Geothermal Heat for Industrial Decarbonisation in Europe: Policy Evidence from the GEOFLEXHEAT Project

Executive Summary:

Decarbonising industrial heat is a critical yet under-addressed component of the European Union's energy transition. While renewable electricity deployment has advanced rapidly, heat production — particularly for industrial applications — remains dominated by fossil fuels.
Geothermal energy, when combined with high-temperature heat pumps, thermal storage, and digital optimisation, offers a reliable and scalable solution to reduce emissions from industrial heat demand.

This policy brief situates the technological solutions developed within the GEOFLEXHEAT project in the broader European policy and research landscape, drawing on academic literature, EU institutional data, and industrial heat pump performance studies to identify structural barriers and derive targeted policy insights. Where relevant, alignment with DG ENER and DG CLIMA frameworks is highlighted to ensure coherence with EU energy and climate objectives.

1. Industrial heat in the European energy system

Heating and cooling account for approximately 50 % of EU final energy consumption, with industrial processes responsible for a significant share. Despite long-standing climate commitments, fossil fuels — primarily natural gas and coal — continue to dominate industrial heat supply, resulting in persistent greenhouse gas emissions.

According to the European Environment Agency and Eurostat, progress in renewable heat deployment has been markedly slower than in electricity, reflecting both technological and policy asymmetries.

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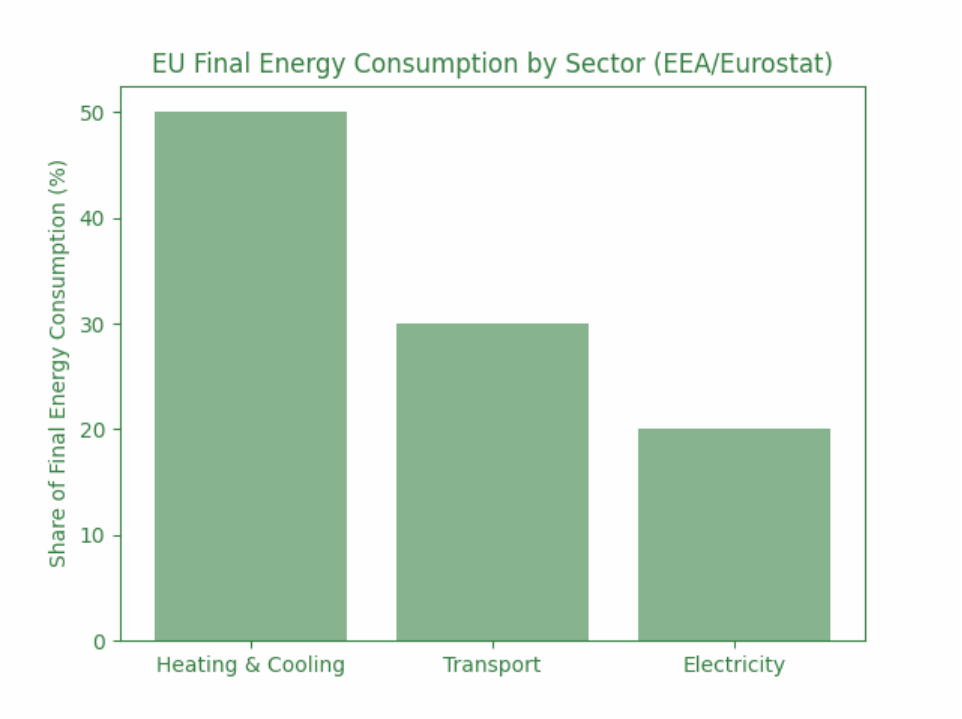
Table 1- EU Final energy consumption by sector



2. Geothermal energy and the contribution of GEOFLEXHEAT

Geothermal energy is a dispatchable, non-intermittent renewable resource, capable of delivering continuous heat independently of weather conditions. Lifecycle assessments consistently demonstrate that geothermal heat has among the lowest greenhouse gas intensities of renewable heat technologies. Yet its share in the EU heat mix is marginal (<1 % of renewable heating and cooling).

The GEOFLEXHEAT project directly addresses technical and systemic constraints limiting geothermal uptake in industry. By integrating advanced geothermal heat extraction systems, high-temperature heat pumps optimised for industrial process heat, digital twins and predictive control systems, flexible thermal storage and hybrid process integration, GEOFLEXHEAT demonstrates that geothermal heat can be adapted to high-temperature industrial applications, including sectors such as food processing, chemicals, and materials manufacturing, where electrification alone is insufficient or cost-prohibitive.

2.1 Technical Innovations for industrial geothermal systems

GEOFLEXHEAT aims to demonstrate how geothermal energy can be integrated into industrial energy systems through a combination of advanced subsurface engineering, high-temperature heat upgrading, and digital system optimisation. The project's technical architecture is designed to address several persistent challenges that have historically limited geothermal deployment in industrial contexts: variable reservoir conditions, scaling and corrosion risks, mismatches

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between geothermal temperatures and industrial heat requirements, and limited operational flexibility.

A central component of the project is the development of improved geothermal heat extraction systems capable of operating reliably in demanding subsurface conditions. These systems incorporate advanced monitoring technologies to manage scaling, mineral precipitation and brine chemistry. Such innovations are particularly relevant in high-enthalpy reservoirs or deep geothermal resources where mineral deposition can reduce heat exchange efficiency over time. By integrating monitoring tools and adaptive operational strategies, GEOFLEXHEAT aims to increase the long-term reliability of geothermal production wells and reduce maintenance costs.

Another key technological pillar of the project is the integration of high-temperature heat pumps capable of upgrading geothermal heat to temperatures suitable for industrial processes. Industrial heat demand frequently exceeds the temperature range available directly from geothermal reservoirs, especially in sectors such as food processing, chemical production and materials manufacturing. High-temperature heat pump technologies, which can deliver heat above 120°C, allow geothermal resources to be used more broadly across industrial applications. Advances in refrigerants, compressor technologies and lubricant systems have significantly improved the efficiency and reliability of these systems in recent years. These developments are supported by recent technical studies on working fluids and system design for industrial heat pumps, which show that properly optimised systems can achieve high coefficients of performance even at elevated temperatures.

Beyond heat generation, the project places strong emphasis on system flexibility. Industrial facilities often experience fluctuating heat demand due to operational cycles or seasonal variations. GEOFLEXHEAT addresses this challenge through the integration of thermal storage technologies and digital optimisation tools. Thermal storage enables surplus heat to be stored during periods of lower demand and released when demand increases, improving overall system efficiency and reducing the need for backup fossil fuel systems. At the same time, digital twin technologies and predictive control algorithms allow operators to optimise geothermal production and heat pump operation in real time, adjusting system parameters based on demand forecasts, reservoir behaviour and electricity market conditions.

Together, these technological elements create a flexible geothermal heat system capable of providing reliable, low-carbon energy to industrial users. Importantly, the project does not treat geothermal heat as an isolated technology but rather as part of a broader integrated energy system in which heat pumps, storage and digital optimisation play complementary roles. This systems approach is

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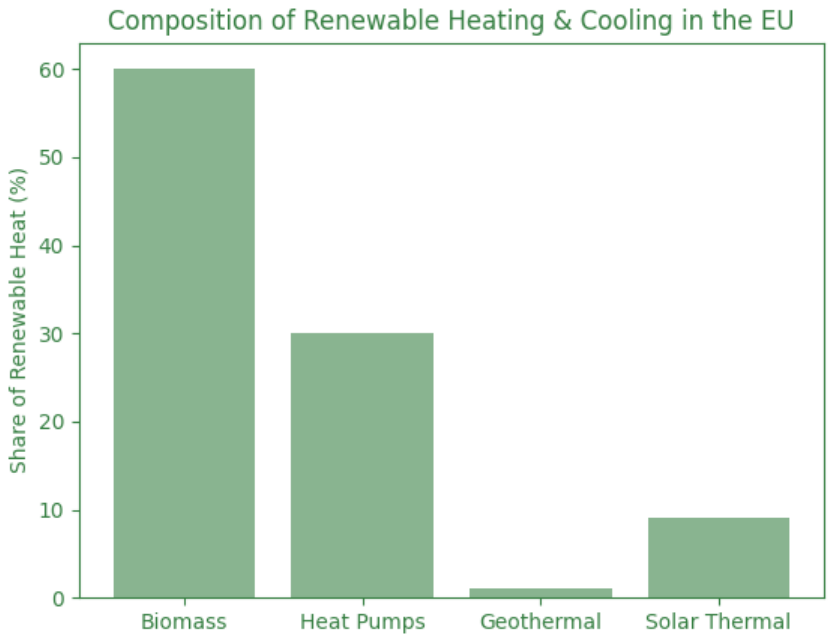
increasingly recognised in academic literature as a key requirement for scaling renewable heat solutions in complex industrial environments.

3. Renewable heat: structural imbalances and untapped potential

While the share of renewable energy in heating and cooling reached ~26 % in 2023, this figure masks strong concentration in biomass and ambient heat technologies. Geothermal remains underrepresented despite technical maturity.

Table 2 - Composition of renewable heating and cooling in the EU



This imbalance reflects a broader policy focus on electricity decarbonisation, where wind and solar benefit from market incentives and streamlined permitting. By contrast, renewable heat — particularly geothermal — has lacked equivalent policy visibility, financial de-risking instruments, and investment support, which GEOFLEXHEAT directly addresses through demonstration and modelling of flexible industrial geothermal systems.

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4. Barriers to industrial geothermal deployment

Persistent barriers include **high upfront costs** and **geological uncertainty**, **regulatory fragmentation across Member States**, and **limited availability of subsurface data and specialized workforce**.

GEOFLEXHEAT addresses these through digital monitoring, predictive optimisation, and modular system designs, which reduce operational risk and enhance investor confidence.

While these structural barriers are widely recognised in the literature, the demonstration activities within the GEOFLEXHEAT project provide concrete examples of how geothermal technologies interact with national regulatory and investment frameworks. The project's demonstration environments therefore offer valuable insights into how policy conditions influence geothermal deployment in practice.

5. Demonstration sites and national policy context

The demonstration activities within GEOFLEXHEAT provide real-world evidence on how geothermal technologies interact with national energy policies, regulatory frameworks and investment environments. By situating technical innovations within specific national contexts, these sites illustrate how supportive policy conditions can accelerate geothermal deployment while also revealing institutional barriers that may hinder expansion.

5.1 Italy demonstration site: geothermal heat in an established geothermal region

Italy represents one of the most historically significant geothermal regions in the world. Industrial geothermal power generation began in Larderello, Tuscany, in the early twentieth century and remains a central component of the country's renewable energy landscape. Today, geothermal plants in Tuscany provide a substantial share of regional electricity supply and contribute to local economic development through employment, infrastructure investments and municipal revenues.

Recent policy developments have renewed attention on geothermal energy as part of Italy's broader energy transition strategy. In 2024, the European Commission approved a national renewable energy support scheme under the **FER2 decree**, designed to accelerate the deployment of innovative renewable technologies including geothermal energy through contracts-for-difference and feed-in tariff mechanisms. The programme has an annual budget of approximately €1.85 billion and aims to support new renewable capacity by 2028.

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At the regional level, Tuscany has also taken steps to provide regulatory stability for geothermal investments. In 2025, the region approved a **20-year extension of geothermal concessions held by Enel Green Power**, allowing operations to continue until 2046. This decision was closely linked to a proposed investment plan of approximately **€3 billion for geothermal infrastructure upgrades and new plants**, reflecting renewed confidence in the sector after a decade of limited expansion.

These developments demonstrate how long-term concession frameworks and investment incentives can strengthen investor confidence in geothermal technologies. For GEOFLEXHEAT, the Italian context offers an opportunity to evaluate how advanced geothermal heat technologies can be integrated into existing geothermal regions where regulatory frameworks and technical expertise are already well established.

5.2 Iceland demonstration site: leveraging a mature geothermal ecosystem

Iceland provides a contrasting but equally informative policy environment. The country has developed one of the most comprehensive geothermal energy systems in the world, with renewable sources accounting for roughly **85% of total primary energy supply** and geothermal energy playing a dominant role in heating systems.

Geothermal district heating has been a cornerstone of Iceland's energy system for decades. Today, approximately **85–90% of homes are heated with geothermal energy**, delivered through extensive district-heating networks that supply hot water directly from geothermal reservoirs.

Recent policy initiatives aim to expand geothermal utilisation further, particularly in areas that still rely on electricity or fossil fuels for heating. In 2025, the Icelandic Ministry of the Environment, Energy and Climate announced a programme allocating **around ISK 1 billion between 2025 and 2028 to support geothermal exploration and heating infrastructure**, targeting communities that are not yet connected to geothermal district heating systems. The initiative is expected to generate substantial economic benefits while reducing energy costs and emissions.

Complementary investments are also being directed toward geothermal infrastructure in smaller municipalities. In 2025, state-backed geothermal projects received over **ISK 1 billion in grants** to expand district heating networks and install heat pumps capable of reducing electricity demand by up to 80% in some communities.

The Icelandic case illustrates how consistent long-term policy frameworks and sustained public investment can enable geothermal energy to become a central

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pillar of national energy systems. Within the context of GEOFLEXHEAT, this environment provides a valuable opportunity to test advanced geothermal technologies within a mature geothermal ecosystem where infrastructure and technical expertise are already highly developed.

Taken together, the Italian and Icelandic demonstration environments illustrate how geothermal deployment depends not only on resource availability but also on institutional frameworks, investment conditions and system integration strategies. These empirical observations provide a practical foundation for evaluating how European policy instruments could support wider geothermal heat deployment across industrial sectors.

5. Policy implications and recommendations

Evidence from the GEOFLEXHEAT demonstration environments and the broader European geothermal market suggests several policy priorities that could accelerate geothermal heat deployment across industrial sectors:

1. **Integrate renewable industrial heat into National Energy and Climate Plans (NECPs) and national renewable heating strategies.**
   Renewable heat solutions for industry should be more explicitly integrated into **National Energy and Climate Plans (NECPs)** and national renewable heating strategies. While many Member States have established targets for renewable electricity generation, explicit strategies for industrial heat decarbonisation remain limited. Incorporating geothermal heat and high-temperature heat pumps into national planning frameworks would provide clearer signals to investors and industrial operators.
   For example, **the Netherlands' Climate Agreement and Industrial Heat Transition Programme** explicitly recognise geothermal heat as a strategic option for industrial clusters, particularly in the Rotterdam and Westland regions where geothermal systems are being deployed to supply both greenhouses and industrial facilities. Similarly, **France's national geothermal development strategy** has prioritised geothermal heat for district heating and industrial applications through targeted funding and regulatory support.
   These approaches illustrate how national planning frameworks can create clearer pathways for renewable heat deployment in industry.

2. **Establish financial de-risking mechanisms targeting geothermal exploration and drilling**.
   The high upfront costs associated with geothermal exploration and drilling remain one of the most significant barriers to project development. Public

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financial instruments that share geological risk with private investors can substantially improve project bankability.

A notable example is Germany's geothermal financing model, which combines low-interest loans provided by the public development bank KfW with Exploration Risk Insurance (ERI) offered by Munich Re. Under this scheme, a significant portion of drilling risk is insured, and partial debt waivers may apply if wells fail to reach expected production levels. By reducing financial exposure for developers and utilities, this mechanism has significantly improved investment conditions for geothermal district heating projects.

Similar geothermal risk mitigation schemes have also been implemented in countries such as France, where the Geothermal Risk Guarantee Fund supports exploration activities for geothermal district heating systems.

3. **Streamline permitting and regulatory procedures**.

   Regulatory fragmentation across Member States continues to create uncertainty for geothermal developers. Permitting procedures often involve multiple administrative authorities and lengthy approval timelines, which can delay project implementation.

   Germany recently introduced the **Geothermal Acceleration Act**, which designates deep geothermal projects, large heat pumps and thermal storage facilities as projects of **overriding public interest**. The legislation aims to streamline approval procedures by establishing clearer permitting processes, binding timelines for administrative decisions and greater use of digital application systems.

   Such regulatory reforms demonstrate how streamlined permitting frameworks can significantly reduce administrative barriers while maintaining environmental safeguards.

4. **Support integrated renewable heat systems and innovation**.

   Renewable heat solutions increasingly rely on **integrated energy systems** combining multiple technologies, including geothermal heat production, high-temperature heat pumps, thermal storage and digital optimisation tools. Policy frameworks that support integrated solutions rather than individual technologies can unlock greater efficiency and flexibility in industrial heat systems.

   EU research and innovation programmes already play an important role in supporting such integrated solutions. **Horizon Europe projects**, including GEOFLEXHEAT, demonstrate how combining geothermal resources with advanced heat upgrading technologies and digital optimisation tools can deliver reliable industrial heat while improving system efficiency and operational flexibility.

   At the national level, **Denmark represents a great example of district heating innovation programmes** that have also supported hybrid systems

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combining geothermal heat with heat pumps and thermal storage, enabling greater flexibility in renewable heat supply.

These measures align with DG ENER objectives (e.g. renewable heating and cooling deployment, energy efficiency targets) and DG CLIMA objectives (reducing industrial emissions in hard-to-abate sectors).

6. Geothermal investment momentum and policy opportunity

Investment in geothermal energy reached unprecedented levels in 2025, reflecting a global shift toward decarbonising both power and heat. According to the International Energy Agency (IEA), capital inflows into geothermal have surged:

- Investment in **next-generation geothermal technologies** rose to over **USD 2 billion in 2025**, up from just USD 20 million globally in 2018.
- Funding for **conventional geothermal power projects** reached nearly **USD 5 billion in 2025**, a fourfold increase since 2018.
- **Geothermal heating projects alone** secured more than **USD 11.5 billion in 2025**.

Several factors are driving this momentum. Strong demand from data centres and the willingness of industrial buyers to pay premiums of up to **USD 130 per MWh for clean, reliable, round-the-clock power** are significant contributors. Long-term power purchase agreements (PPAs) are also supporting the bankability of projects.

Regionally, investment trends reflect varied priorities and market dynamics:

- **Europe:** Focused on decarbonising heat, particularly through district heating systems aligned with ambitious climate targets.
- **United States:** Growth is driven by enhanced geothermal systems (EGS) and rising baseload electricity demand from data centres.
- **Southeast Asia:** Geothermal is increasingly used to meet fast-growing electricity demand.

Policy mechanisms are proving decisive in unlocking geothermal potential. **Germany** provides a compelling example: the combination of low-interest KfW loans, Munich Re Exploration Risk Insurance (ERI), and the Geothermal Acceleration Act has made deep geothermal heat projects bankable and scalable. Shared exploration risk, partial debt waivers for underperforming wells, and faster permitting procedures have turned geothermal into a reliable core of the country's decarbonised heat supply.

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The IEA's Renewables 2025 report projects that annual geothermal capacity additions could reach nearly **1.5 GW by 2030**, triple the increase seen in 2024, while geothermal heat use in buildings is expected to **double by 2030**, led by strong growth in China, Iceland, Türkiye, the EU, and the US. Supportive policies, drilling-risk insurance, and technological advances are accelerating project deployment, reducing both timelines and costs.

The current investment surge represents a historic opportunity to align **GEOFLEXHEAT solutions** with robust financial and regulatory support. By combining **de-risking mechanisms, streamlined permitting, and integration with industrial heat demand**, the EU can accelerate the uptake of geothermal heating at scale, turning it into a cornerstone of industrial decarbonization.

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7Conclusion

Industrial heat decarbonisation remains one of the most challenging aspects of Europe's climate transition. Geothermal energy, particularly when combined with advanced high-temperature heat pumps, digital optimisation, and flexible thermal storage, represents a credible, scalable, and immediately deployable solution.

The GEOFLEXHEAT project demonstrates that geothermal heat can be adapted to meet industrial temperature requirements, operate reliably, and integrate flexibly with existing systems. Recent global and European investment trends reinforce this potential: capital inflows into geothermal have surged, with industrial heating projects alone securing more than USD 11.5 billion in 2025, reflecting growing market confidence and willingness to pay for reliable, decarbonised energy. Examples from Germany show that financial de-risking, insurance mechanisms, and streamlined permitting can unlock geothermal as a scalable, bankable solution for industrial heat.

This convergence of technical readiness, policy support, and financial momentum positions geothermal energy — and GEOFLEXHEAT solutions in particular — as a central lever for industrial decarbonisation in the EU.

By aligning regulatory frameworks, investment support, and industrial deployment strategies, the EU can accelerate geothermal adoption at scale, complementing electrification, hydrogen, and other renewable heat solutions, and achieving substantial emissions reductions in the short to medium term.

Geothermal is no longer an experimental niche — it is entering a decade of rapid growth. GEOFLEXHEAT provides the technological and systemic evidence to ensure Europe can capture this momentum and establish geothermal heat as a core pillar of industrial decarbonisation.

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