

Enhancing Geothermal Energy in Industry: Technical Synergies in Heat and Cooling Systems and Stakeholder Engagement in the Horizon Europe GEOSYN Project

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ABSTRACT

Geothermal energy has the potential to decarbonize Europe's energy systems due to its reliability, flexibility, and storage capabilities, providing green heating, cooling, and electricity. However, high initial costs and lack of awareness pose barriers to its widespread adoption, leading to concerns within local communities and mistrust among policy makers and potential users. The GEOSYN Project (2024-2027), funded by the EU's Horizon Europe Programme, aims to demonstrate affordable, high-temperature geothermal heating solutions that also generate cooling for industrial applications. GEOSYN's system, which uses a heat pump and chiller with water as the refrigerant, eliminates environmental risks and global warming potential. The technology can adapt to various thermal sources and will connect to energy storage systems, enhancing flexibility. The initiative emphasizes raising awareness and building trust among stakeholders, including communities, policy makers and industries, to ensure a successful deployment. Effective communication of benefits and addressing stakeholder concerns is key. Socio-economic factors and public attitudes will guide targeted communication campaigns.

Outcomes related to the environmental and financial benefits of geothermal technologies in different contexts will foster broader acceptance and integration of this renewable energy source. Additionally, GEOSYN will promote women in geothermal careers and entrepreneurship.

1. INTRODUCTION

Currently, industries consume approximately 2,950 TWh per year, distributed across process heating (66%), space heating (11%), process cooling (3%), space cooling (1%), and non-thermal uses (19%). About 78% of the 1,952 TWh used annually for process heating is supplied by fossil fuels, primarily natural gas, with significant contributions from coal and oil. This results in CO₂ emissions from the EU-28 industrial sector that are comparable to those from passenger vehicles (De Boer et al., 2020). Notably, temperatures below 200 °C account for 37% of the process heat demand. Hot sedimentary aquifers could supply about 8 TW of heat at 90 °C across Europe, with most of the resources located within a depth of 3,000 meters (IEA, 2024). In addition, geothermal heat can be stored to improve the flexibility of energy supply, and residual heat from power production can be used in cascade, further improving the sustainability of plants.

Although heat pumps with output temperatures above 100 °C are still limited and not yet considered a fully

evaporates at ~ 2 bar at 120 °C and condenses at ~ 15.5 bar at 200 °C, corresponding to a pressure ratio of 1.6–2 per stage. Intermediate de-superheating between stages is implemented to reduce discharge temperatures and compressor workload, as illustrated in the system schematic (Fig. 1).

Compression is driven by an electric motor with speed modulation enabled via a variable frequency drive (VFD) inverter, allowing for flexible operation.

2.2 Heat-driven chiller using water

At the core of the proposed heat-driven cooling system is the liquid reservoir, which supplies the evaporator. This configuration enables efficient utilization of water's latent heat - remarkably the highest among all potential working fluids. The system is designed to be powered by the geothermal source delivering saturated steam at 130 °C, and to provide a cooling load of 20 kW at a target temperature of 12 °C. Under these operating conditions, the expected Coefficient of Performance (COP) of the system, i.e., the ratio of useful cooling effect to the thermal input, is approximately 0.4.

A crucial element ensuring the reservoir's effectiveness is the steam ejector, which maintains the reservoir at sub-atmospheric pressure. The ejector continuously removes vapor generated both by flash evaporation at the expansion valve and by boil-off within the reservoir itself. To support the cooling load and enable efficient operation, the ejector is designed with an entrainment ratio (ER) of 0.428, which defines the ratio of motive steam mass flow to the entrained vapor mass flow from the reservoir.

To minimize boil-off losses, the reservoir must be thoroughly thermally insulated. Moreover, all components operating below ambient pressure must be completely sealed against air infiltration. While this is relatively straightforward when using static joints between components, the pump represents a potential leakage point due to its moving shaft. This issue can be mitigated by employing a magnetic coupling between the electric motor and the pump, eliminating the need for dynamic seals. A simpler and even more robust alternative is to eliminate the pump altogether by introducing a hydraulic head between the reservoir and the evaporator. Due to water's high density, the required elevation is modest, making this a practical and low-cost solution.

Beyond feeding the evaporator, the reservoir also serves as a cold thermal storage. When properly sized, it can buffer fluctuations in cooling demand, allowing the ejector to operate closer to its design point and maintain consistent performance even under variable thermal loads. A schematic of the cycle is presented in Fig. 2.

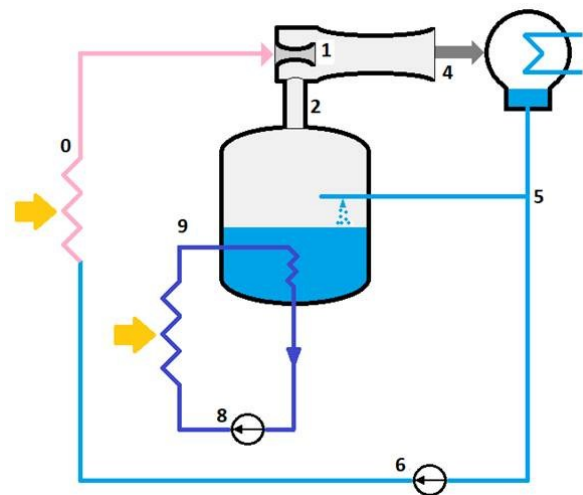


Figure 2: Heat driven chiller schematic.

2.3 Control logic and flexible heating and cooling production

The aim of the control logic is to ensure short starting time, the required heat output at high efficiency, and safe operation of the system. This includes strategy for the initial warm up process, ramping up to the nominal operating condition, transient operation, setpoint achievement, and shutting down. During the initial startup of the system from a cold state, there is a risk of steam condensation inside the compressor and thereby liquid compression. This is mainly due to cold regions in and around the compressor. Since reciprocating compressors are highly sensitive to liquid slugging, it is crucial to prevent any occurrence of liquid compression. Hence, the system needs to be preheated before starting the steam compression. Preheating also gradually rises the temperature of the parts, thereby reducing the effects of thermal shock, which could otherwise occur during the startup.

Preheating is typically achieved using a crankcase heater or electric heating rods/mats. While this method provides a faster temperature rise, it can result in uneven heating inside the compressor, as some areas may not be heated directly. An alternative approach is to introduce air into the system and compress it repeatedly until the system reaches the required temperature, after which the air is gradually replaced by water. This method ensures more uniform heating compared to the former technique.

Furthermore, to safeguard the compressor against liquid compression during both ramping and transient operation, a superheating degree of approximately 20 K must be maintained at all stages of compression, as recommended by the compressor manufacturer. Simultaneously, the maximum discharge temperature of the compressor must be limited to 260 °C, in accordance with the manufacturer's guidelines. For this reason, it is essential to control the ramping rate during capacity modulation, among others, to maintain the appropriate superheating degree at the suction across different compression stages. This requires precise control of both the compressor frequency and the

expansion valve opening degree. Additionally, it may be necessary to regulate the flow rate of the secondary fluids and the level of de-superheating in the desuperheater to optimize the system performance.

Different options are available for achieving the required superheating degree at the first stage, including steam recirculation, the application of an internal heat exchanger (IHX), and dry steam production from the evaporator by controlling the expansion valve. Among these, the application of an IHX is the preferred choice, as it can also enhance system performance by increasing subcooling on the high-pressure side. However, provisions should be made for condensate bypass to control the degree of superheating, and an optional trace heater is recommended for increasing the superheat during ramping and startup. Additionally, for off-design and ramp-up conditions, it may be necessary to recirculate or tap off steam between stages to achieve an optimum pressure ratio and limit the discharge temperature.

To meet the above operating requirements, it is essential to develop a reliable and robust control system for the GEOSYN solution. Therefore, a control strategy ensuring operational flexibility for the proposed solution will be developed and demonstrated within the project.

Geothermal energy can be used directly or indirectly for various heating applications across different industries. It can also be effectively utilized as a heat source for various cooling cycles, including absorption, adsorption, and heat-driven ejector processes. In absorption and heat-driven ejector systems, geothermal heat drives a thermodynamic cycle, reducing dependence on electricity. Adsorption systems can use geothermal heat to regenerate solid adsorbents, enabling an intermittent and low-maintenance heating/cooling process.

For heating applications, in addition to direct usage, geothermal energy can serve as a heat source for vapor-compression or absorption heat pumps, as well as for heat transformers, which can produce temperatures much higher than the source. Vapor compression heat pumps offer several advantages over absorption heat pumps, including a higher COP, more compact design, faster response time, and generally lower initial cost. However, they also have some disadvantages, including higher electricity consumption, often the use of synthetic refrigerants, more maintenance, and greater noise compared to absorption heat pumps.

In industrial applications, heating requirements typically exceed 100 °C for key processes, such as drying, boiling, bleaching, pasteurization, sterilization, distillation, molding, and colouring. These processes are commonly used in industries such as paper and printing, food and beverages, chemicals, metal, plastics, automotive, wood, textiles, and more (Zühlsdorf et al., 2023).

3.1 The GEOSYN case study: the San Martino Dairy Factory

The San Martino Dairy Factory uses superheated geothermal steam from a nearby powerplant (Fig. 3) to meet its process heat demand. It will pioneer the testing and implementation of the GEOSYN solution for geothermal energy utilization in both heating and cooling within the dairy industry. This case study will integrate geothermal energy into its heating and cooling systems to enhance sustainability and reduce energy costs.

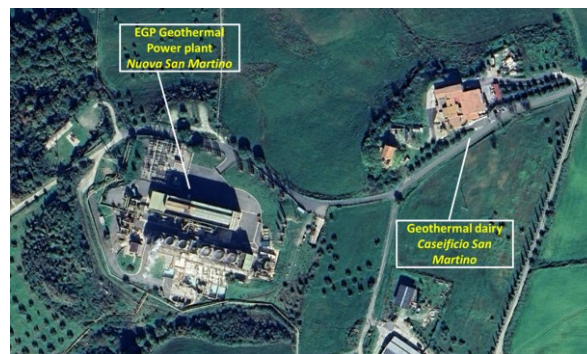


Figure 3: The San Martino dairy factory and the geothermal power plant.

The GEOSYN system will be integrated into the plant to upgrade the geothermal fluid for heating and to exploit its thermal energy for cooling, replacing the traditional vapor compression cooling systems with a more efficient, renewable heat-powered cooling solution, as detailed in Table 1. This will make San Martino the first cheese and dairy factory worldwide to fully exploit geothermal energy. The case study represents a groundbreaking step in sustainable food production, demonstrating that geothermal energy can be harnessed not only for heating but also for efficient cooling solutions in industrial settings.

Table 1: Key facts and objectives for the San Martino case study.

Key facts for the case study	
Location	San Martino, Monterotondo Marittimo, Italy
Heating Capacity	220 kW
Cooling Capacity	106 kW
Geothermal Heat Capacity	220 kW
Geothermal Supply Temperature	135 °C
Objectives for the case study	
HTHP Coefficient of Performance	> 2
Electricity savings	45.000 kWh/year
CO ₂ emissions savings	12.000 kg/year
Cooling system operating costs	- 50%

3.2 The GEOSYN virtual case study: drying slag system in a cement plant in Ukraine

The GEOSYN project also includes a virtual case study evaluating the integration of geothermal heat into the

Neo-ECO Cement Plant in Ukraine (Fig. 4), focusing on the further utilization of heat from the geothermal wells.



Figure 4: 3D view of the Neo-ECO Cement Plant in Ukraine (virtual case study).

As detailed in Table 2, the plant requires steam at a rate of 11 kg/s (38 t/h) and a temperature above 200 °C to dry ground slag, a process essential for its annual production of 810,000 tons of cement. The geothermal source supplies 220 kW of heat at 200 °C, returning at 150 °C, with a 500-meter-long pipeline connecting the heat source to the drying area.

Table 2: Key facts and objectives for the Neo-ECO Cement Plant virtual case study.

Key facts for the case study	
Location	Mykolaiv region, Ukraine
Steam	11 kg/s (38 t/h)
Steam Temperature Required	> 200 °C (optional 250°C)
Geothermal Heat Capacity Supplied	220 kW
Geothermal Supplied Temperature	200 °C

The geothermal flow is sourced from the network connected to a thermal power station within the industrial zone, designed for green and circular reconstruction, where the low-carbon cement plant is located. To maximize efficiency, the GEOSYN network will be virtually integrated with waste heat recovery systems from other industrial units. The project aims to reduce CO₂ emissions, enhance energy security by minimizing dependency on fossil fuels, and achieve long-term energy cost savings, all while ensuring compliance with stringent environmental regulations.

3.3 GEOSYN replication opportunities

In addition to the real case study and virtual cement plant, several case studies will be evaluated to demonstrate the versatility and applicability of the GEOSYN solution. The project will map potential industries across sectors such as paper, wood, food, dairy, chemicals, pharmaceuticals, cement, and others, primarily from partner countries and other EU nations. Interviews with approximately 50 industries will be

conducted to increase acceptance and trust in geothermal energy.

A strategic methodology will guide the selection of industries for geothermal energy integration, using multiple parameters to assess their suitability for heating and cooling applications. The key selection criteria are: (1) Energy Intensity; (2) Thermal Demand & Temperature Requirements; (3) Geographical Distribution; (4) Industrial Relevance; (5) Waste Heat Potential; (6) Innovation & Sustainability Commitment; (6) Willingness to Collaborate.

Industries meeting these criteria will be invited to participate in interviews regarding geothermal applications. This methodology ensures a balanced selection process that evaluates technical feasibility, economic impact, and industry engagement while aligning with sustainability goals.

Additionally, five EU industries will be selected to assess the integration of GEOSYN technology for addressing their heating and cooling needs, showcasing opportunities for scaling across various sectors.

The GEOSYN solution is suitable for heating applications up to 250 °C and cooling applications in the range of 5-25 °C. It is ideal for indirect processes that involve heat transfer via a heat transfer medium. Indirect process heating typically utilizes boilers, furnaces, heat pumps, and solar collectors, but each system has its limitations. Combustion-based systems (boilers and furnaces) rely on fossil fuels, leading to lower efficiency, higher emissions, and fuel dependency, making them less environmentally and economically sustainable. Heat pumps and solar collectors provide significant energy savings and emission reductions compared to combustion-based systems. However, solar collectors, while emission-free, have limitations such as intermittency and high initial costs, making them less reliable as a standalone solution. Although heat pumps typically draw power from thermal power plants, their reliability and ability to utilize waste heat make them ideal for various heating applications. Different industrial heating processes that can be supported by the GEOSYN solution are outlined in Table 3.

Other than space cooling, process cooling within the scope of GEOSYN solution exists in industries related to non-metallic minerals, paper & printing, and food & beverage (Rehfeldt et al., 2018). In non-metallic minerals industries, process cooling in the range of 0 °C to 15 °C is used to control reaction temperatures, solidify materials, and cool equipment during manufacturing processes. In the paper & printing industry, cooling is essential for maintaining ink stability, cooling rollers, machinery, and conditioning paper sheets to prevent deformation and ensure quality printing. In the food and beverage industry, cooling requirements within the 0 °C to 15 °C range are critical for maintaining the freshness and shelf life of perishable products such as dairy, meat, fruits, and vegetables, as well as for controlling fermentation in

brewing, winemaking, and dairy processes. This temperature range is also used for cooling beverages before packaging, chocolate processing, rapid cooling after pasteurization, and maintaining optimal temperatures for process water and other production stages.

Table 3: Industrial processes with heating temperatures up to 250°C and heat transfer medium (Sharma et al., 2017)

Industry	Processes	Maximum temperature requirement (°C)	Mediums used
Food & beverage industries	Cooking, pasteurization, sterilization, drying	150	Steam, water & air
Textile industries	Drying, pressing, fixing and printing	180	Steam & water
Paper & printing	Bleaching, drying, pulp preparation	200	Steam, water & air
Chemical & pharmaceutical	Distillation, evaporation, drying, thickening	200	Steam, water & air
Automobile	Baking of paints, paint drying	225	Steam & air
Leather products, rubber, plastic, and glass manufacturing	Drying, preparation, distillation, Extrusion, Laminating	200	Steam & air

4. TOWARDS INCREASED TRUST AND ACCEPTANCE OF GEOTHERMAL INTEGRATION IN INDUSTRY

The GEOSYN project aims to increase awareness of the benefits, safety, and opportunities offered by geothermal energy through comprehensive and targeted communication, awareness and engagement campaigns targeting policy makers, citizens and industry stakeholders.

4.1 Existing experiences of geothermal heating and cooling integration in industry

The ongoing energy crisis, the instability of international markets, and the growing demand for low carbon, sustainable products are driving increased interest in renewable energy sources. However, geothermal H&C integration in industry remains a niche area. The limited availability of public information and fragmented examples contribute to a lack of awareness and trust among H&C intensive industries, which in turn limits the widespread adoption of this energy source in production lines.

Entrepreneurs require reassurance about the real opportunities in terms of initial and operational costs before committing to investments. They also need information on how geothermal energy can enhance the environmental credentials of their products. To address these needs, it is essential to develop effective tools that provide easy access to information on the benefits and challenges of geothermal H&C. In this context, the GEOSYN project is mapping existing case studies of geothermal H&C integration across various industry sectors to collect information and feedback from companies already utilizing this energy source. The collected evidence will be compiled into a database, with public data available on the GEOSYN project website, demonstrating the affordability of geothermal solutions with concrete case studies.

As of April 2025, the research mapped 52 cases of geothermal H&C integration in production lines, with more examples expected to be identified before the project's completion. The majority of these cases are in the agrifood sector, with greenhouses being the most common application, followed by hydroponics, biomass drying, fish farming and distilleries, as shown in Fig. 5a. Although fewer in number, geothermal energy is also being used in energy-intensive activities such as clothes washing and drying, chemical and pharmaceutical industries, data centre cooling, cosmetics, automotive manufacturing, and food processing. Moreover, additional geothermal H&C integrations are planned or under construction for new applications, including the pulp and paper industry, as well as the sectors mentioned above (EGEC, 2025). The distribution of case studies by country, shown in Fig. 5b, indicated that most of geothermal applications in industry are in Iceland and Italy, reflecting the geothermal expertise of these two countries. However, geothermal H&C is also being applied in thirteen other European countries, including France and the Netherlands.

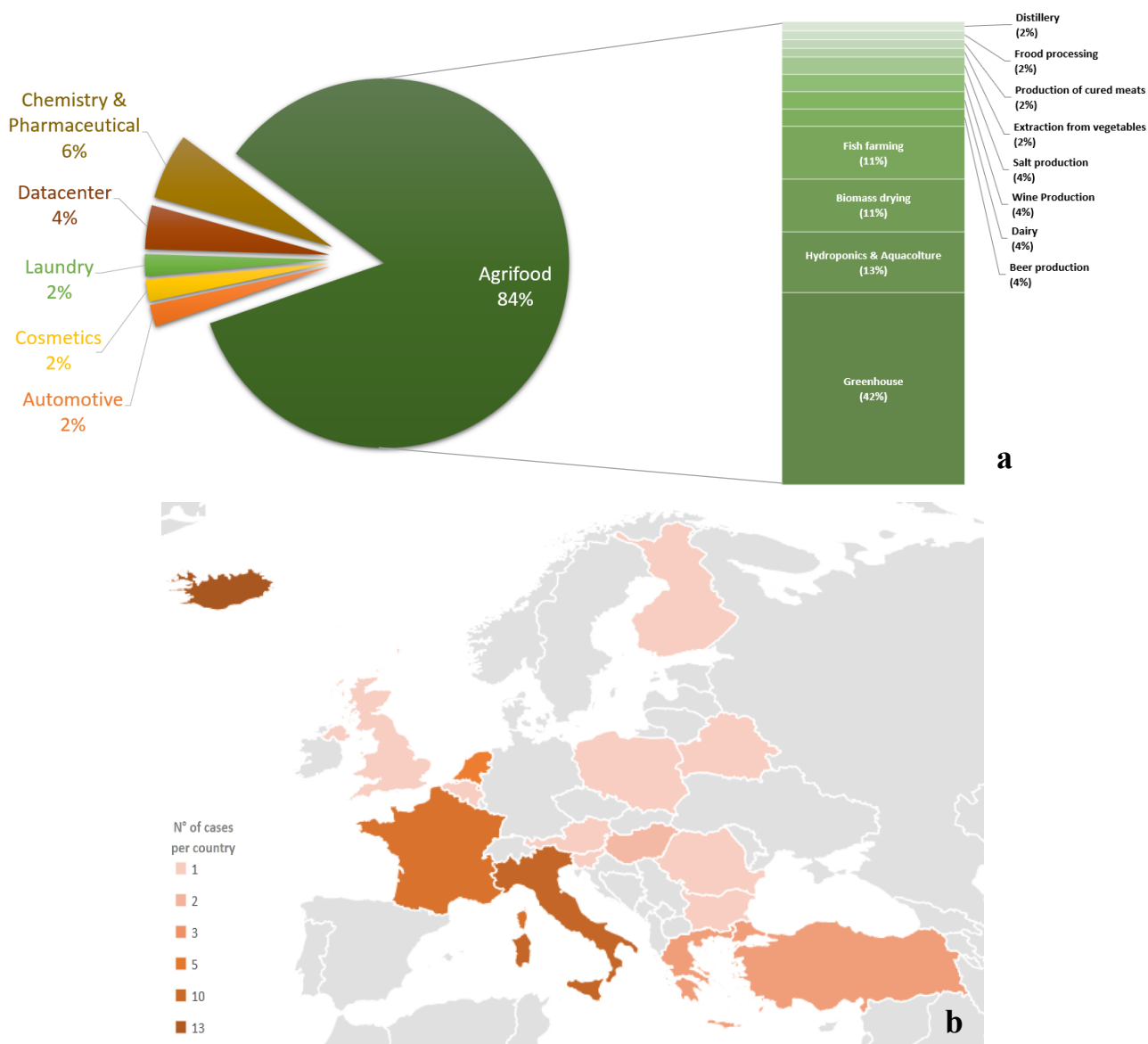


Figure 5: distribution of geothermal H&C integration in industry and production processes in Europe, by sector (a) and country (b). These are the interim results of an ongoing research of the GEOSYN project.

4.2 Actions to improve trust among industrial stakeholders

In addition to mapping existing case studies, preliminary results from the techno-economic analysis and business models for the GEOSYN technology, based on simulations for both the test site and the virtual case studies, will be used to develop training materials. These materials will be shared with identified industry stakeholders participating in the online workshops, known as the “Industry Engagement Café”. The Café will enhance the geothermal energy literacy among industrial players, help them discover GEOSYN key findings, and provide them with the opportunity to off suggestions for improving the integration of the developed technology across various production lines. This approach will also provide valuable feedback on the feasibility of the GEOSYN results.

4.3 Actions to assess and improve the perception of geothermal energy

Public awareness on geothermal technologies and their applications is essential for their acceptance and wider deployment. To promote geothermal energy and strengthen public investments in these technologies, it is vital to provide transparent, reliable information while also effectively communicating both the risks and benefits to different stakeholder groups. Furthermore, fostering public participation in decision-making processes is crucial.

Before launching communication and engagement efforts, a survey will assess the expectations and perceptions of local communities toward geothermal technologies, particularly in the context of industrial H&C applications. Questionnaires and engagement workshops will target various stakeholders, including civil society representatives, geothermal experts, potential end-user companies, the tourism sector, and

local authorities, to evaluate the socio-economic impacts of geothermal H&C technologies in production lines, specifically in areas of Italy and Ukraine.

In a second phase, the project will launch tailored awareness campaigns and mutual learning workshops, followed by a final survey to assess the impact of these actions. As part of the outreach efforts, GEOSYN will produce a podcast series featuring at least five episodes on topics such as geothermal literacy, GEOSYN recommendations, tips for women entrepreneurs, market support and financial frameworks for industrial integrations, and the benefits of geothermal integration in industrial processes. The podcast will reach both the general public and specialised audiences.

GEOSYN will also target policy makers to raise awareness of the opportunities offered by geothermal H&C integration in industrial processes, supporting the deployment of new cases and the replication of GEOSYN's technology. A guide will be produced to inform on geothermal energy and measures to promote market supporting policies and financial frameworks. This document will include recommendations for more gender-responsive policies, which will be fine-tuned through discussions with regional and national policymakers in Italy and Ukraine.

5. CONCLUSIONS

The GEOSYN project aims to demonstrate the technical and socio-economic potential of integrating geothermal heating and cooling into industrial processes. By developing a high-temperature heat pump and a heat-driven chiller using water as a refrigerant, GEOSYN offers a sustainable, efficient, and low-impact alternative to conventional systems. The project's core strength lies not only in its innovative technology but also in its comprehensive approach to stakeholder engagement, which is designed to raise awareness and build trust among industries, policymakers, and communities.

Geothermal energy holds significant potential for decarbonising production processes across Europe. Sharing information on the technical reliability of geothermal energy with both potential and actual end-users will help to build trust and promote wider uptake of geothermal energy. In addition, this will assist policymakers in recognizing the opportunities geothermal energy offers and in proposing policies that support the use of underground heat. Through targeted communication, inclusive training, and public outreach, the project aims to promote acceptance and shape future energy strategies and policies in Europe. Geothermal energy is not a niche solution; it is a scalable and versatile option for a decarbonized industrial future.

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