as biomass and waste heat dropped. Investors had been sought to lease the heating plant, but after failing the company was declared bankrupt in early 2019. The geothermal plant currently is in the state of conservation and is not monitored. It is unclear what the cost would be to relaunch the operation of the geothermal plant (Valančius et al., 2023).

The Geothermal Atlas of Lithuania was compiled in 2002 (Šliaupa S, 2002) and updated in 2016 integrating the geothermal data into the national geological information system “GEOLIS” of the Geological Survey of Lithuania (Baliukevičius A., 2016). It includes 11 maps of the geothermal aquifers, 1 map of the temperature of the crystalline basement, 4 maps of major aquitards, 7 maps of temperatures at the depths of 100, 200, 500, 1000, 1500, and 2000 m, 1 map of the geothermal gradient of the sedimentary cover, 1 map of the heat flow in Lithuania. More than 500 deep wells were drilled in Lithuania for oil exploration, geological mapping and gas storage research. The Geothermal Atlas is based on 204 deep boreholes. A total of 118 thermal logs in the deep wells have been digitalised.

The measurement of boreholes started in 1960’s. The range of the measured wells varies from 210 m in southeastern Lithuania (well Marcirkonys-2) to 2556 m in the west (well Vydmantai-1).

In 2025 the study by (Zajacs et al., 2025) presented that the most prospective geothermal resources are available in the Cambrian aquifer (Deimena Regional stage) in Lithuania and Latvia, and in the lowermost Cambrian-Ediacaran (Vendian) in Estonia. The temperature exceeds $>30^{\circ}\text{C}$ in the western part of Lithuania and the southernmost and middle part of Latvia which correlates to the burial depth increasing to the southwest of the Baltic basin. The study by (Makauskas et al., 2024) showed that developing a geothermal site in Lithuania promises both environmental and economic advantages. Despite initial investment, the long-term cost savings and the overall positive impact on Lithuania’s energy landscape make geothermal development a strategic and sustainable choice.

As of the end of 2024, no information was available on existing energy geostructures or real case study analyses in Lithuania.

3. DISTRICT HEATING MARKET IN LITHUANIA

The Lithuanian DH sector is among the most developed in Europe, with 57% (Šiluminė technika, 2024) of households connected to DH networks. Over the past two decades, Lithuania has undergone a rapid transition from fossil fuels to renewable energy sources (Jonynas et al., 2020), primarily biomass, making it one of the “greenest” DH systems in the EU (Šiluminė technika, 2024; Lukoševičius, 2024). In 2023, 73.5% of DH production was sourced from renewables (Fig. 2 and Fig. 3). In the near future, the capacity of biomass-using facilities and waste-to-energy power plants (WtE) will remain the same in the national DH system. But it is expected that the capacity of compressor HP used during the non-heating season will increase by about 400 MW_{th} (thermal), particularly for domestic hot water heating. .

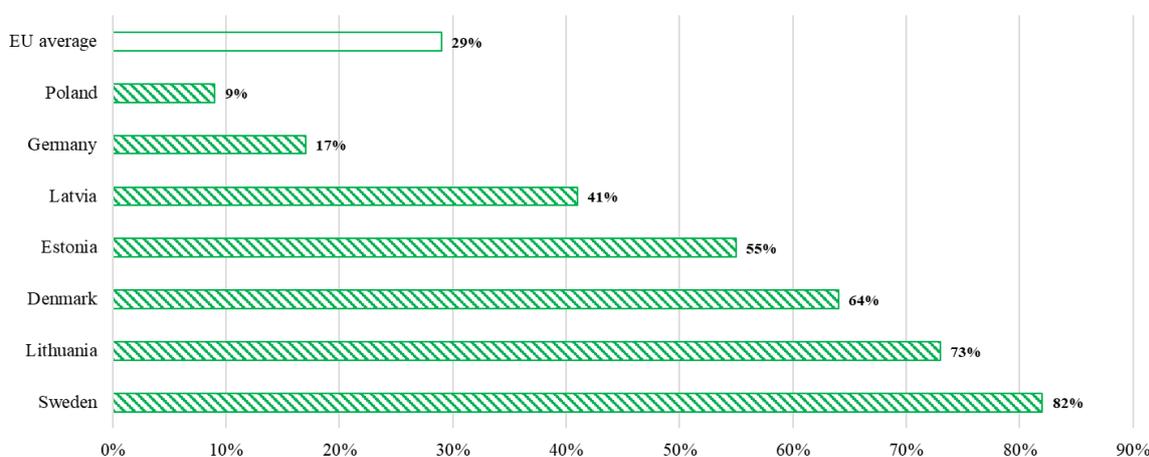


Figure 2: Share of renewable energy in DH production in EU Member States in 2023, (%)

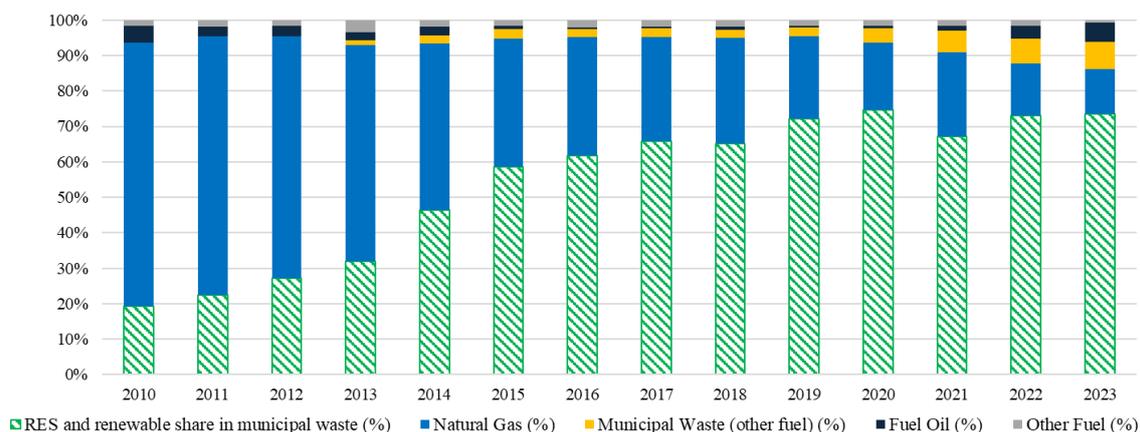


Figure 3: District Heating Fuel Mix by Year in Lithuanian DH Sector

The Lithuanian government’s National Energy Strategy aims for full decarbonization by 2050 (NENS 2024), with a shift towards low-temperature heating networks and the integration of HP and waste heat utilization. The Specific Plan of Lithuania’s Heat Sector is a municipal special planning document which, through the implementation of heat management measures, identifies the existing and planned new areas of heat consumers, and identifies possible and alternative heating methods to meet the needs of heat consumers at the lowest cost and within the limits of the permitted negative environmental impacts. New buildings situated within specified DH zones must be connected to the DH network and only authorized DH companies are allowed to supply heat within these zones to guarantee regulated and standardized service (Pažėraitė et al., 2022). In locations outside the DH zones, developers are permitted to install individual heating systems.

The Lithuania DH sector is clearly regulated by the government, but the amendments to the Republic of Lithuania Law on Heat Sector and related sub-legislative acts, entered into force at the end of 2023, have brought significant legal changes to this sector. Notably, revisions related to pricing regulations aim to

enhance clarity and transparency in the role of the State Energy Regulatory Council (VERT), the authority responsible for overseeing Lithuanian energy companies in accordance with EU directives. Under the new framework DH companies have been granted greater flexibility in setting monthly heat prices; however, their total annual revenue remains subject to a maximum cap. Furthermore, municipalities and heat supply companies are now mandated to develop strategic plans and investment roadmaps spanning a ten-year period. Additional new changes are related to the purchasing of thermal energy from independent heat suppliers and the implementation of mandatory energy efficiency measures in multi-apartment residential buildings. Following the energy crisis in 2023 and the resulting increase in fuel prices (Fig. 4).

DH heat tariffs increased. However, the average price of DH in Lithuania has stabilized since then, falling from 88 EUR/MWh to 74 EUR/MWh (VAT excluded), the level similar to that in 2013 (Fig. 5) (Šiluminė technika, 2024). Also, for comparison Fig. 5 shows how electricity price levels have changed for non-domestic consumers, which of course has a very significant impact on users of heat pump systems.

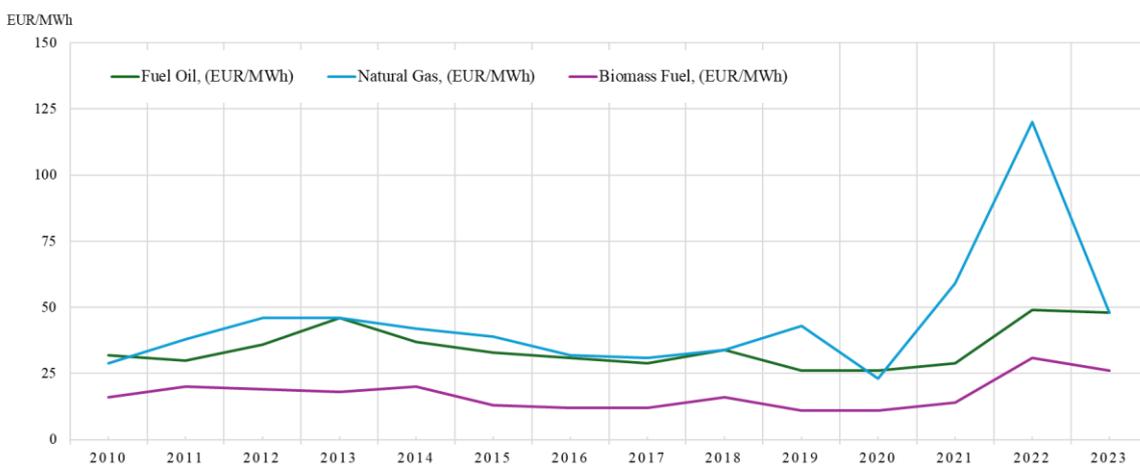


Figure 4: Average Fuel price in DH sector exl. Tax in Lithuania 2010-2023, (EUR/MWh)

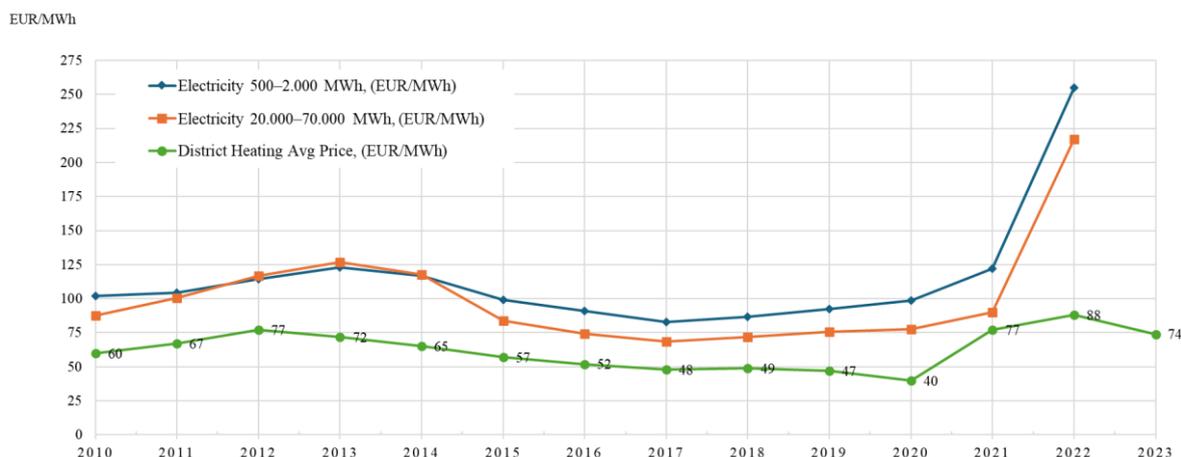


Figure 5: Average DH heat price exl. Tax in Lithuania 2010-2023, in comparison with non-household electricity price exl. Tax, (EUR/MWh)

4. TECHNICAL AND NON-TECHNICAL BARRIERS

One of the main technical barriers for the use of geothermal energy in buildings is energy inefficiency of the existing building stock in Lithuania, it requires a high temperature (up to 80 °C) heating system based on radiators. Renovation of apartments and detached buildings is inevitable but the transformation to low temperature heating requires additional financial support.

Other obstacles are cold winter temperatures that might cause technical issues using HP and high electricity consumption that puts extra burden on the existing electricity grids (especially in rural and older urban areas). Major upgrade of the electricity grid and large-scale investment are required in the future.

Finally, the required space for the installation of a heat pump equipment can be a significant limitation. Outdoor “air-source” heat pump units generate additional noise and require extra space and ground-source HP need sufficient land area. Therefore, both types can face installation barriers in densely populated urban areas

Non-technical barriers have been extensively analysed during the last decade in the United States (Bhatnagar et al., 2022; Aaron et al., 2022; Young et al., 2019) and Europe (Aresti et al., 2024; Dumas & Angelino, 2015; Olabi et al., 2023; Ramos-Escudero & García-Cascales, 2022); they include regulatory, economic, and social factors that may impact adoption of geothermal energy integration.

Regulatory issues such as the lack of specific policies or legal frameworks governing the design and implementation of geothermal technologies in DH can create uncertainty for developers and investors. Moreover, integration of geothermal energy in DH systems is a subject to regulation at a local (municipal), national (state) and sub-national (European) levels. Both regulatory and financial measures must be taken by national and local authorities to ensure that the

benefits of geothermal integration into DH systems are captured by the established pricing regimes. Existing policies must ensure that they do not disadvantage DH systems because of subsidies (direct or indirect) to other fuels or renewable energy sources (IRENA and Aalborg University, 2021). Additionally, energy geostructures often require coordination between multiple sectors, such as construction, energy, and environmental protection, which can result in administrative delays and regulatory bottlenecks. Bureaucratic issues, such as lengthy permitting processes and inadequate coordination among agencies, can hinder effective implementation (Magdy et al., 2025). These barriers require more comprehensive policies and simplified administrative procedures to promote geothermal energy as a viable source for DH.

Economically, the high initial costs of geothermal energy or geostructure installation, including advanced design requirements and specialized installation processes, is a significant obstacle, especially in regions with a low economic capacity. The mature DH market structure creates significant competition for energy geostructures that lack similar market mechanisms or pricing frameworks to support their integration (Volkova et al., 2022). Limited financial incentives, subsidies, or accessible financing mechanisms exacerbate this issue, making it difficult for geothermal systems to compete with more established technologies in the DH sector. Moreover, DH systems that are already based on renewables as the main source for heat supply, may limit integration of geothermal technologies. For example, for over a decade biomass is a major contributor to Lithuania’s DH systems. The widespread use of biomass-based DH, often subsidized and locally sourced, creates additional competition for new technologies like energy geostructures or geothermal DH.

Social acceptance also plays a critical role; a lack of public awareness and knowledge about the available geothermal technologies and their benefits may lead to

scepticism and resistance from policy makers, investors, stakeholders, and public (Figueira et al., 2024). A lack of awareness may lead to the NIMBY (“not in my backyard”) phenomenon, despite the will to decarbonise energy production (Meirbekova et al., 2024). For example, the case of Lithuania shows that stakeholders involved in the biomass supply chain, including producers and DH companies, resist the introduction of alternative technologies that could disrupt their business models. Additionally, concerns about potential environmental impacts, such as non-sustainable management of groundwater/surface water or changes due to the land usage, could reduce public support (Soltani et al., 2021).

5. POTENTIAL AND STRATEGIC PATHWAYS

Lithuania shows a high potential for geothermal heat energy application due to an anomalous heat flow in the west of the country. However, geothermal systems for DH in the rest of the country have not attracted much interest, because the heat flow and associated temperatures decrease towards the east of Lithuania (Kaminskaitė-Baranauskienė et al., 2024). The Klaipėda Geothermal Demonstration Plant was the only geothermal DH plant in Lithuania, presently it is closed. Economically favourable Cambrian geothermal conditions are identified by the recent study in Klaipėda, Šilutė, and Kretinga cities (Makauskas et al., 2024). Moreover, review of the previous research shows that geothermal solutions combined with the complementary solutions might have favourable economic effects in the utility field (e.g. geothermal + photovoltaic or geothermal + wind) (Chomać-Pierzecka et al., 2022). However, the geothermal potential is underestimated in the National Energy and Climate Plan by 2030, and existing energy policies overlook geothermal energy as one of the potential options for DH (Zajacs et al., 2025).

The Seimas of the Republic of Lithuania approved the updated National Energy Independence Strategy on 27 June 2024. The strategic objective of achieving independence from Russia regarding natural gas and electricity was successfully achieved in 2022. Moreover, the process of disconnection from the BRELL system and the synchronization with continental Europe was finalized in February 2025. Therefore, the updated Strategy outlines revised energy goals to be achieved by 2050 and foresees Lithuania as the energy independent country that produces energy for its own needs and export. These goals include 100% climate-neutral energy, a transition to an electricity-based economy, and ensuring a safe and reliable energy supply for consumers. Electrification of the energy sector and growth in electricity demand are projected to be the most prominent trends in the energy sector by 2050. The use of HP is forecasted in both the more electrified DH sector and the individual heating sector.

The electrification of the energy sector and the significant increase of HP in Lithuania requires policies and support measures to facilitate the acceleration of

this process. The main available support measures for HP in detached houses and DH systems in Lithuania are described below.

The Lithuanian Energy Agency (LEA) provides financial support for the replacement of inefficient biomass or fossil fuel boilers with more efficient, renewable heat generation technologies in single-family houses /detached buildings not connected to a DH system. This measure includes installation of HP (air source, water source, and ground source) in single-family houses and apartment buildings that are not connected to the DH system and helps to reduce the initial investment in the heat pump as well as significantly accelerates its payback. The compensation is not based on the purchase price of the heat pump, but only on the government's rates per 1 kW for the installation. The maximum amount of support is up to 50% of the eligible costs calculated at fixed rates for different types of heat pumps.

Unfortunately, the Environmental Project Management Agency (APVA) terminated financial support for the installation of renewable energy sources (solar and geothermal technologies) in multi-apartment buildings in 2022. This measure provided up to 30% state support for heat pumps.

National Development Bank ILTE provides soft loans to heat suppliers and independent heat producers that increase the use of renewable energy sources in the DH sector. The loan is combined with a grant of up to 25% of the eligible costs of the project, up to a maximum of 50% of the funding decided by ILTE. The installation of HP is part of the ILTE low-interest loan scheme, with a fixed interest rate of 2% and a loan period of up to 20 years.

The Climate Change Programme partly funded absorption HP in Kaunas (2,4 MW) and Vilnius (8,5 MW) DH systems. This technology has the potential to reduce the costs associated with heat production.

Carbon neutrality could be achieved through geothermal adoption in DH by developing a long-term strategy that considers technological advantages, targeting policies and regulation, providing financial incentives and business models, prioritizing environmental sustainability, and increasing social acceptance. Enabling the potential of the diversification of renewable energy sources in DH is essential in order to make geothermal technologies competitive with dominant biomass technologies in Lithuania. Challenges such as high initial costs and local site-specific limitations remain, but strategic investments and innovation can make geothermal technologies in DH a significant part towards carbon neutrality goals of 2050.

6. CONCLUSIONS

Even though shallow and medium-depth geothermal energy resources are well investigated in Lithuania, and various types of HP have demonstrated high efficiency

and long-life spans, Lithuania remains among the countries where the potential of geothermal energy is underestimated and insufficiently reflected in national energy and climate plans to support technological development or meet carbon-neutrality targets.

In designated DH zones, new buildings must be connected to the DH network, and only authorized DH companies are permitted to supply heat within these areas. This regulation limits the installation of all types of HP in urban areas.

The main technical barriers include the high operating temperatures of existing heating systems and the need for adequate land area for ground-source heat pumps. Furthermore, a significant upgrade of the electricity grid and large-scale investments will be required in the future. Not only due to the growing installation of heat pumps, but also due to the increasing use of other electric appliances, including electric vehicles.

Efforts to address non-technical barriers should focus on comprehensive policies, clear regulatory frameworks, simplified administrative procedures, diversification of the renewable DH portfolio, financial support mechanisms, collaborative stakeholder engagement, and public education campaigns to build awareness and trust in geothermal energy and energy geostructures.

To overcome local barriers, Lithuania should establish supportive policies for geothermal energy use in the heating sector and energy geostructures. This may include pilot programs, subsidies, or integration incentives, while gradually diversifying its renewable DH strategy beyond biomass auctions.

REFERENCES

- Aaron L., Smith, L.E.P., Robins J., Witter E., Smith C. & Haffner C. (2022). Non-Technical Barriers to Geothermal Development in California and Nevada. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-83133. <https://www.nrel.gov/docs/fy23osti/83133.pdf>
- Allahvirdizadeh, P. (2020). A review on geothermal wells: Well integrity issues. In *Journal of Cleaner Production* (Vol. 275). <https://doi.org/10.1016/j.jclepro.2020.124009>
- Ancona, M. A., Baldi, F., Branchini, L., De Pascale, A., Gianaroli, F., Melino, F., & Ricci, M. (2022). Comparative Analysis of Renewable Energy Community Designs for District Heating Networks: Case Study of Corticella (Italy). *Energies*, 15(14). <https://doi.org/10.3390/en15145248>
- Aresti, L., Alvi, M. R., Cecinato, F., Fan, T., Halaj, E., Li, Z., Okhay, O., Poulsen, S. E., Quiroga, S., Suarez, C., Tang, A. M., Valancius, R., & Christodoulides, P. (2024). Energy geo-structures: A review of their integration with other sources and its limitations. *Renewable Energy*, 230, 120835. <https://doi.org/10.1016/J.RENENE.2024.120835>
- Baliukevičius A. (2016). *Geothermal data module*.
- Bhatnagar, D., Rabinowitz, H.S., Boff, D. S., Pennel, G., Holland, C.A., Weimar, M., Huang, B., Wu, D. Bonneville, A., (2022). Nontechnical Barriers to Geothermal Development. U.S. Department of Energy
- Bourne-Webb, P., Burlon, S., Javed, S., Kürten, S., & Loveridge, F. (2016). Analysis and design methods for energy geostructures. In *Renewable and Sustainable Energy Reviews* (Vol. 65). <https://doi.org/10.1016/j.rser.2016.06.046>
- Chomać-Pierzecka, E., Sobczak, A., & Soboń, D. (2022). The Potential and Development of the Geothermal Energy Market in Poland and the Baltic States—Selected Aspects. *Energies*, 15(11). <https://doi.org/10.3390/en15114142>
- Concerning the Approval of the Procedure of the Design, Installation and Elimination of Geothermal Boreholes (In Lithuanian) (2015).
- Dumas, P., & Angelino, L. (2015). GeoDH: Promote Geothermal District Heating Systems in Europe. In *Proceedings World Geothermal Congress*.
- Eslami, S., Noorollahi, Y., Marzband, M., & Anvari-Moghaddam, A. (2023). Integrating heat pumps into district heating systems: A multi-criteria decision analysis framework incorporating heat density and renewable energy mapping. *Sustainable Cities and Society*, 98. <https://doi.org/10.1016/j.scs.2023.104785>
- Figueira, J. S., García Gil, A., Vieira, A., Michopoulos, A. K., Boon, D. P., Loveridge, F., Cecinato, F., Götzl, G., Epting, J., Zosseder, K., Bloemendal, M., Woods, M., Christodoulides, P., Vardon, P. J., Borg, S. P., Erbs Poulsen, S., & Andersen, T. R. (2024). Shallow geothermal energy systems for district heating and cooling networks: Review and technological progression through case studies. *Renewable Energy*, 236, 121436. <https://doi.org/10.1016/J.RENENE.2024.121436>
- Fischer, D., & Madani, H. (2017). On heat pumps in smart grids: A review. In *Renewable and Sustainable Energy Reviews* (Vol. 70). <https://doi.org/10.1016/j.rser.2016.11.182>
- Gaigalis, V., Skema, R., Marcinauskas, K., & Korsakiene, I. (2016). A review on Heat Pumps implementation in Lithuania in compliance with the National Energy Strategy and EU policy. In *Renewable and Sustainable Energy Reviews*. <https://doi.org/10.1016/j.rser.2015.09.029>
- Guelpa, E., & Verda, V. (2019). Thermal energy storage in district heating and cooling systems: A review. In *Applied Energy* (Vol. 252). Elsevier Ltd. <https://doi.org/10.1016/j.apenergy.2019.113474>
- International Trade Administration. (2024, May 27). *Lithuania - Country Commercial Guide*. <https://www.trade.gov/country-commercial-guides/lithuania-energy>.
- IRENA and Aalborg University. (2021). *Integrating low-temperature renewables in district energy systems: Guidelines for policy makers*.
- Jonynas, R., Puida, E., Poškas, R., Paukštaitis, L., Jouhara, H., Gudzinckas, J., Miliauskas, G., & Lukoševičius, V.

- (2020). Renewables for district heating: The case of Lithuania. *Energy*, 211, 119064. <https://doi.org/10.1016/J.ENERGY.2020.119064>
- Kaminskaitė-Baranauskienė, I., Cichon-Pupienis, A., & Makauskas, P. (2024). Silurian barrier reef in Lithuania: Reservoir properties and low enthalpy geothermal heat potential. *Heliyon*, 10(4). <https://doi.org/10.1016/j.heliyon.2024.e26360>
- Lukoševičius, V. (2024) Kas lems pigesnę šilumą Lietuvos miestuose? *CŠT pasiekimai ir iššūkiai*. 2024. https://lsta.lt/wp-content/uploads/2024/10/1_VL-CST-pasiekimai-ir-issukiai-spalio-2-dienai-F.pdf
- Loveridge, F., McCartney, J. S., Narsilio, G. A., & Sanchez, M. (2020). Energy geostructures: A review of analysis approaches, in situ testing and model scale experiments. *Geomechanics for Energy and the Environment*, 22. <https://doi.org/10.1016/j.gete.2019.100173>
- Magdy, A., Ogunleye, O., Mroueh, H., Di Donna, A., & Singh, R. M. (2025). A review of exploiting shallow geothermal energy through tunnels: Current status and future prospects. *Renewable Energy*, 238, 121958. <https://doi.org/10.1016/J.RENENE.2024.121958>
- Makauskas, P., Kaminskaitė-Baranauskienė, I., Rashid Nabi Memon, A., & Pal, M. (2024). Assessing Geothermal Energy Production Potential of Cambrian Geothermal Complexes in Lithuania. *Energies*, 17(5). <https://doi.org/10.3390/en17051054>
- Marčiukaitis, M., Dzenajavičienė, E., Kveselis, V., Savickas, J., Perednis, E., Lisauskas, A., Markevičius, A., Marcinauskas, K., Gecevičius, G., & Erlickytė-Marčiukaitienė, R. (2016). Atsinaujinančių energijos išteklių naudojimo Lietuvoje patirtis, reikšmė ir siekiai. *Energetika*, 62. <https://doi.org/10.6001/energetika.v62i4.3394>
- Meibodi, S. S., & Loveridge, F. (2022). The future role of energy geostructures in fifth generation district heating and cooling networks. *Energy*, 240. <https://doi.org/10.1016/j.energy.2021.122481>
- Meirbekova, R., Bonciani, D., Olafsson, D. I., Korucan, A., Derin-Güre, P., Harcouët-Menou, V., & Bero, W. (2024). Opportunities and Challenges of Geothermal Energy: A Comparative Analysis of Three European Cases—Belgium, Iceland, and Italy. *Energies*, 17(16), 4134. <https://doi.org/10.3390/en17164134>
- Memon, A., Makauskas, P., Kaminskaite-Baranauskiene, I., & Pal, M. (2024). Unlocking Geothermal Energy: A Thorough Literature Review of Lithuanian Geothermal Complexes and Their Production Potential. *Energies*, 17(7), 1576. <https://doi.org/10.3390/en17071576>
- NENS 2024. Lithuanian Ministry of Energy. (2024). *National energy independence strategy*. <https://enmin.lrv.lt/public/canonical/1731396595/5432/NENS%202024-2.12.pdf>
- Olabi, A. G., Mahmoud, M., Obaideen, K., Sayed, E. T., Ramadan, M., & Abdelkareem, M. A. (2023). Ground source heat pumps: Recent progress, applications, challenges, barriers, and role in achieving sustainable development goals based on bibliometric analysis. *Thermal Science and Engineering Progress*, 41. <https://doi.org/10.1016/j.tsep.2023.101851>
- Palaitis, Ž., & Satkūnas, J. (2016). *CORRELATION BETWEEN THE COMPOSITION OF GEOLOGICAL SECTIONS AND HEAT CONDUCTIVITY*.
- Pažeraitė, A., Lekavičius, V., & Gatautis, R. (2022). District heating system as the infrastructure for competition among producers in the heat market. *Renewable and Sustainable Energy Reviews*, 169, 112888. <https://doi.org/10.1016/J.RSER.2022.112888>
- Pelda, J., Stelter, F., & Holler, S. (2020). Potential of integrating industrial waste heat and solar thermal energy into district heating networks in Germany. *Energy*, 203. <https://doi.org/10.1016/j.energy.2020.117812>
- Radeckas, B., & Lukoševičius, V. (2000). Klaipeda geothermal demonstration project. *Proceedings World Geothermal Congress 2000*.
- Ramos-Escudero, A., & García-Cascales, M. D. S. (2022). Barriers behind the Retarded Shallow Geothermal Deployment in Specific Areas: A Comparative Case Study between Southern Spain and Germany. *Energies*, 15(13). <https://doi.org/10.3390/en15134596>
- Romanov, D., & Leiss, B. (2022). Geothermal energy at different depths for district heating and cooling of existing and future building stock. In *Renewable and Sustainable Energy Reviews* (Vol. 167). <https://doi.org/10.1016/j.rser.2022.112727>
- Rose, J., Thomsen, K. E., & Balslev-Olesen, O. (2022). The Balance between Energy Efficiency and Renewable Energy for District Renovations in Denmark. *Sustainability (Switzerland)*, 14(20). <https://doi.org/10.3390/su142013605>
- Šiluminė technika, 2024, 2(91). ISSN 1392-4346. <https://lsta.lt/wp-content/uploads/2024/09/LSTA-Silumine-technika-2024-Nr-2-91.pdf>
- Šliaupa S. (2002). *Geothermal Data Base of Lithuania*.
- Šliaupa S, & Kežun J. (2011). Hydrothermal resources of Middle Lithuania. *Geologija*, 53(2), 75–87.
- Šliaupa, S., Zinevičius, F., Mazintas, A., Petrauskas, S., & Dagilis, V. (2019). Geothermal Energy Use, Country Update for Lithuania. *European Geothermal Congress 2019, June*.
- Soloha, R., Pakere, I., & Blumberga, D. (2017). Solar energy use in district heating systems. A case study in Latvia. *Energy*, 137. <https://doi.org/10.1016/j.energy.2017.04.151>
- Soltani, M., Moradi Kashkooli, F., Souri, M., Rafiei, B., Jabarifar, M., Gharali, K., & Nathwani, J. S. (2021). Environmental, economic, and social impacts of geothermal energy systems. In *Renewable and Sustainable Energy Reviews* (Vol. 140). <https://doi.org/10.1016/j.rser.2021.110750>
- Song, X., Li, G., Huang, Z., Shi, Y., Wang, G., Song, G., & Xu, F. (2023). Review of high-temperature geothermal drilling and exploitation technologies. *Gondwana*

Research, 122.
<https://doi.org/10.1016/j.gr.2022.10.013>

The European Geothermal Energy Council. (2023, July 14). *ESEC Geothermal Market Report 2022*.
<https://www.egec.org/media-publications/egec-geothermal-market-report-2022/>.

The European Heat Pump Association. (2024). *Market data*.
<https://www.ehpa.org/market-data/>.

The Lithuanian District Heating Association. (2022). *CŠT sektoriaus apžvalga*. <https://lsta.lt/silumos-ukis/cst-sektoriaus-apzvalga>

Valančius, R., Černeckienė, J., Jurelionis, A., Aresti, L., Rman, N., & Singh, R. M. (2023). Analysis of the Wider Potential for Heat Pump and Geothermal Energy Integration in Traditional Systems and Grids. *Energetika*, 69(1).

Valančius, R., Černeckienė, J., & Singh, R. M. (2019). *Review of Combined Solar Thermal and Heat Pump Systems Installations in Lithuanian Hospitals*.
<https://doi.org/10.18086/eurosun2018.01.06>

Valančius, R., Singh, R. M., Jurelionis, A., & Vaiciunas, J. (2019). A review of heat pump systems and applications in cold climates: Evidence from Lithuania. In *Energies* (Vol. 12, Issue 22).
<https://doi.org/10.3390/en12224331>

Volkova, A., Pakere, I., Murauskaite, L., Huang, P., Lepiksaar, K., & Zhang, X. (2022). 5th generation district heating and cooling (5GDHC) implementation potential in urban areas with existing district heating systems. *Energy Reports*, 8.
<https://doi.org/10.1016/j.egy.2022.07.162>

Vonžudaitė, O., Martišauskas, L., Bakas, R., Urbonienė, S., & Urbonas, R. (2023). Optimization of Heat Pump Systems in Buildings by Minimizing Costs and CO2 Emissions. *Applied Sciences (Switzerland)*, 13(8).
<https://doi.org/10.3390/app13084864>

Young, K.; Levine, A.; Cook, J.; Heimiller, D.; Ho, J. (2019). *GeoVision Analysis Supporting Task Force Report: Barriers—An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios*. Golden, CO: National Renewable Energy Laboratory. NREL/PR-6A20-71641.
<https://www.nrel.gov/docs/fy19osti/71641.pdf>.

Zajacs, A., Shogenova, A., Shogenov, K., Volkova, A., Sliupa, S., Sliapiene, R., & Jõelet, A. (2025). Utilization of geothermal energy: New possibilities for district heating networks in the Baltic states. *Renewable Energy*, 242, 122375.
<https://doi.org/10.1016/J.RENENE.2025.122375>

Zinevičius, F., Šliaupa, S., Mažintas, A., & Dagilis, V. (2015). Geothermal Energy Use in Lithuania. *World Geothermal Congress 2015, April*.

ACKNOWLEDGEMENTS

This article is based upon work from COST Action CA21156 – European network for fostering large-scale Implementation of energy geostructure (FOLIAGE), supported by COST (European Cooperation in Science and Technology).