PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

The Geothermal District Heating Market: Challenges and Opportunities in Europe

Aniko N. Toth, Miklos Antics, Tamas Csrefko and David K. Fenerty

3515 Miskolc-Egyetemvaros

toth.aniko@uni-miskolc.hu

Keywords: Geothermal, district heating, cooling, efficiency, solve a problem, brings value, describes a novel approach.

ABSTRACT

Geothermal district heating (GDH) is a cost-effective, environmentally friendly way to transport the heat required for large-scale heating and cooling in residential and commercial properties. The method is well-suited for the EU's decarbonization roadmap, as these GDH systems hold great potential for providing clean, sustainable and efficient heating throughout Europe. Nonetheless, scaling up and fully exploiting these systems requires that the following challenges be met: high initial investment costs and concurrent long payback periods; resources which can be difficult to access; seismic and environmental concerns; occasionally adverse public and political perception; regulatory and permitting hurdles; imperfect technology; and, perhaps most importantly, uncertain economic viability.

To overcome these challenges, governments must co-operate with the geothermal industry to provide innovative private/public partnerships which incentivize new-project investment. Governments in particular can play a key role in de-risking geothermal projects by offering financial support, tax breaks, or loan guarantees. As regards the role of technological innovation, advances in drilling technology, heat pump efficiency and geothermal system design can make investment more attractive by helping lower costs and improve efficiency. Public awareness campaigns are also vital in increasing the general public's understanding of geothermal energy's benefits. Such efforts will build support for geothermal's adoption, particularly in regions with high potential. Finally, international cooperation can also accelerate geothermal deployment across Europe by encouraging the exchange of best practices between countries, particularly between those with more developed geothermal sectors (e.g., Iceland or France) and those which represent the less-developed geothermal countries (e.g., Romania or Hungary). This article will try to cover all these relevant issues in analyzing the present and future of geothermal district heating and cooling.

1. INTRODUCTION

The use of geothermal as a source for district heating (DH) is not new; it dates back to Roman times, as seen in the ruins of city homes and baths heated via natural hot water catchments and piping.

With the help of modern technology, and partially because of the oil crises of the 1970s, more and more DH projects started to use geothermal resources with temperatures at or above the 50-60°C range. This upswing halted in the 80s and 90s when the oil and gas industry developed better directional drilling methods, which again made fossil fuels more competitive. Now, after thirty years of slower development, the GDH market is again enjoying renewed momentum, notably as a consequence of the Ukrainian war, higher oil and gas prices, new technological developments, and renewed concerns over energy dependency and sustainability.

Every year, the European Geothermal Energy Council (EGEC) Geothermal Market Report analyses market trends and developments in the European geothermal sector. There are approximately 6,000 DH systems in Europe. These range from small, local networks to large-scale systems supplying heat to entire cities. District heating provides about 12-15% of the total heat demand in Europe, with significant national variations (as per the 2024 EGEC Geothermal Market Report). DH systems are widespread throughout Europe. Countries like France, Denmark, Sweden, Finland, and Poland have the highest penetration rates, with DH covering up to 50–70% of heat demand in urban areas. In Southern Europe, DH is less common but is becoming more and more important as these systems are used to improve energy efficiency and integrate renewable energy sources into the existing heating and cooling network. This segment of the heat sector is largely dominated by fossil fuels and, to a lesser extent, industrial waste heat. For instance, 80% of DH in Germany is supplied by conventional combined heat and power (CHP), 76% is supplied by coal in Poland, 76% and 43% is supplied by natural gas in Italy and France, respectively. Because DH has the potential to more efficiently and sustainably use geothermal and other renewable heat sources, it is considered a key technology for decarbonizing the heat sector and reducing Europe's dependency on fossil fuels (EGEC, 2024).

2. KEY ELEMENTS OF GEOTHERMAL DISTRICT HEATING (GDH) IN EUROPE

2.1 An Overview of GDH in Europe

The first GDH system in Europe was established in Chaudes-Aigues, a small town in the Auvergne region of France, during the 14th century. This system utilized the town's natural hot springs, specifically the Par river spring, which produces water at temperatures of up to 82°C (179.6°F). As reported in the city annals, heated homes were charged a tax by the local landlord in exchange for maintenance duties. The geothermal water was then channeled through a network of wooden and stone pipes to heat buildings and provide hot water. This makes Chaudes-Aigues one of the earliest known examples of geothermal heating in the world.

Larderello in Italy is considered the birthplace of industrial geothermal energy, as it was the first place in the world where geothermal steam was used to generate electricity (in 1904). By 1913, those geothermal resources were also adapted for district heating purposes, serving the local community and industrial processes.

The first large scale GDH system in Europe was established in Reykjavík, Iceland, in 1930. This system used geothermal water from the Laugardalur hot springs to provide heating for homes, schools, and a hospital. Over time, it expanded to serve more of the city, laying the foundation for Reykjavík's modern geothermal heating system, which now provides heat for nearly 90% of Icelandic homes.

France soon after, establishing the first modern GDH system in 1945 in Bouillante, on the French overseas territory of Guadeloupe, in the Caribbean. This system harnessed geothermal energy from volcanic activity to supply heat and electricity. In mainland France, GDH systems became more prominent in the 1960s and 1970s, particularly in the Paris Basin. One of the first and most significant systems was installed in the Val-de-Marne area near Paris in 1969. This system utilized geothermal energy from the Dogger aquifer, a large underground reservoir of hot water. To this day, the Paris Basin remains one of the World's largest geothermal district heating development.

In 1950, a GDH system was established in Szeged, Hungary, utilizing the country's abundant geothermal resources. Hungary has extensive geothermal potential, and systems like the one in Szeged helped lay the groundwork for expanded geothermal energy use throughout the country.

In Germany geothermal-based heating always had a role. The first such system was established in Riehen, in 1984, near Freiburg im Breisgau (technically in Switzerland, but closely associated with German infrastructure). The first geothermal district heating system that specifically served Germany was developed in Erding, Bavaria, in the 1990s. Erding's system tapped into the deep hot water reservoirs of the Molasse Basin and became one of the pioneers of modern geothermal heating in Germany, Cataldi et al (1999).

2.2 Current Market Overview

Geothermal district heating and cooling systems have grown continuously since 2010, and witnessed a steady boom in the number of new projects under construction. By the end 2023, a total of 346 systems were in operation, 298 of them in EU Member States. In 2023, for example, 8 new systems were commissioned in the European Union: 1 in Germany; 3 in Finland; 1 in the Netherlands; 2 in Romania; and 1 in Slovakia. Furthermore, 64 new projects were announced that year: 10 in Croatia; about 30 in Germany; 2 in Italy; 3 in Spain; about 17 in the Netherlands; and 2 in Romania. The 8 new geothermal systems added 33.9 MWth to Europe's geothermal heating and cooling capacity. The total installed capacity across Europe was 6 GWth across 29 countries, of which 21 are Member States of the European Union. The coverage of geothermal heating and cooling systems is expected to increase to 34 when Bosnia, Ireland, Latvia, Luxemburg and Malta complete the projects currently in their respective pipelines. Figure 1 shows the map of main geothermal district heating and cooling reservoirs, and their temperature ranges (EGEC, 2024).

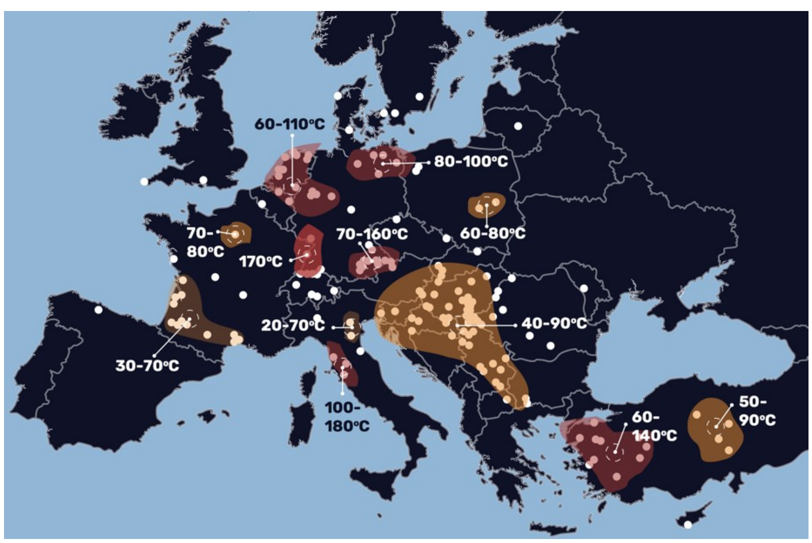

Figure 1: Geothermal reservoirs for district heating and cooling (source EGEC)

Over 360 geothermal district heating and cooling projects are in development or under consideration in the EU, with Germany, France and the Netherlands having the most systems. This could result in more than a doubling of capacity within the next 4 to 5 years. As in previous years, France remains the country with the largest installed geothermal district heating capacity in the European Union, second in Europe only to Iceland. Three geothermal systems were commissioned in Finland, and two in Romania. Single systems were installed in Germany, the Netherlands and Slovakia. 2023 saw fewer plants put into operation than during the last years, especially in comparison with 2022 and 2021, when 14 new installations were inaugurated. In 2024, however, 14 new GDH systems were again commissioned (EGEC, 2024).

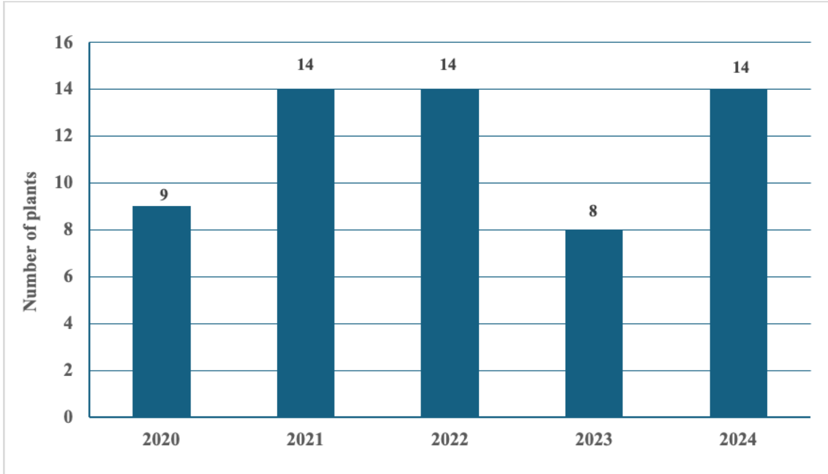

Figure 2: New GDH plants commissioned in the last 6 years (source EGEC)

2.3 Recent Developments in Europe

The European Commission introduced the Net Zero Industry Act (NZIA) in March 2023, which was officially adopted in 2024. This policy initiative aims to bolster domestic manufacturing of clean energy technologies, including geothermal, to reduce reliance on external sources. Geothermal was recognized as a strategic net-zero technology under this act, with the objective of having EU manufacturing capacities meet 40% of domestic deployment needs by 2030.

In December 2024, EU member states collectively endorsed geothermal energy for the first time. They requested that the European Commission develop a comprehensive plan to incentivize geothermal projects, including financial guarantees and simplified permitting processes. The REPowerEU Plan, the revised Energy Efficiency Directive (EED) and the revised Renewable Energy Directive (RED) set out ambitious measures, including the increase of the share of renewable energy and waste heat in district heating systems, and suggestions for improving the efficiency of district and cooling networks. The Commission has mobilized close to €300 billion to fund the REPowerEU Plan. The Recovery and Resilience Facility (RRF) is at the heart of this funding. District heating and/or cooling operators/owners will have to prepare and implement plans so that existing systems fulfil the criteria for "efficient district heating and cooling", as defined in the EED.

Figure 3 shows, listed by country, the number, of GDH projects currently being operated and planned (under development or under consideration). Germany, France and the Netherlands are particularly prominent in this list, followed by Italy, Hungary and Croatia, (EGEC, 2024).

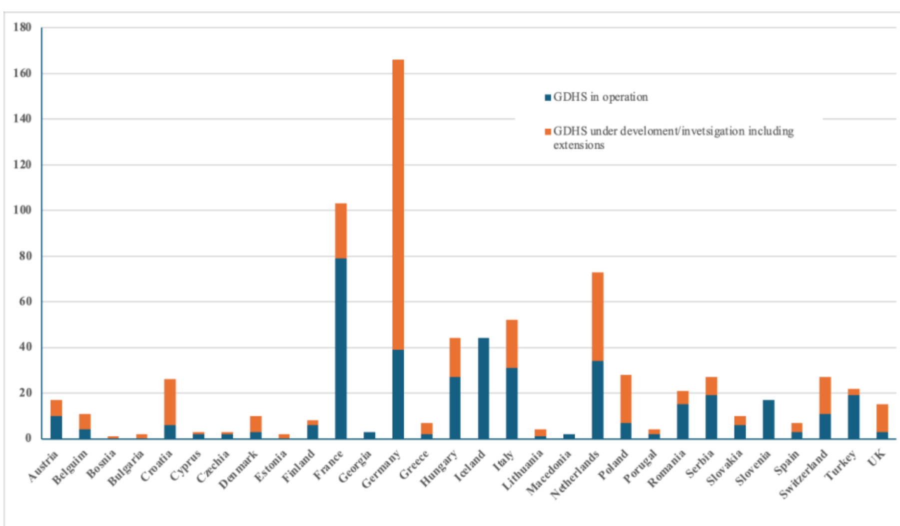

Figure 3: Operating and planned GDH systems in Europe (source EGEC)

2.3.1 Examples of national initiatives and projects from the last few years

In Germany, a new geothermal DH plant was commissioned in 2023 in Schwerin. The project cost almost €20.5 million and received a €4.2 million subsidy from the European Regional Development Fund, European Commission, (2023). The heating plant has wells at a depth of 1300 meters, supplying 56 °C heat. With a capacity of 7,5 MWth, the heat will be supplied to 2000 households. This project faced several technical challenges during its development due to suspended particles in the fluids. In 2023, several research activities were initiated on this site, to create a model for geothermal in Northern Germany which would generate a digital reservoir model of the sandstone aquifer, comprising 3D seismic surveys. Some geothermal heat plants were finalized in 2023 and began operation in 2024. In June 2024, Germany announced plans to expedite approval processes for geothermal plants, heat pumps and heat storage systems. The proposed law aims to streamline bureaucratic procedures and facilitate the expansion of renewable heat sources, aiming to increase geothermal energy generation to 10 terawatt hours (TWh) by 2030.

In France a geothermal heating and cooling system was developed for the 2024 Olympic games. 600 000 m^2 of residential and office buildings, including the village of Athlets, received 350 GWh/year of heating and cooling, 68% of it from renewable energy -- thanks to geothermal. The system consists of a 10 km. supplementary heating and cooling grid, connected to a 70 km.+ existing network. Total investment was estimated 29 million €, with 5,8 million € of public investment from ADEME, SOLIDEO and the region of Île-de-France.. This new system, inaugurated in December 2023, began operation in 2024 and will help prevent the release of 4747 tons of CO2 per year (EGEC, 2024).

Furthermore, three municipalities near Paris - Fontenay-aux-Roses, Sceaux et Bourg-la-Reine - established a local public company, GéoSud92, to collectively develop a GDH system. With an expected investment of 63 million €, the project aims to heat 15,000 residences by 2026. This new system will be connected to the existing system, with 65 000 households already supplied by Sipperec, the operator. Estimated heat costs are about 100 €/MWh, approximately 10 to 15 % cheaper than with individual fossil-fuel heating installations (EGEC, 2024).

The Netherlands has been increasingly exploring and adopting GDH as part of its energy transition strategy to reduce greenhouse gas emissions and move away from fossil fuels. Currently, 26 geothermal energy projects are operational in the Netherlands, primarily supplying greenhouses between Hague and Rotterdam. Some notable developments: the Purmerend project aims to supply sustainable heat to approximately 27,000 connections within the existing heating network, which currently relies on biomass and natural gas; the Aardwarmte Vogelaer project is also expanding its geothermal heating network, whereby the addition of a new doublet will increase capacity to serve new customers, notably in a residential area in the city of Monster; the Delft Geothermal Heating Initiative, which has initiated a geothermal heating project to reduce CO_2 emissions; and the multi-Municipality Geothermal Network in Bollenstreek (EGEC, 2024).

In Italy, in November 2023, plans were announced to establish Florence's first geothermal district in Novoli; The proposed geothermal heating plant in the San Donato area aims to serve public services, offices, a university, and private buildings, promoting urban redevelopment and cleaner air. In the same year, in 2023, Fri-El Geo partnered with A2A Calore e Servizi to develop geothermal resources for heating in Milan. This collaboration is part of the Pangea project, which seeks to build geothermal plants across Northern Italy, contributing to the areas decarbonization efforts. Verona's Geothermal Investment, in January 2024, saw the AGSM AIM Group announce investments in a geothermal project to supply clean, renewable heat to Verona's district heating network. The project is expected to reduce gas consumption by 40% and lower CO2 emissions by approximately 30,000 tons. Radicondoli in Tuscany also undertook an expansion of its geothermal heating system. In June 2024, the European Commission approved Italian state aid schemes to support approximately 4.6 gigawatts (GW) of new renewable energy capacity, including geothermal projects. These schemes, extending until the end of 2028, aim to promote the construction of plants based on innovative technologies such as geothermal energy (EGEC, 2024).

3. OBSTACLES TO GROWTH

Developing GDH systems faces several challenges, ranging from technical and economic to social and environmental factors. Significant untapped potential for geothermal energy remains to be further explored and used. Securing financing can be difficult, however, due to high upfront costs and long payback periods. It can still be hard for GDH systems to compete with cheaper or more established energy sources like natural gas.

In contrast to wind and solar, legacy hydrothermal/geothermal commercial performance has been a barrier to venture capital and private equity investment. Existing regulatory alternatives for power plant decommissioning schedules and scope are not widely used by industry, limiting opportunities for re-skilling personnel and sustaining municipal GDP.

3.1 Resource Identification and Assessment

Identifying suitable geothermal resources requires significant investment in geological surveys and drilling. There's a risk of not finding sufficient or sustainable resources. Lack of detailed subsurface data can hinder resource estimation and planning. The lack of data, including subsurface data, and limited public accessibility to existing geological data, allows risk to remain in the early stage of project development, and to impedes the more rapid deployment and wider uptake of geothermal energy.

More specifically, the multiwell (doublet, triplet, quadruplet, quintuplet) heat extraction scheme faces three major, occasionally critical, concerns: 1/ the difficulty of replacement of aging and possibly damaged well infrastructures with more productive structures; 2/ excessive well location density in several locations (Figure 4), which can lead to heat-mining disputes, fewer well replacement opportunities and more difficult future developmentand reservoir cooling problems, and, last but not least; 3/ inefficient heat reclamation from moderately to poorly productive areas as a result of wasteful “skimming-off-the-cream” operations, where appropriate, field-tested, innovative well architectures are not made available (Ungemach et al, 2024).

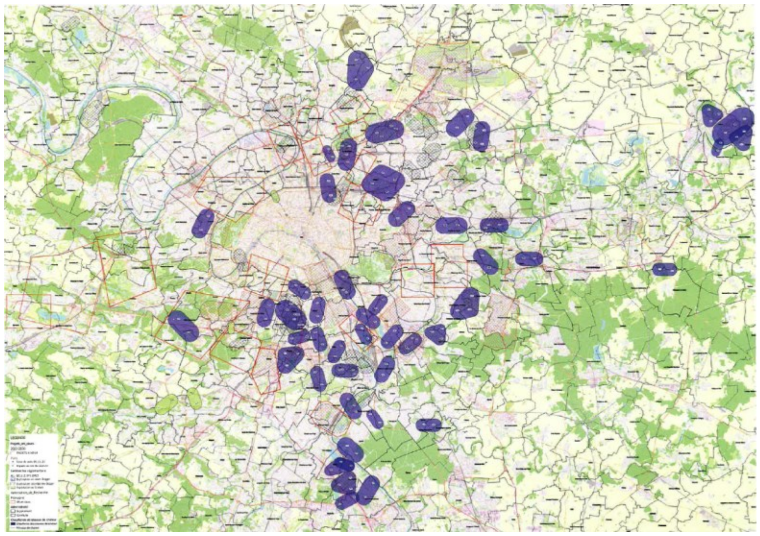

Figure 4: Operating GDH grids in the Paris Basin (source GPC IP)

3.2 High Initial Investment and Technological Challenges

Despite the relatively low operating cost, the commercial viability of deep geothermal investments is unlikely to increase without measures to address high upfront investment costs and risks related to exploration, capital and drilling. Geothermal systems require resources at specific temperature ranges, limiting their application in some regions. Geothermal fluids can cause scaling and corrosion in equipment, increasing maintenance costs. Integrating geothermal systems into existing heating infrastructure can be technically complex. Drilling geothermal wells is expensive, often accounting for a significant portion of the project budget. Building the district heating network (pipelines, heat exchangers) adds to the upfront costs.

Fossil energy resources supply more than half the EU residential sectors’ final energy consumption for district heating and cooling. In those situationsgeothermal energy could provide affordable and secure heating and cooling supply to decarbonize buildings’ energy consumption in buildings and make industries more competitive and sustainable. Still, low natural gas prices make fossil fuel a tough competitor, as the average gas retail price has continuously decreased of late, from 139 €/MWh in 2022 to only 106 €/MWh in 2024.

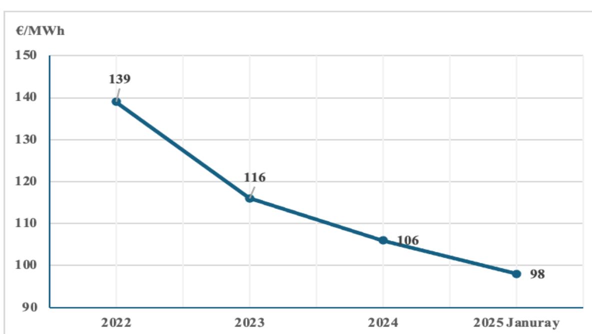

Figure 5: The average gas retail price in Europe (Eurostat, 2024)

3.3 Regulatory and Policy Issues

Lengthy and complex permitting processes can delay projects. A lack of clear or supportive policies for renewable energy development can discourage investment. The regulatory complexity, financial and commercial barriers, insufficient human capacity or technology-specific experience in permit-granting authorities, and the lack of a skilled workforce and specialized companies are all factors contributing to the suboptimal use of geothermal energy potential.

3.4 Environmental Concerns and lack of social recognition

Geothermal energy production needs to align with the environmental framework, including nature and groundwater protection and safety requirements. Because geothermal drilling and extraction can induce minor seismic events, residents frequently raise concerns about new or even existing geothermal operations. Local opposition to drilling or infrastructure development due to perceived environmental or aesthetic impacts can stall projects. Limited understanding of geothermal energy benefits can lead to resistance from stakeholders. Over-extraction of geothermal resources can lead to depletion or reduced output. Seasonal variations in heat demand can complicate operational efficiency and financial returns.

4. ADDRESSING THE CHALLENGES

To overcome these obstacles, the Council of the European Union made a Call (16248/24) to draw up a comprehensive strategy on the decarbonization of heating and cooling accompanied by a dedicated European Geothermal Action Plan, with measures to facilitate geothermal projects and to accelerate the deployment of geothermal energy. The Call formulated a policy supporting the requirements, a combination of technological developments, public involvement and financial incentives. It also highlighted the key importance of cooperation between governments, private investors and research institutes to assure the successful development of GDH systems.

4.1 European Union's Action plans to accelerate the deployment of geothermal energy

- possible guarantee schemes to mitigate upfront investment risks;
- guidance and best practices to enhance investment in geothermal projects and relevant infrastructure, including adequate storage for district heating/cooling networks;
- best practices and guidance to accelerate and simplify permit-granting procedures, including the involvement of local communities, so as to facilitate the end-to-end delivery of geothermal projects;
- training programs to address the lack of a skilled workforce, and to improve capacity throughout the whole geothermal value chain;
- actions to facilitate data sharing, subsurface data availability, data accessibility and new geological data collection;
- best practices or models to facilitate long-term contracts, such as renewable heating/cooling purchase agreements;

4.2 Regulatory framework and financial aspects

The Council of the European Union also called on the Commission and the Member States to provide a structured forum, such as a European Geothermal Alliance, to bring together policymakers, industry stakeholders, investors and other relevant stakeholders throughout the entire value chain. This would allow them all to exchange best practices and successful business models, create new partnerships and identify common bottlenecks and remedial actions. It specifically called on them to:

- promote an optimal, more sustainable design of district heating and cooling systems, by for example lowering the allowable temperature at which such systems can operate, so as to integrate geothermal energy;
- consider geothermal energy solutions in their building codes as a driver for more efficient and sustainable buildings;
- encourage the application of an integrated approach to subsurface activities in order to align geothermal energy usage with groundwater protection practices, as well as with other subsurface activities such as hydrogen storage and carbon capture/storage;
- facilitate projects reconverting fossil underground facilities to use them for geothermal energy or encourage the development of solutions enabling the faster realization of such projects;
- consider improving access to financial-aid or investment-guarantee schemes and other incentives, so as to mitigate high upfront costs and risks related to drilling and exploration, to promote the construction of geothermal infrastructure and to facilitate the commercial viability of geothermal investments

5. TRENDS AND ACHIEVEMENTS

Because the problem is multifaceted, the solution must be multifaceted. One key element is drilling and exploration techniques. Drilling techniques which use geophysical surveys and AI-powered models to identify optimal drilling locations can reduce exploration risks and costs. There is a growing demand among geothermal facility operators for innovative well architectures that handle complex, tectonically challenging, multilayered reservoir settings and/or thermochemically sensitive fluid environments in a way that can sustain high production capacity and long thermal lifetimes.

Other key achievements include integrating heat pumps into GDHS to enhance flexibility and support low-temperature operations, and developing hybrid systems to combine geothermal heat pumps (GHP) with renewable electricity from solar or wind.

One of the most promising innovations would allow peer-to-peer energy trading within bidirectional district heating grids, whereby buildings could share surplus heat or cooling. This presupposes energy prosumer models, where users act as both producers and consumers of thermal energy.

In all of these new developments, smart meters can be deployed to provide real-time data on energy consumption, empowering users to adjust their usage. This means implementing demand response programs to align consumption with renewable energy availability, thereby reducing peak loads. Two final elements in this innovative framework are the use of blockchain technology for secure and transparent energy transactions in decentralized heating systems, and the automation of network operations to minimize human intervention and ensure consistent performance.

5.1 Drilling in urban areas

Drilling in the dense urban areas of Europe is a challenge, but developing appropriate drilling techniques for geothermal energy in such domestic areas is critical for making geothermal heating and cooling systems more accessible, cost-effective, and minimally disruptive.

The challenges for geothermal wells vary, depending on the particular EU country, but everywhere they somehow relate to the legal situation as it determines rig and infrastructure transportation, rig operation (running from the electric grid) and local wellsite design. Other significant limitations are load dimensions and weights, traffic limitations, air and noise pollution, and wellsite access. Operators usually have to devise especially innovative, custom-designed drilling technologies and methods, optimized for geothermal applications in residential or urban environments.

Figure 6: Geothermal well drilling at Bonneuil-sur-Marne, Paris, France (source GPC IP)

5.1.1 Technology transfer from the oil and gas industry

The oil and gas industry, and Nabors Industries in particular, has pioneered unconventional oil and gas production to make hitherto 'tapped-out' reservoirs economical, using such advancements as directional drilling, reservoir stimulation, multi-well pad development, purpose-built rigs and continuous well improvement, to increase production and lower costs. All these methods can be used to equal advantage in GDH systems, so that newly engineered solutions from the oil and gas sector can help expand the world's geothermal supply in a safe, reliable and cost-effective way. Oil and gas industry advancements with direct potential benefits for GDH system development include:

- Applying digitalization and automation to advanced stimulation techniques used in unconventional-field production, so as to further lower drilling costs by achieving consistency & continuous improvement
- Improving the reliability of high-temperature drilling equipment, and using autonomous floor operations to remove people from the load path and any hot fluid – these are keys to assuring the safety and reliability of continuous production
- Innovative Drilling Technologies, which drill deep hard rock more quickly and efficiently
- Automation developed to reduce the cost per well by allowing for the automated drilling of sections with predictable characteristics for consistency, where there's little time variation.
- Managing temperature and pressure while drilling to avoid unplanned trips and improve wellbore instability, while lowering mud and casing costs.
- Improving the casing/cementing in wells, while using new chemical methods to make more reliables bond, handle temperature fluctuation and prolong the life of the well.
- Developing new working fluids and turbines for a more efficient conversion of heat to power – this is of particular importance for the geothermal industry.
- Treating the rig as an integrated platform, an approach which helps minimize transportation risk, cost, emissions, and fuel consumption.
- Production growth in grid supply, grid firming, and the development of independent micro-grids.
- Multiple integrated drilling technologies which help provide effective, safe and quiet drilling in urban areas, such as:; Drilling and Directional Automation, to allow for flexible and versatile solutions, with stick/slip mitigation and unparalleled levels of automation;
- Development of new-generation Top Drives, with high torque and noise reduction, for more energy efficiency.
- Treating the rig as an integrated platform, which lowers personnel transportation risk, cost, emissions and associated fuel and other consumption.
- Using integrated methods to increase production growth in grid supply, firm up the grid and develop independent micro-grids.

Figure 7 shows a drilling site in Dallas-Fort Worth Metropolitan Area, where the Highline power grid connects to the drilling rig, powering all electrical components without the need for a diesel-generated power drilling rig.

Figure 7: ***Nabors Industries' Pace-R rig drilling in Dallas-Forth Worth (2023)***

5.1.2 Challenges in transferring technology from the oil and gas industry

For large closed-loop downhole heat exchanger systems, long lateral wells are needed. These require larger, more capable rigs which can sometimes be hard to find in Europe. A related challenge is the required European certification, Conformite Europeene (CE), whereby compliance requirements and rig acceptance can vary from country to country. This problem is further complicated when drillers also plan to use their rigs outside of the EU, and seek to maximize their use of standard, stackable, 'off-the-shelf' rigs.

Personnel requirements are another challenge, as the unconventional-drilling industry (working mostly in the US and other oil-and gas-producing countries) is more developed than in Europe. That might make it hard to find the local European workers needed to carry out necessary drilling operations on a large scale. The related personnel challenge involves finding the necessary vendors and sub-contractors, who are used to catering to a more developed unconventional-drilling industry. The lack of such partners can make it necessary for the drilling company to bring along a lot of extra tools and spare parts, which could significantly add to the cost of a geothermal drilling project.

5.1.2 Innovative well design – an example from the Paris Basin

The Paris Basin GDH system (GDHS) is based on a deep-seated dependable resource of regional extent, a hot saline brine at 1600 to 2000 m depth in the Dogger (Mid Jurassic) carbonate platform. Since the late 1970s and into the early 1980s, it provided heating for up to 1,5 million inhabitants of suburban Paris, representing a 1500 GWh_{th} annual supply via a grid of fifty (50) well doublets/triplets.

Figure 8: Cachan subhorizontal geothermal well, Paris, France (source GPC IP)

In 2018, the company GPC IP (GPC Instrumentation Process) began a series of innovative drilling projects in that region, using two sub horizontal well (SHW) and one multiradial well (MRW) architectures. A third well format, aa multilateral well (MLW), was commissioned for a low permeability reservoir location, and was due to be completed by late 2024.

GPC's design aimed to take advantage of the area's multilayered reservoir structure, at the Cachan and Grigny sites. These subhorizontal, multiradial and multilateral geothermal well architectures were commissioned for the initially less productive margins of what had otherwise been a geothermally dependable part of the Dogger carbonate platform(Ungemach et al., 2024).

5.2 The 5th-generation district heating and cooling (5GDHC) systems

Nowadays, rerban heating is progressing from traditional centralized high-temperature to lower temperature supply. Decreasing the supply temperature also allows for more efficient operation (e.g., less heat loss), better integration and a greater variety of renewables/ waste heat sources (see Lund et al, 2018). The 5th generation of geothermal district heating and cooling system represents a modern, highly efficient, and decentralized approach to geothermal energy utilization. It builds upon earlier generations by emphasizing sustainability, energy efficiency and smart systems integration. Figure 7 shows the difference between generations in chronological order.

The district heating/cooling network is categorized into generations (1st to 5th GDHC), based on the operational temperature and the method of heat transport within the network. In some cases, a low or high-temperature heat pump can be employed to raise the network temperature either centrally (with a central heat pump) or at the end-user level (using a decentralized heat pump).

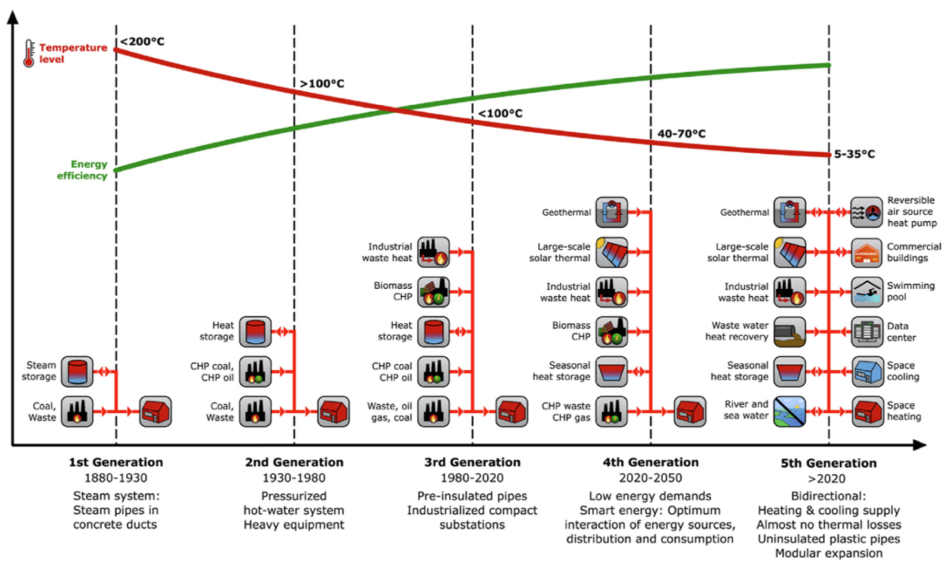

Figure 9: Evolution of district heating and cooling networks Wirtz et al, (2020)

<u>5.2.1 Key Characteristics of 5GDHC</u>

This is a low-temperature network, which operates at temperatures of around 10–40°C, allowing for minimal heat loss and higher overall efficiency.It utilizes heat pumps at the end-user level to raise temperatures to desired levels.

Heat can flow both ways, allowing for simultaneous heating and cooling within the same network. Users can act as both consumers and suppliers of thermal energy, allowing them to share energy.

It is a decentralized system, combining multiple smaller-scale geothermal resources, using solar, thermal, or waste heat sources within local distribution systems. This encourages local generation and consumption, reducing dependency on centralized infrastructure.

The system is integrated with other renewable energy, seamlessly integrating with other renewable energy sources like wind, solar PV, and biomass. It enhances grid flexibility and helps achieve carbon neutrality goals.

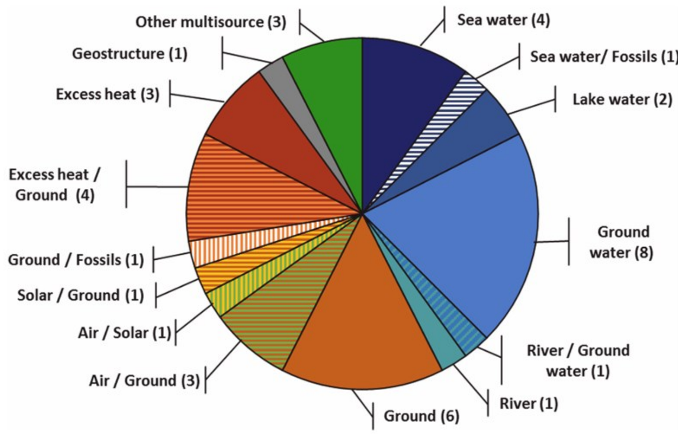

Figure 10: 5GDHC case studies by source, Buffa et al, (2019)

The system's smart energy management employs advanced monitoring and digital control systems for dynamic optimization of energy use, and integrates the Internet of Things (IoT) technology and artificial intelligence for predictive maintenance and demand forecasting.

The system can be used equally well for urban and rural Applications. It is well-suited both for retrofitting older buildings and deploying in new developments, and is adaptable to dense urban areas or dispersed rural locations. It features reduced greenhouse gas emissions compared to earlier generations, and focuses on circular energy systems by using local and sustainable resources.

So far in Europe there are more than 200 5th generation DHC systems, especially in Germany, Sweden, Switzerland, France, Denmark, Austria, Italy and the Netherlands. More than 60% of 5th generation DHC projects are in newly constructed areas, and 16% are in existing areas with a new district network. For the most part, these DHC systems are less than 10 km in length with heat capacity less than 100 MWth (with less than 20 MWth for coolling capacity). In terms of sources, geothermal is the leader with 39%, and is used mainly in Switzerland, Germany, Denmark, France and UK.

5.2.2 State-of-the art 5GDHC systems in Europe

The Mijnwater project, in the Netherlands was a pioneer. The system is one of the first so-called 5th generation district heating and cooling (5GDHC) grids, an integrated heating and cooling system that uses a multitude of energy sources, technologies and digital tools to provide flexible supply specifically designed for the city's fluctuating needs. The city of Heerlen's unique approach to its 5GDHC is an example of how to exploit the legacy of coal mining to generate significant social, environmental and energy benefits. It was started in 2008, in the Dutch province of Limburg, and was originally designed as a way to repurpose coal mines which had been closed in the 1970s. The concept was to use flooded coal mines as a natural geothermal reservoir, with 28° - 35°C water in deeper layers and 16° - 8°C in shallower areas. These can be tapped for both heating and cooling purposes. At Mijnwater, customers are also suppliers: energy can flow in both directions, enabling users to exchange surplus heating or cooling. Since December 2023, work has continued on the expansion of the mine water pipeline network (European Commission, 2024).

The Paris Saclay District Heating and Cooling network is one of the most innovative DHC grids in Europe. Its network relies on geothermal energy extracted from a ca. 700-meter deep aquifer. The water produced water is around 28°C, and is the basis for a heating and cooling system. Since this system is a low-temperature network, heat loss is minimized during transmission. Heat pumps are used to raise the temperature to levels suitable for heating buildings, while cooling is provided directly from the geothermal system or via absorption chillers. The energy flow is bidirectional. The users can exchange thermal energy within the network, with excess heat from one user potentially being utilized by another. The network integrates geothermal energy with solar thermal or biomass, to ensure reliability and sustainability. This system was inaugurated in June 2019, and is designed to expand its capacity, aiming to supply heating and cooling to 2.15 million square meters of floor space by 2027, with a target of achieving 63% renewable and recovered energy usage (GPC Instrumentation Process, 2024).

The lighthouse project Vridsløsemagle is situated in a suburban area near Copenhagen, Denmark, where the local district heating company (Høje Taastrup Fjernvarme) converted a small village with individual oil boilers to district heating with geothermal heat pumps, connected to a centralized bore field with 23 shallow geothermal probes and a pumping station. This system operates at low temperatures (10–40°C) reducing heat losses and improving energy efficiency. Alongside geothermal energy, this network integrates solar thermal, wind power, and waste heat recovery. The Vridsløsemagle Lighthouse Project was initiated in 2020 as part of the EU-funded REWARDHeat program, which aims to demonstrate innovative low-temperature district heating and cooling solutions across Europe.

These systems could serve as a model for other urban and suburban developments aiming to decarbonize their energy systems.

6. CONCLUSION

Geothermal energy reduces dependency on imported fossil fuels, enhancing energy security for European nations. It provides a reliable, local energy source that operates independently of external supply chains. The success of GDH in Europe can be attributed to several key factors which make it an especially effective and sustainable energy solution: the relative high population density of Europe's urban/suburban centers, often concentrated in high-rise apartment complexes –a circumstance which tends to make GDH a more economical investment; the faith which many Europeans tend to have in government-funded geothermal investment as a good way to reduce energy costs, and not least; the now generally held belief that developing Europe's own energy sources, whether for heating/cooling or electricity production, is safer than depending on unstable foreign providers like Russia or the US.Although many European countries have significant geothermal resources, even with minimal geothermal resources such countries as Germany and Norway have shown that GDH systems are a good bet.

At the EU level, policies like the EU Green Deal encourage the development of clean energy technologies. While the initial investment of a GDHS can be high, the systems provide stable and affordable energy for decades. Technological advances in the geothermal drilling and heat pump sector, along with technological developments borrowed from the oil and gas sector, have made the geothermal heating needed for district heating networks more efficient. Modern district heating systems such as those created by GPC IP in Paris are able to use multiple innovative well architectures to reach hitherto unattainable geothermal sources, while optimizing energy use by integrating multiple energy sources. EU funding programs like Horizon Europe and structural funds play a significant role, withmany European governments providing additional subsidies, tax incentives, and regulatory frameworks to promote their own GDH projects. Many European cities have integrated GDH systems into their urban planning, making it easier to implement large-scale projects that benefit entire communities.

To sum up, combination of favorable natural conditions, strong policy support, technological innovation, and public acceptance has made GDH a successful and sustainable solution in Europe.

REFERENCES

Buffa, S., Cozzini, M., D'Antoni, M., Baratieri, M. and Fedrizzi, R.: 5th generation district heating and cooling systems: A review of existing cases in Europe, Renewable and Sustainable Energy Reviews, Vol. 104: 504-522, (2019)

Cataldi, R., Hodgson, S. F. and Lund, J.W.: Stories from a Heated Earth: Our Geothermal Heritage, ISBN0934412197, 9780934412193, Geothermal Resources Council, (1999)

Council of the European Union: The promotion of geothermal energy - Council conclusions, No. prev. doc.:16248/24, 16939/24, (2024)

EGEC Geothermal Market Report2023, 13th Edition, (2024)

European Commission: Directorate-General for Energy, The use of mine water in district heating systems – An example from Heerlen, Netherlands, Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2833/962328

European Commission: Renewable Energy Directive, (2023) https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en

European Commission: EU co-funded geothermal heating plant in Schwerin, (2023)

Eurostat: Natural gas price statistics (2024) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics

GPC Instrumentation Process, https://www.geoproduction.fr/

Lund, H., Duic,N., Østergaard, P.A. and Mathiesen,B.V.: Future district heating systems and technologies: On the role of smart energy systems and 4th generation district heating, Energy 165, (2018), 614-619

Nabors Industries Ltd: Personal Communication, Houston, TX (2024)

Ungemach, P., Antics, M., Sarda,D., Bethune,G. and Gaillard, M.: Multilateral wells. A key architecture in maximising geothermal exposure and multilayered reservoir performance. A review of Paris Basin well design achievements, Proceedings, 49th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2024).

Wirtz, M.; Kivilip, L.; Remmen, P.; Müller, D. Quantifying Demand Balancing in Bidirectional Low Temperature Networks. Energy Build. (2020)

Zosseder, K, Haas, C., Schifflechner, C., Chicco, J., Hajto, M., Ciapała, B., Hałaj, E., Aymard, D., Poulsen, S.E., Giordano, N., Kulich, J., and Turewicz, V.: Integration of Geothermal Energy into District Heating and Cooling Networks, Project SAPHEA, funded by the European Union's HORIZON EUROPE research and innovation programme under the Grant Agreement number 101075510, Work Package: 2, (2023)

ACKNOWLEDGEMENT

„The research was funded by the Sustainable Development and Technologies National Programme of the Hungarian Academy of Sciences (FFT NP FTA). „