GeoBOOST Final report

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Table of contents

List of tables

List of figures

Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
ANN	Artificial Neural Network
ASHP	Air-Source Heat Pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATES	Aquifer Thermal Energy Storage
BEG	German support scheme for efficient buildings ("Bundesförderung für effiziente Gebäude")
BHE	Borehole Heat Exchanger
BTES	Borehole Thermal Energy Storage
CBA	Cost–Benefit Analysis
CDD	Cooling Degree Days
CAGR	Compound Annual Growth Rate
CAE	Energy-savings certificates mechanism (Certificados de Ahorro Energético)
CAPEX	Capital Expenditure
CFC	Chlorofluorocarbon
CLS	Closed-Loop Systems
CO_2	Carbon dioxide
COMSOL	COMSOL Multiphysics (simulation software)
COP	Coefficient of Performance
CTES	Cavern Thermal Energy Storage
DTH	Down-The-Hole (drilling hammer/method)
DHW	Domestic Hot Water

Abbreviation	Meaning
EEDT	"Easy Drill / EEDT" piling-integrated drilling approach
EFEM	External Factor Evaluation Matrix
EGEC	European Geothermal Energy Council
EHPA	European Heat Pump Association
EIA	Environmental Impact Assessment
EER	Energy Efficiency Ratio
EN 14825	European standard for seasonal efficiency / climate zones used in HP performance calculations
EPC	Energy Performance Contracting
ESCO	Energy Service Company
FEFLOW	Finite Element subsurface flow & transport modelling software
GIS	Geographic Information System
GHEX	Ground Heat Exchanger
GHP	Geothermal Heat Pump
GRD	Geothermal Radial Drilling
GSHP	Ground-Source Heat Pump
GWP	Global Warming Potential
GWHP	Groundwater Heat Pump
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefin
HDD	Heating Degree Days
HT-ATES	High-Temperature ATES
IFEM	Internal Factor Evaluation Matrix

Abbreviation	Meaning
IGME	Instituto Geológico y Minero de España (as referenced)
IoT	Internet of Things
IRR	Internal Rate of Return
ITGBES	Dutch national thermal-interference assessment tool (as referenced)
KPI	Key Performance Indicator
KfW	Kreditanstalt für Wiederaufbau (German development bank; financing in the text)
LCOE	Levelized Cost of Energy
LCCA	Life-Cycle Cost Analysis
LT-ATES	Low-Temperature ATES
MIC	Microbially Induced Corrosion
MODFLOW-MT3DMS	Groundwater flow + solute/transport modelling toolchain
MOOC	Massive Open Online Course
MOP	Maximum Operating Pressure
MPa	Megapascal
MRS	Minimum Required Strength (polymer pipe rating)
MT-ATES	Medium-Temperature ATES
MTES	Mine Thermal Energy Storage
NGO	Non-Governmental Organization
NPV	Net Present Value
OLS	Open-Loop Systems
OPEX	Operating Expenditure
ÖWAV	Austrian Water and Waste Management Association (as referenced)

Abbreviation	Meaning
PCMs	Phase Change Materials
PE	Polyethylene
PE100	Polyethylene pipe grade (PE100)
PE-RC	Crack-Resistant Polyethylene
PE-RT	Polyethylene of Raised Temperature resistance
PE-X	Crosslinked Polyethylene
PID	Proportional–Integral–Derivative (control method)
PPP	Public–Private Partnership
PV	Photovoltaics
PVT	Photovoltaic–Thermal (hybrid collector)
PREE	Spanish renovation/support programme (as referenced)
R&D	Research and Development
RED	Renewable Energy Directive
ROI	Return on Investment
ROT	Swedish tax deduction scheme (as referenced)
SCOP	Seasonal Coefficient of Performance
SDR	Standard Dimension Ratio
SGU	Geological Survey of Sweden
SPF	Seasonal Performance Factor
SSRH	Support Scheme for Renewable Heat
SWOT	Strengths, Weaknesses, Opportunities, Threats
TAP	Thermal (or Thermo-hydrogeological) Assessment/Planning method (as referenced, esp. Munich/groundwater potential)
TEWI	Total Equivalent Warming Impact

Abbreviation	Meaning
TES	Thermal Energy Storage
TOUGH2	Multiphase flow/heat transport simulation software
UTES	Underground Thermal Energy Storage
WACC	Weighted Average Cost of Capital
WHG	German Federal Water Act (“Wasserhaushaltsgesetz”)
WP	Work Package
ZUM	Polish approved product list (“ZUM list”, as referenced)
5GDHC	5th Generation District Heating and Cooling

Introduction

Decarbonising heating and cooling is one of Europe's biggest energy-transition challenges. Space heating, domestic hot water, and the increasing cooling demand, still rely heavily on fossil fuels in many Member States. with cities and regions having to simultaneously manage affordability, grid constraints and climate-resilience. In this context, geothermal heat pumps—more broadly ground-source heat pumps (GSHPs) and groundwater heat pump systems—offer a proven, high-efficiency pathway to deliver renewable heating and cooling using a local, stable energy source in the shallow subsurface. Their long asset lifetimes, ability to provide passive or high-efficiency cooling simultaneously to heating from single infrastructure and compatibility with low-temperature buildings and networks, make GSHPs a strategic option for Europe's climate-neutrality objectives.

At the same time, GSHP deployment across Europe remains uneven. Market maturity differs strongly between countries based on differences in climate, geology, drilling practices, electricity –fuel price ratios, policy drivers and the availability of support schemes. Non-technical aspects such as fragmented permitting procedures, inconsistent technical thresholds, limited or non-standardised registration data, and uncertainty around cumulative impacts such as thermal interference in dense urban areas are identified as key barriers to the uptake of GHSPs. The energy-security shock after Russia's invasion of Ukraine, further accelerated the need to reduce dependency on imported gas and to scale domestic and commercial renewable heating options, creating both the opportunity for shallow geothermal and the urgency of removing practical bottlenecks.

The GeoBOOST project addresses these challenges by building a coherent, EU-wide, evidence based set of practical tools to accelerate a responsible and sustainable scaling of geothermal heat pump solutions. This report consolidates the key findings and outputs of GeoBOOST work packages into a single, structured reference. The document is written for a broad audience: policymakers and authorities responsible for regulation and permitting; municipalities and spatial/energy planners; investors, financiers, and programme designers; utilities and ESCOs, as well as drillers, designers and installers that are identified as key market actors needing clear benchmarks and implementable pathways.

What this Final Report delivers

This report summarises the outputs of the GeoBOOST deliverables into an integrated "end-to-end" narrative—from market status and data availability, through to technical and legal planning frameworks, finance, technology choices, training, and bankable business models. All deliverables can be downloaded from the website: https://gogeothermal.eu/projects/geoboost/.

Market knowledge and data availability (D2.1, D2.2) provide a comparative view of the GSHP markets across Europe, including actors, drivers, and typical technical choices, as well as a focus on the critical role of registration, reporting, and monitoring of systems for reliable statistics and better planning.

Technical and legal planning for sustainable deployment (D3.1), proposes a shared framework that clarifies *thermal interaction* versus *thermal interference*, maps technical parameters to implement key regulatory elements, and highlights planning-tool archetypes that make permitting workable in practice—especially in urban settings.

Integration into spatial and energy action planning (D3.2), defines a workflow for translating subsurface potential into actionable priority areas and measures, supported by good practices that link mapping, zoning, stakeholder coordination, and monitoring.

The reduction of licensing barriers is discussed in D3.3 as structured diagnosis of licensing, administrative, and regulatory barriers across the project partner countries, translated into a set of streamlined and transferable best practices that maintain environmental safeguards and data visibility.

Economics and investment enablement (D4.1, D4.2) for GSHPs is considered from a life-cycle cost and affordability perspective, that explains GSHP values and the CAPEX–OPEX mismatch. This is supported by a catalogue of financial mechanisms beyond classic grants (on-bill repayment, Heat-as-a-Service, performance-based incentives, tariff reform, guarantees, and risk mitigation).

A technology catalogue and implementation strategies based on real cases are discussed in D5.1. A structured overview of open- and closed-loop systems, UTES concepts, drilling technologies, hybridisation pathways, controls, refrigerants, and circulation fluids—emphasising that outcomes depend on integrated system design and local boundary conditions is presented in detail.

Skills and market capacity building (D5.2) are defined by the development of a new European modular MOOC that supports harmonised training across stakeholder groups, from fundamentals to applied practice.

Bankable delivery models that present a user-tailored catalogue of business models across different project scales—from individual households to district networks—showing how ownership, operation, risk allocation, and revenue structures can be designed to make shallow geothermal investable and replicable is presented in D5.3.

How to use this report

This report is organised by deliverable chapters, allowing the readers to directly access the part most relevant to their role and the ability to cross reference these sections with the individual and more detailed deliverables. However, the core cross-cutting message is: scaling geothermal heat pumps requires *alignment* between (i) market data and monitoring, (ii) proportionate and predictable permitting, (iii) interference-aware planning tools and spatial workflows, (iv) finance mechanisms that reduce upfront barriers, and (v) high-quality technical design, installation, and operation supported by training and standardisation. The GeoBOOST project outputs are intended to be modular and transferable, allowing countries and regions at different market maturity levels to adopt the elements that close their most limiting gaps first.

By consolidating these findings and tools, this Final Report provides both a stocktake of the current practices and provides a practical blueprint for accelerating geothermal heat pumps in Europe at scale in a safe, sustainable, affordable way.

Deliverable D2.1 - Ground Source Heat Pumps in Europe: An analysis of the Geothermal Heat Pumps market

European countries have become leaders in renewable energy deployment to cut CO_2 emissions, with geothermal energy—especially geothermal/ground-source heat pumps—growing rapidly over the last two decades as fossil fuels, notably natural gas, are phased out. Adoption and financial support vary by country, but the energy-security shock following Russia's invasion of Ukraine accelerated efforts to reduce dependence on Russian gas and helped trigger increased private investment in geothermal infrastructure, particularly in Eastern Europe. To clarify market status and data availability, the geoBOOST project uses two partner surveys: one to identify which datasets are needed and realistically obtainable across countries, and another to capture the maximum available information on the GSHP market, while also tracking emerging actors and business models. Where subsidies exist, they often unlock higher-quality technical datasets (e.g., subsurface temperatures, geological profiles, and thermal properties), which can feed into stronger regional energy strategies.

Methodology

Deliverable 2.1 compares national GSHP practices and future opportunities across Europe, showing that market and design differences are mainly driven by climate and regional heating/cooling demand, as well as local geology. Geological variability affects rock types, drilling methods, and project complexity—especially in sedimentary settings where casing is needed to protect shallow aquifers and stabilize boreholes—while harder rock and fewer aquifers often allow faster drilling and shorter completion times. The analysis also highlights non-technical drivers, including income levels, building standards (insulation and system temperature requirements), and the availability of subsidies, which together shape how GSHPs are adopted in each country

Data acquisition and registration of ground source heat pumps varies widely across Europe: Finland, the Netherlands, and Sweden operate comprehensive systems that record essentially all GSHP installations, enabling reliable market insights and technical datasets. On the other hand, countries such as Ireland, Germany, Spain, Poland, and Austria lack similarly robust mechanisms, resulting in limited and fragmented information. Although most countries require local or national permits for new geothermal boreholes, the approval rules differ substantially in each jurisdiction. For this analysis, per-capita deployment indicators were used based on 2023 population figures taken from Wikipedia and cross-checked against Worldometer.

Deliverable D2.1 focuses on three main geothermal heat pump configurations—vertical closed-loop, horizontal-loop, and open-loop systems—while the broader range of technologies is covered in the technology review in D5.1. Closed-loop systems dominate the market because they are versatile, efficient, and relatively low-maintenance, using a sealed pipe circuit with heat-transfer fluid. Open-loop systems are less common and are typically applied in larger buildings (e.g., offices, hospitals, schools) where groundwater can be used directly as the heat source or sink. Horizontal-loop systems are generally considered the simplest and cheapest but also the least efficient; they are often poorly captured in registration systems, which can bias national statistics, even though they may still be relevant in specific local situations.

The main end-users and investors

The GSHP market is shaped by a diverse set of end-users and investors: homeowners mainly adopt smaller systems but often choose air-source heat pumps due to lower upfront costs, even though GSHPs typically place less strain on electricity grids and can provide highly efficient "free cooling" in new developments. Larger installations are concentrated in commercial buildings where owners value long-term operating savings and sustainability targets. Local and state governments influence uptake through subsidies and regulation, while sometimes restricting drilling due to environmental concerns. ESCOs and utilities also drive deployment via programs and service-based models, though long-term contracts and maintenance/operation risks can reduce market diversity and, in some cases, contribute to higher energy prices.

New actors

Shallow geothermal energy is expanding rapidly, driven by a widening ecosystem of "new actors" that includes traditional oil and gas companies applying subsurface and directional drilling expertise, new private and corporate investors financing both small residential systems and large projects (often backed by bank loans), and energy suppliers integrating GSHPs into cleaner portfolios alongside R&D efforts from academia. PV stakeholders increasingly view geothermal as a storage partner in hybrid PV–heat pump concepts that can reduce ground-exchanger size and improve seasonal balance by reinjecting summer heat. NGOs support growth through climate advocacy and, in some urban areas, indirectly boost GSHP acceptance as noise complaints from densely installed air-source units rise. At the same time, IT companies and AI are emerging as influential players—data centres are pushing demand for low-carbon energy and smarter load management—while established manufacturers scale up pumps, heat pumps, and related components, and research institutions advance 3D geological modelling and hydrochemistry to reduce drilling and operational risks.

Investment trends in EU

EU investment in ground-source heat pumps is rising as part of the wider shift to clean, efficient heating: the European heat pump market was valued at about €15.9 billion in 2023 and is forecast to grow strongly (around 18% CAGR for 2024–2032), despite a ~5% sales dip in 2023 linked to high interest rates, high electricity prices, and changing national policies. Growth is supported by manufacturers expanding capacity, ESCOs bundling finance and delivery of larger integrated projects, and a market shift towards new installations over replacements (e.g., Sweden reports roughly 70% new vs 30% replacement), alongside a move to deeper boreholes and larger borehole fields and the rollout of low-temperature grids. Hybrid systems combining GSHPs with PV or solar thermal remain an important pathway for flexibility and efficiency, although in mature markets the stand-alone geothermal heating/cooling solution can increasingly dominate.

Main market drivers

GSHP adoption is primarily driven by high energy efficiency and lower operating costs in both new builds and retrofits, reinforced by climate and air-quality goals and stricter EU building regulations. Financial incentives (subsidies, tax credits, low-interest loans) further improve project economics, while GSHPs offer standout value for cooling—especially passive cooling—and seasonal thermal energy storage. Energy security has also become a key factor, particularly in Central Europe's push to reduce reliance on Russian gas. Finally, compared with air-source heat pumps, GSHPs are often seen as more grid-friendly, supporting electrification without the same peak-load impacts.

Market models

GSHP market models are shaped by a broad ecosystem of demand, investors, district heating and urban planning, regulation, and continuous improvement through R&D, best practices, and workforce training, with project viability strongly influenced by finance (risk management, incentives, savings, and loan products). Key actors include installers and manufacturers, banks and funds, local communities and cities, as well as energy suppliers ranging from single-system operators to integrated heating and cooling grids, serving both households and businesses. Common business models include ESCO-style performance or pay-as-you-save contracts, smart-technology and data-analytics services for optimization and predictive maintenance, financing/leasing to reduce upfront CAPEX, community-based shared systems (often linked to urban development), "energy-as-a-service" delivery of thermal energy instead of equipment sales, and approaches that leverage government incentive programs to improve economics and scale.

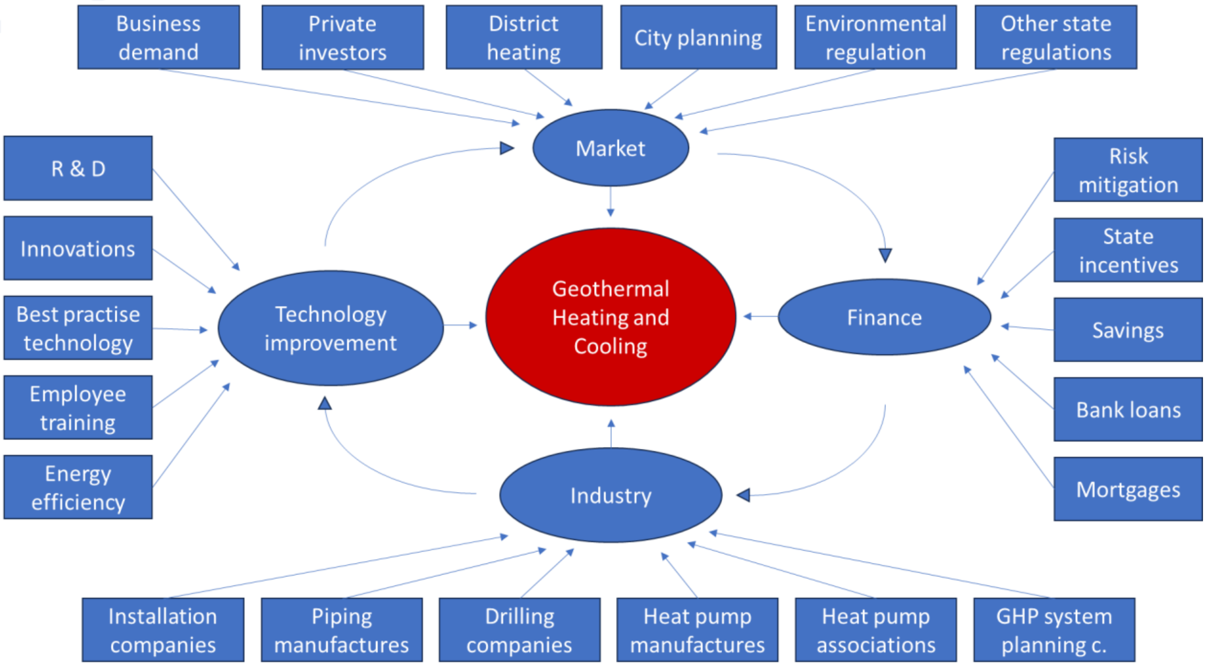

Figure 1: Market model for GSHP with the main players and processes

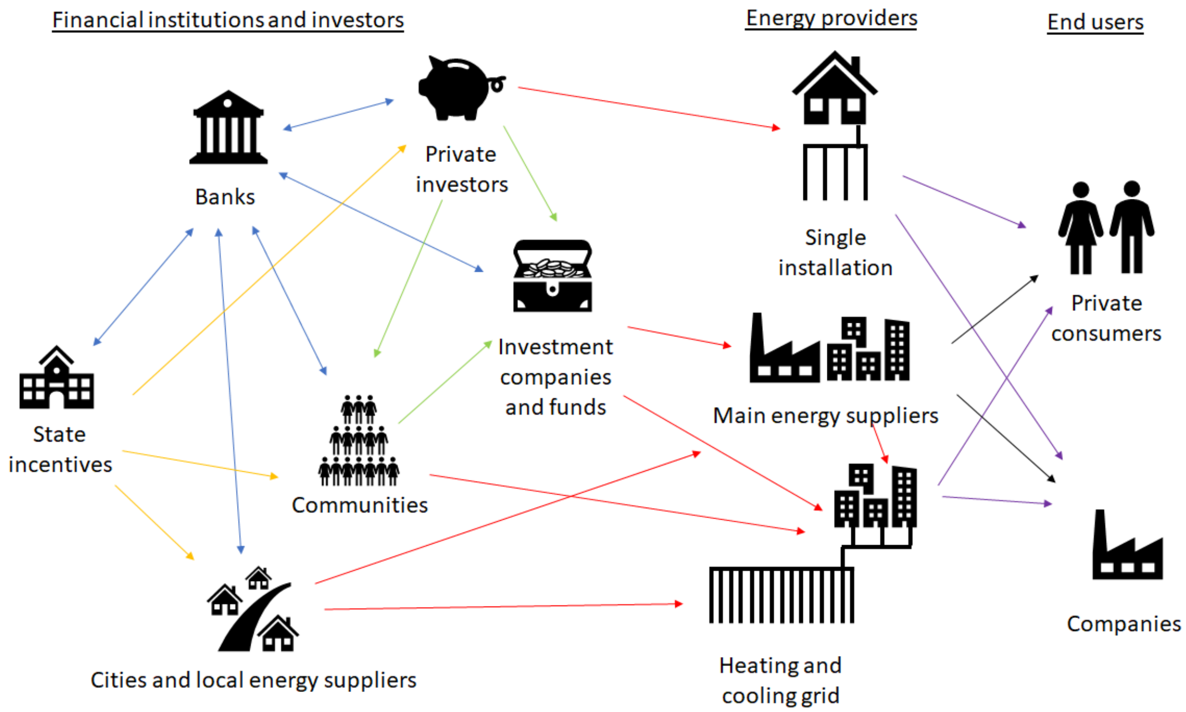

Figure 2: Relation between the market players

Closed loop systems

Across Europe, closed-loop GSHP systems (including energy piles) typically use borehole heat exchangers near the practical permitting limit, so average depths commonly fall in the ~100–300 m range, with deeper averages in countries with higher regulatory thresholds (e.g., Netherlands, Sweden, Switzerland) and shallower averages where deeper drilling triggers more complex permitting (e.g., Germany). Adoption per capita varies, with the most mature Scandinavian markets reaching roughly 50 GSHPs per 1,000 people, while countries like France and Poland lag due to climate, energy-price structure, building insulation quality, and weaker reporting requirements. Technical choices also differ: Central Europe often uses ethylene-glycol mixtures, Sweden frequently uses ethanol, and warmer parts of Spain may use water-only designs unless ground temperatures are low; borehole diameters reflect geology and grouting rules (narrower where grouting is not mandatory, wider where casing and minimum grout thickness are required). Installation costs are driven by diameter, drilling method, automation, labour costs, and market balance—lowest in highly automated markets like the Netherlands and higher in Germany and France. Databases and reporting quality is uneven, with strong national registration in the Netherlands and more fragmented or incomplete registries elsewhere. Probe configurations vary as well, with double-U (often 32 mm) more common in Austria/Germany/France/Spain and single-U more common in Ireland/Netherlands/Poland/Sweden (typically ~40 mm, increasing for deeper probes).

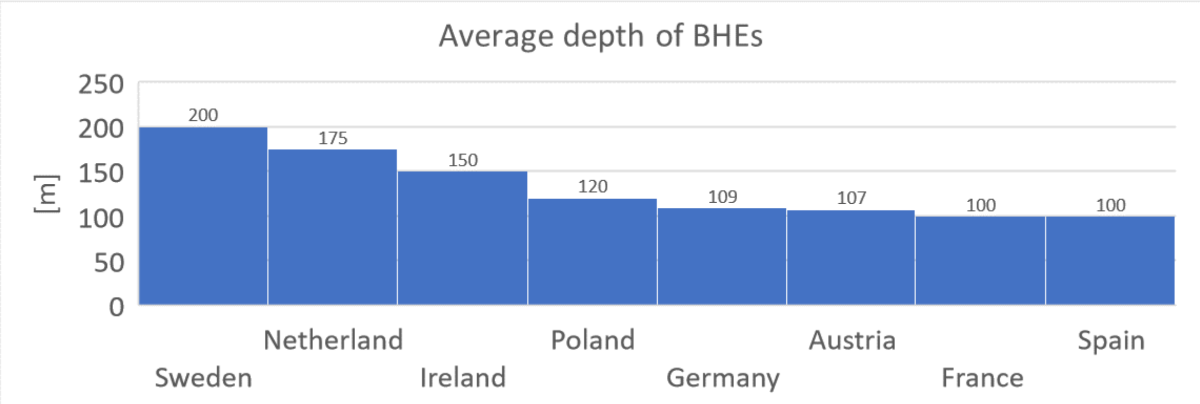

Figure 3: Average depths of BHEs

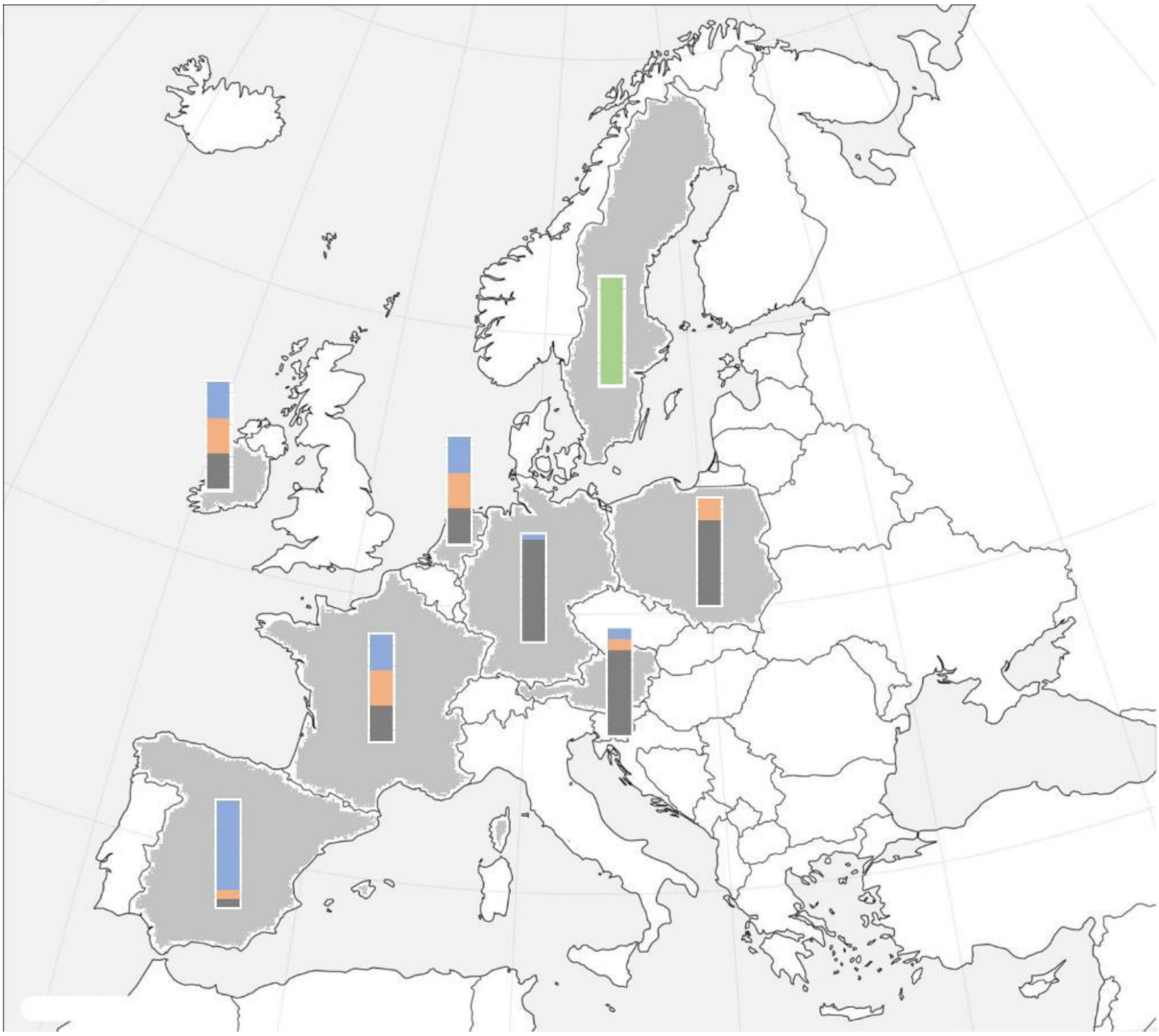

Figure 4: Circulation media among different countries

red - propylene glycol water solution, grey - ethylene glycol water solution, green - ethyl alcohol water solution in bio-quality, blue - pure water. (Source: geoBOOST deliverable D1.1, based on project questionnaire)

Circulation fluids are climate- and practice-dependent

In Central Europe, ethylene glycol solutions (around 25% or 33%) are described as common heat-carrier fluids. Sweden is said to favour ethyl alcohol due to lower viscosity at higher concentrations, while the Netherlands uses both MPG and MEG. Spain often uses water-only where ground temperatures are high (15–20 °C), but recommends antifreeze in colder areas, with the note that water-only systems require careful temperature and heating/cooling balance design.

In Spain there is used mostly pure water. In Netherlands is growing number of systems with water (one of the largest suppliers uses water exclusively). With regard to the other fluids the recommendation of the Environmental Agency is to use pure product (no additives). There are some newer fluids, advertised as “environmentally friendly” or “better heat transfer” coming on the market as well.

Borehole diameter is driven by geology and regulation

Typical borehole diameter depends on rock stability, depth, casing needs in sediments, and national grouting rules. Strong igneous/metamorphic rocks can allow smaller diameters, while sediments often require wider holes for casing. Regulatory differences matter: Sweden’s non-mandatory grouting enables narrower bores, whereas Germany’s minimum grout thickness increases required diameter.

Reported typical borehole diameters by country

The survey lists typical ranges such as Austria 152–168 mm, France 145 or 165 mm, Germany 152–168 mm (igneous) and ≥178 mm (sediments), Ireland 152 mm, Netherlands 140–180 mm, Poland 110 mm (DTH) plus larger ranges for 1U/2U in sediments, Spain 110–150 mm, and Sweden commonly 114 mm (sometimes 139 mm).

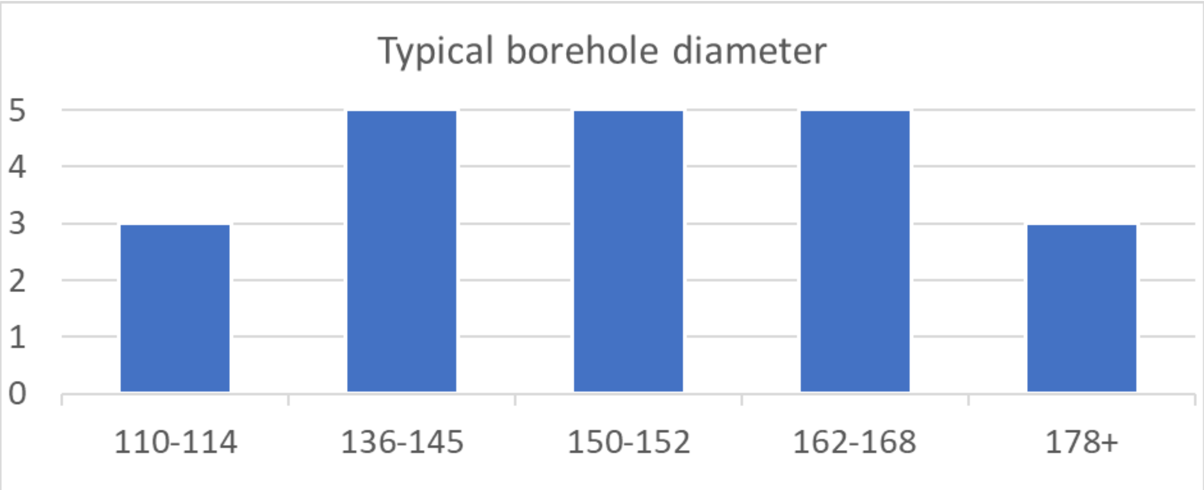

Figure 5: Typical borehole diameter *among studied countries.*

Installation cost per meter depends on technology and market maturity

Drilling and installation costs are linked to borehole diameter, drilling method, automation, workforce requirements, wages, and backfilling requirements. The text emphasizes that supply–demand balance and competition can be decisive. The Netherlands is presented as lowest-cost due to high automation, Sweden next due to narrower drilling, Poland low due to labour costs, and Germany/France highest due to wider bores, higher labour costs, and weaker competition.

Reported €/m values (note differing inclusions)

Approximate values include Austria €70–80/m (single-family), France €100/m, Germany €90–130/m (drilling + probe + grout), Ireland €56–62/m, Netherlands €25–35/m, Poland ~€35/m (incl. glycol), Spain €75–85/m (complete borehole, excluding "lost casing"), and Sweden €30–32/m for drilling only (excluding groundworks). Comparisons would improve if separated into "drilling-only" versus "total BHE completion cost."

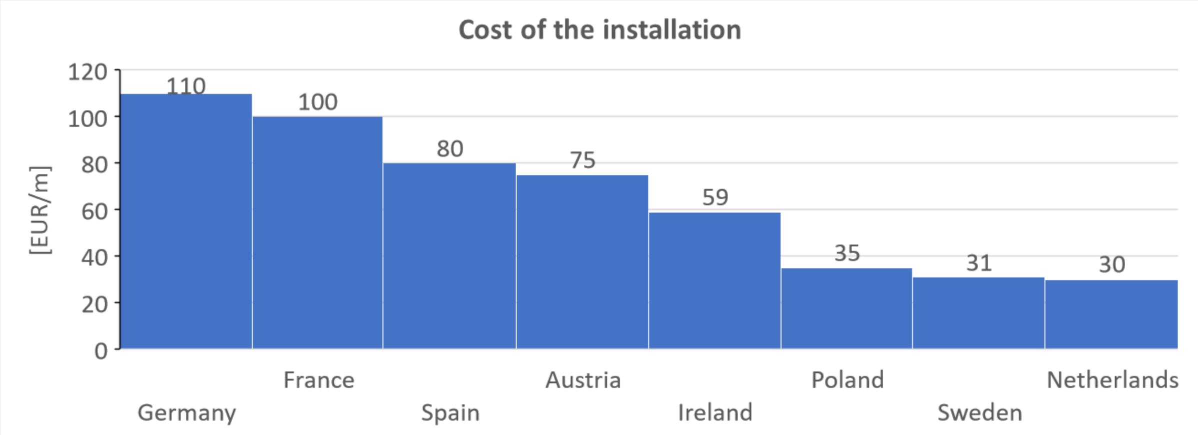

Figure 6: Average cost of installation

Explanations for low uptake in France and Poland

France and Poland are presented as lagging markets, but for different reasons. In France, milder climate and lower heating demand reduce incentives, and the price of electricity in France is the lowest in Europe. In Poland, the market is described as earlier-stage for renewables, affected by building insulation quality and by a lack of mandatory reporting on new heat pump installations.

Databases: the key constraint on reliable market statistics

All countries are said to have some form of registry, but data completeness varies widely and is often fragmented across regions. Sweden and the Netherlands are described as having the strongest databases, while Poland and Ireland have weak coverage where reporting is often not mandatory. The Netherlands is highlighted for mandatory registration since 2013; Sweden's borehole archive is public, but full installation data may require municipality-level checking.

Heat exchanger configurations and pipe diameters

Austria, Germany, France, and Spain are reported to favour double-U probes, commonly with 32 mm pipes. Ireland, the Netherlands, Poland, and Sweden more often use single-U probes, with pipe diameters typically 32–50 mm and commonly around 40 mm; deeper installations tend to use 40–50 mm. These choices reflect practical constraints such as depth, hydraulics, and drilling/grouting practices.

Table 1: Summary of the preferred heat exchanger design

Main types of probes	Austria	France	Germany	Ireland	Netherland	Poland	Spain	Sweden
Type of probe is being commonly used	Double U32	Double U32	Double U32	PE100 - single U 40mm	Single U probes dia. 32 – 40 mm - mainly PE-RC	Single U probes Ø40 mm - mainly PE-RC	Double U32	Most common simple-U, 40, 45 and 50 mm, sometimes Double-U 32 mm
Type of probe is being used, for deeper BHE (125m).	Double U32mm x 2,9 mm	Double U32	Double U40	PE100 - single U 40mm	Single U probes dia. 32 mm - mainly PE-RC	Single U probes Ø40 mm - 45 mm, mainly PE-RC	Double U32	Most common simple-U, 40, 45 and 50 mm, sometimes Double-U 32 mm
Type of probe is being used, for deeper BHE (200m).	Double U40mm x 3,7mm, double U50mm for down to 400 m	Double U40	Single U40 or U50	As above - but PEX probes occasionally used	Single U probes dia. 32 mm - mainly PE-RC	Double U Ø40 mm - PE-RC or PE-Xa, Single U Ø45 mm - PE-RC	Not used in Spain	40 mm up to 250 m, 45 mm up to 320, after that 50 mm

Open-loop systems: where and why they are used

France is described as leading in the number of open-loop systems, while Austria and the Netherlands show high per-capita deployment linked to favourable sedimentary settings and groundwater access. Open-loop systems are portrayed as mainly large-scale solutions (commercial/industrial), rarely economical for single-family homes due to risk, maintenance, and shorter lifespan. Bavaria is mentioned as an exception where drilling limits can push choices toward open-loop options.

All open loop systems in Netherlands require a permit and the effect/design study is available through the permitting agency. Also all open loop wells are included in the shallow geothermal database (WKO tool) and are required to monitor and provide the monitoring data to the authorities. In NL there is also a combination of wells for fire (sprinkler) installations and open-loop use.

Open-loop designs often use an extraction–injection doublet and require sufficient separation to avoid thermal interaction. Poland is said to use larger layouts (two doublets) in bigger installations, while the Netherlands may include a spare well to maintain continuity and optimize performance. Databases for open-loop are widely incomplete because geothermal wells are not consistently distinguished from ordinary water wells, limiting national-scale assessment.

Horizontal collectors: common in practice, scarce in statistics

Horizontal loop systems require careful sizing based on soil type, moisture, shallow groundwater presence, and thermal conductivity. A rough rule of thumb cited is about twice the heated floor area (around 200 m^2 for a typical house), with slinky loops most common, followed by parallel collector trenches, with heat baskets being the least common. As permits are often not required, most countries do not track horizontal systems; Austria is noted as a partial exception with municipal-level data.

Country-by-country legislative notes (data collection focus)

Austria uses water-right licensing for many systems with county water registries and, sometimes, Baugrundkataster. Finland requires municipal permits for boreholes and has sales statistics via the heat pump association. Ireland is described as moving toward stronger registration and monitoring requirements (with open-loop abstraction/re-injection already regulated). Germany requires permits for vertical systems and sends geological reports to surveys, but practices vary by state. In the Netherlands all systems require a registration and/or permit (depending on the municipality for closed loop, this has changed this year). There are regulations through national law and protocols and in areas where many systems may be installed the municipality can prescribe a " ground source energy plan" with specific regulations.

Poland, Spain, Sweden: three different data-policy models

Poland has no general obligation to register GSHPs in the national archive; only a small share is captured via geological documentation routes. Spain is described as decentralized with no unified public database, making market analysis region-dependent (example: Madrid). Sweden mandates reporting of geothermal boreholes to SGU, with public access via Brunnsarkivet and strong involvement of sector organizations supporting transparency and market development. In Netherlands, with regard to data collection: all systems need to be registered and monitored. For closed loop if the capacity is < 70 kW on the ground side the data needs to be retained on site for 10 years, larger systems need to report to authorities. Only single family houses (or apartments) with an individual borehole system are exempt.

Overall takeaway for stakeholders

Data policy, permitting practice, and standardized reporting as central enablers of GSHP market growth—alongside geology, climate, and cost structure. These provide useful comparative "typical values" for design and economics, but also shows that inconsistent definitions (e.g. The reporting of cost assumptions for GHSP systems) can limit cross-country benchmarking.

Deliverable D2.2 - Reporting and monitoring geothermal heat pumps in Europe

Objectives of Deliverable D2.2

- To outline the current mechanisms for reporting and monitoring of market indicators at the European level referring to available European market reports.
- To provide a critical analysis of the EU's methodologies for accounting renewable energy contributions from heat pumps, with a focus on GHPs for heating and cooling.
- To conduct an evaluation of the situation for reporting and monitoring within the GeoBOOST partner countries to capture specific insights within national markets.
- To identify and catalogue essential parameters for improved granularity and reliability of GHP installation data.
- To propose a standardised framework for capturing GHP installation data for key system types in order to facilitate consistent and clear data sharing and analysis with third parties.

Strategic rationale: why data is the bottleneck

The report frames data gaps as a structural barrier to deployment. Without systematic datasets, stakeholders struggle to distinguish market trends between system types, understand where installations cluster (often highly heterogeneous within countries), and evaluate whether regulatory requirements are being applied consistently. The same lack of detail also limits technical learning (e.g., what designs work best in which subsurface settings) and makes it harder to plan responsibly where underground thermal impacts or interference risks may accumulate in dense urban areas. The report therefore establishes standardized data templates.

Policy background: EU targets, heat demand, and the role of heat pumps

The EU's climate and energy targets (Fit for 55, Green Deal, and the updated Renewable Energy Directive) raise the required renewable share by 2030 while heating and cooling still represent roughly half of final energy use. Although renewable heating and cooling shares have been rising, the report highlights large differences between Member States, indicating both progress and the need for faster change. In this context, GHPs are positioned as efficient, cost-effective technologies whose contribution remains relatively marginal in many national energy portfolios, despite strong technical performance.

Market obstacles: economics, regulation, and system complexity

Beyond general awareness and investment barriers, the text points to economic signals, especially the electricity-to-gas price ratio—as a key driver of consumer choices (with caveats for Nordic markets where gas is less relevant). It also emphasises that GHPs are increasingly relevant to system-level challenges such as electrification and grid cost management, not only building energy savings. However, policy, regulatory, and financial frameworks often fail to reflect the diversity of GHP configurations, reinforcing the need for better categorisation and monitoring.

GeoBOOST project context: what the consortium tries to fix

GeoBOOST brings partners from Austria, Belgium, Germany, Ireland, the Netherlands, Poland, Spain, and Sweden to remove barriers that keep GHPs from "mainstream" status. The report lists recurring obstacles the project targets: missing monitoring standards, high upfront CAPEX, weak business/finance models, misaligned and burdensome authorisation processes, skills shortages, and limited public understanding of GHP benefits. D2.2 sits specifically in the "Market Topologies" work package and addresses the monitoring/standardisation gap as a foundation for most other reforms.

GHP system classification used in the report

To reduce confusion in reporting, the deliverable clarifies classification by depth (shallow vs medium vs deep), by temperature/enthalpy (low-enthalpy systems needing heat pumps), and by loop type (closed vs open). Closed systems circulate a heat transfer fluid in pipes (vertical borehole heat exchangers or shallow horizontal collectors), while open systems use groundwater directly (typically extraction and reinjection well doublets). It further situates ATES/BTES as UTES subtypes and recognises thermoactive geostructures (energy piles, diaphragm walls, activated slabs) as an increasingly important "closed" category that blends structural and thermal functions.

Scope and definitions: what "data" means here

The report defines "data" broadly as qualitative and quantitative information linked to design, implementation, maintenance, and operation of GHP installations. An "installation" is the full system setup (not just a borehole or a heat pump), so "GHP installation data" should capture both system-level attributes (capacity, mode, energy delivered) and component-level details (borehole/well geometry, materials, coordinates). This framing matters because many existing registries capture partial proxies (e.g., water abstraction permits) rather than geothermal-specific operational realities.

European-level market monitoring: what is currently used

At the European level, the dominant market indicator is still "units sold," because it is relatively easy to collect and compare. D2.2 reviews two major reference reports: the EHPA market report (broad heat pump market across many countries) and the EGEC market report (geothermal-focused across power, district heating/cooling, and GHPs). The report argues that sales indicators are necessary but insufficient: they do not describe the delivered heating/cooling service, system scale, subsurface interaction, nor the configuration differences that drive costs, permitting needs, and environmental impacts.

EHPA Market Report: strengths and limits for GHP visibility

EHPA primarily tracks national sales using a standard questionnaire distributed via associations and statistical bodies, then applies correction factors to align with renewable accounting rules (e.g., excluding AC-only units, adjusting for climate-related usage assumptions, handling hybrid/VRF definitions). D2.2 credits the approach for climate sensitivity, pragmatic corrections, and inclusiveness across heat pump types. However, it identifies major limits for geothermal: when data is grouped by energy source and distribution medium, it becomes very hard to isolate *which* geothermal configurations are being deployed (groundwater vs boreholes vs shallow soil collectors), and sub-national patterns remain largely invisible.

EGEC Market Report: geothermal focus with remaining consistency challenges

EGEC requests data from national coordinators and aims to report both units sold and installed stock, plus system capacities and additional detail for "very large" closed and open systems. The report sees this geothermal focus as essential for delineating trends and recognising large systems' growing relevance. At the same time, it notes that reliance on national coordinators can yield uneven completeness and comparability, and that further refinement is still needed to differentiate GHP system types more consistently and to move beyond national-level aggregation where local diffusion patterns are decisive. Building on the GeoBOOST project, EGEC plans to expand the range of parameters monitored in Geothermal Market Reports.

Key European takeaway: sales alone cannot steer planning or policy

D2.2 concludes that "units sold" cannot adequately represent heating/cooling services delivered, building segment dynamics, or the environmental/planning implications of subsurface thermal use. The diversity of GHP configurations—normally an advantage for fitting local conditions—also creates reporting difficulties when categories are too coarse. The report therefore frames standardised data templates and clearer typologies as the practical route to make European monitoring useful for both market development and subsurface governance.

EU renewable accounting for heating: the Annex VII logic

For heating, the EU method treats ambient/geothermal/hydrothermal energy captured by heat pumps as renewable and calculates renewable heat as delivered usable heat multiplied by a factor based on seasonal performance (SPF). Eligibility depends on meeting a minimum SPF threshold linked to an EU electricity primary-energy efficiency factor (η). In practice, Member States use default values for SPF and equivalent operating hours (H_HP) by heat-pump type and climate zone, and then derive usable heat from rated capacity and assumed operating hours.

EU renewable accounting for cooling: the Delegated Act expansion

A major development discussed is the addition of a methodology to count renewable *cooling* (Delegated Regulation (EU) 2022/759), addressing a previous gap where cooling was poorly represented despite rising demand. The method distinguishes active vs passive cooling, uses primary seasonal performance (SPFp) thresholds, and scales the "renewable share" of cooling supply between a lower bound (minimum efficiency) and an upper bound (high efficiency). It allows both standardised and measured SPF approaches, requires measured values for larger systems and district cooling, and includes rules to allocate auxiliary energy and account for network losses—important for complex geothermal cooling and district cooling arrangements.

Critical analysis: where the methodologies can misrepresent GHP reality

The report argues that, although the equations standardise accounting, they can behave like simplified linear models when SPF is treated as a fixed default by type and climate zone. Real heat-pump systems often perform non-linearly across varying operating conditions; reducing performance to fixed multipliers may over- or underestimate contributions depending on local context. A second concern is the heavy reliance on default assumptions (SPF, operating hours, load hours) without systematic uncertainty treatment, which can hide bias and reduce comparability across diverse geological and microclimatic conditions.

Critical analysis: need for geothermal-specific differentiation and “free cooling” recognition

D2.2 calls for greater technology specificity within geothermal categories. Open groundwater systems often perform differently (and sometimes better) than closed borehole systems, and geothermal “free cooling” can deliver cooling with minimal energy input, which is not always captured clearly in generic categories. Because geology, groundwater flow, and local subsurface conditions influence performance beyond broad climate bins, the report recommends moving toward more empirically grounded datasets that can support better default values, more realistic operating profiles, and fairer representation of geothermal advantages.

Partner-country assessment: why national practices matter

A large portion of the deliverable evaluates current reporting and monitoring practices in GeoBOOST partner countries via a structured questionnaire (general + closed-loop + open-loop; each covering data generation and data accessibility/sharing). Across countries, the report repeatedly finds fragmentation, inconsistent parameter completeness, limited operational data, and barriers to easy access—often driven by how permitting is organised, which authority holds information, and whether reporting is mandatory nationwide.

Country patterns: decentralisation vs structured national registries

Austria and Germany illustrate how decentralised water and permitting regimes can create uneven datasets: coordinates and commissioning years are more likely to exist, while capacities, energy delivered, and detailed technical parameters are often missing or trapped in non-digitised licensing documents. Ireland shows how, without a strong regulatory mandate for closed systems, data can depend on grants, industry associations, or partial registers, while open systems are recorded mainly as groundwater abstraction rather than geothermal use. Poland demonstrates that legal requirements alone are insufficient if compliance and forwarding of documentation to national archives remain low, undermining completeness and reliability.

Best-practice signals: Sweden and the Netherlands

Sweden and the Netherlands are presented as stronger examples because reporting is anchored in clearer obligations and supported by structured templates and accessible tools. Sweden's long-running compulsory reporting and SGU's national database enable broad accessibility and consistent parameter capture, though challenges remain in coordinate precision and missing older installations. The Netherlands shows how national templates, installer/authority cooperation, and a tiered regulatory approach can produce systematic closed-loop data.

The proposed solution: standardised data template sheets

To translate analysis into action, D2.2 provides recommended data sheets meant to be used as templates for state-wide or ideally national databases, and to enable cost-free public sharing in ready-to-analyse formats. The templates are organised by major system types: borehole heat exchangers (BHE), groundwater heat pumps (GWHP), horizontal collectors (HOR), and thermoactive geostructures (TAG). The aim is not to force a single database architecture, but to ensure that whatever is collected can be shared consistently, compared across regions, and reused for planning, research, and policymaking.

Two reporting formats: component-level vs aggregated installation-level

The report distinguishes two practical table formats. Format_1 blends "installation" and "component" detail in a structure that allows one installation to contain multiple boreholes/wells while keeping installation-wide values from being redundantly repeated; this is recommended for completeness and spatial planning needs. Format_2 is a pure "wide" table where each row is an installation with aggregated attributes, making it simpler for high-level statistics and comparisons; it can be derived from Format_1. Together, these formats are positioned as a bridge between ad-hoc spreadsheets and more advanced relational database models.

What "better data" enables: planning, interference management, and credible renewable shares

In the conclusion, the report ties everything back to outcomes: reliable installation datasets are essential for managing thermal and hydraulic interference risks, supporting environmental assessments, and properly quantifying renewable heating and cooling contributions from GHPs. The deliverable argues that better data is not a "nice-to-have" but a prerequisite for scaling GHP deployment responsibly—because it strengthens market intelligence, improves design learning, supports streamlined governance, and makes geothermal contributions visible and verifiable within EU energy accounting.

Deliverable D3.1 - Framework for technical and legal assessment of thermal interference and optimised planning of open- and closed loop GHP systems

Scope and intent of Deliverable

This deliverable (TUM, v2, 10/2024) builds a practical bridge between technical reality and legal practice for shallow geothermal heat pump (GHP) systems. Its core aim is to reduce conflicts and performance losses caused by thermal interference in the subsurface, especially in dense urban areas. The report targets both open-loop (GWHP/ATES-like) and closed-loop (BHE/horizontal) configurations. It also frames "planning tools" as the missing operational layer that turns rules into predictable, optimised deployments.

Why "thermal interference" became a policy problem

The report's starting point is simple: Europe already has millions of heat pumps, and GHPs increasingly cluster at short spacing in redeveloped neighbourhoods. As density rises, the subsurface turns into a shared resource with cumulative impacts. Without spatial planning and consistent thresholds, systems can underperform, trigger permitting conflicts, or constrain future projects. The text rightly positions thermal issues not as niche physics, but as a governance challenge: who may cool/heat the ground, by how much, where, and for how long?

Methodology: from literature confusion to working definitions

A strong contribution is the method: a narrative review first exposes that authors often use "interaction" and "interference" interchangeably, then an integrative review and workshops consolidate consistent meanings for GeoBOOST countries. This is important because regulation depends on definitions that can be applied by authorities and planners. The approach is transparent: define terms → derive technical parameters → map to regulation elements → compare across countries → evaluate with SWOT + IFEM/EFEM.

The key conceptual split: interaction vs interference

The report's definitions are pragmatic and useful. Thermal interaction is framed as the thermal effect within the same system (e.g., between boreholes in one field, or between extraction and reinjection wells of one open-loop system). Thermal interference is the thermal influence between different systems (or between a system and other groundwater users such as drinking water wells), becoming "negative" when thresholds are exceeded. This split clarifies responsibility: interaction is mainly a design optimisation issue; interference is mainly a spatial/resource-allocation issue.

From definitions to regulation elements: a structured parameter map

The report's most operational output is the mapping of technical parameters into six regulation-element groups: distance, temperature, extraction/discharge, seasonal performance, size/layout, subsurface conditions. This structure works well because it matches how permits are typically issued (setbacks, temperature & pumping limits, reporting duties). It also highlights that some "elements" are actually containers (e.g., subsurface conditions) that imply many underlying data needs. The tables for open vs closed, and interaction vs interference, provide a reusable checklist for permitting and design audits.

What the country comparison reveals about Europe's regulatory maturity

The country comparison tables show a fragmented landscape: some elements are "obligatory" in principle but lack clear written thresholds; others are "not regulated" for GHPs but governed indirectly via water/mining/environmental law. A recurring pattern is that distance and temperature are most often regulated (sometimes via fixed values, sometimes case-by-case assessment). By contrast, extraction/reinjection limits are rarely specified numerically (Ireland is noted as an exception for open loop systems), and requirements for registers (production, drilling, geothermal data) vary widely or apply only to subsidised systems.

Typical threshold ranges: convergence exists, but not consistency

Even with national differences, the report extracts useful "ranges" that show emerging European convergence. Examples include: typical minimum distances in the meter to tens-of-meters scale, and temperature-change limits commonly in the few °C/K range (often around 3–6 K, with some higher values depending on jurisdiction). The value of the report is not claiming one universal number, but showing that many countries already operate within overlapping bands—suggesting harmonisation is feasible if anchored in hydrogeology, density, and protection zones.

Legal status vs technical reality: the central tension

One of the strongest analytical chapters is the "remarks" section: it explains why legal status differs by country—geology, climate, history of deployment, data availability, decentralised governance, and protection of water resources. Importantly, it concludes that closed-loop rules are often less stringent than those for open-loop systems, because of the perceived lower risk and the absence of binding legislation. rather than proven lack of impact. The report claims that as the density of closed loops increases, problems may lead to future conflicts.

Technical impact assessment: why each element matters in practice

The technical review is convincing because it links each regulation element to concrete outcomes: preventing thermal breakthrough, avoiding freezing/overheating, protecting drinking water, maintaining long-term COP/SPF, and enabling cumulative-impact management. The report also broadens the purpose of regulation beyond "prevent harm" to "enable markets": registries, drilling reports, and geothermal data are framed as foundations for planning tools, supervision, and iterative improvement. This is a strong framing for policy-makers who need to justify administrative requirements.

Good-practice planning tools: four credible archetypes

- The "planning tools" chapter is a practical highlight, showing that tools are not abstract—they already exist in usable forms:
- Austria: ÖWAV RB 207 spreadsheets (rule-based analytical approach).
- Germany (Munich): Geo.KW web tool (TAP-based, strategy + permitting support).
- Sweden (Stockholm): Temperature Reduction 3000 (densification control with 25-year view).
- Netherlands: ITGBES (nationally embedded interference tool with data-driven search radii).

Together, these form a toolkit spectrum from guideline calculators to spatial decision platforms.

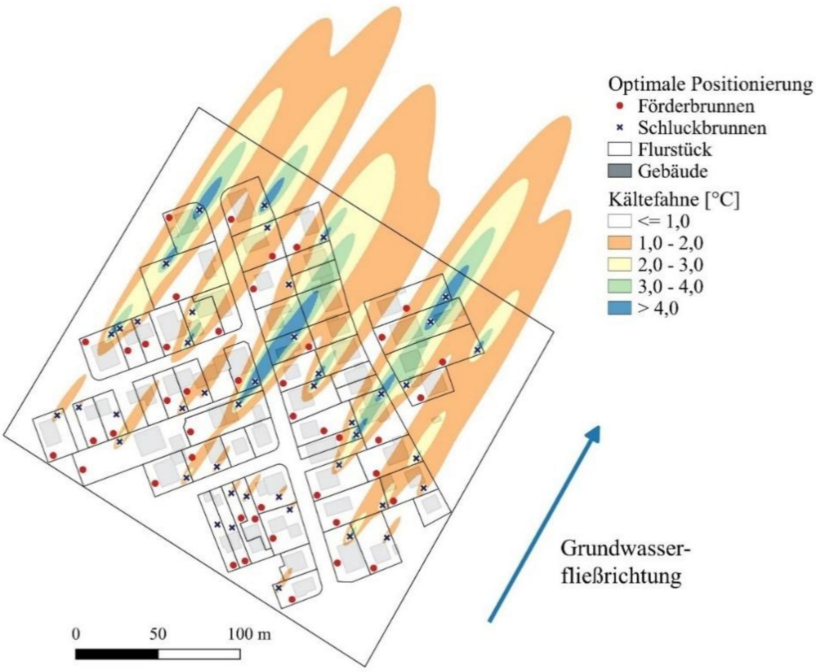

Figure 7: Example of a temperature field showing cold anomalies in a neighbourhood

The figure represents an optimal well positioning under exclusion of a negative thermal influence

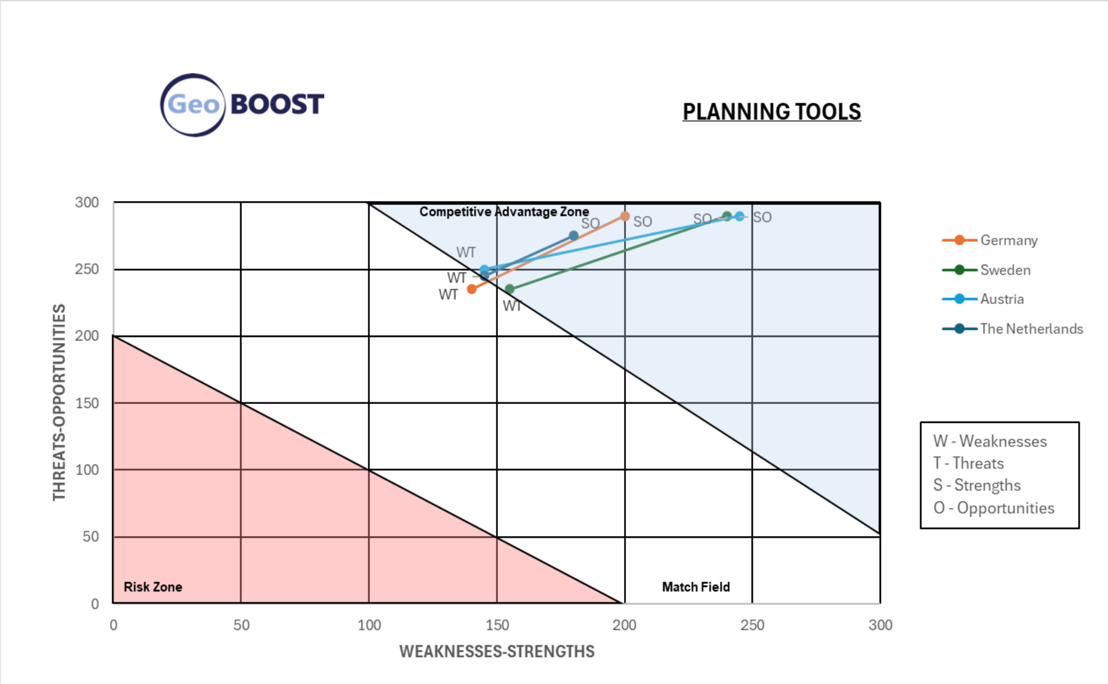

Figure 8: SWOT Analysis for Planning Tools

Austria: strong guidance, weaker explicit optimisation between systems

Austria is presented as having well-regarded guidance (ÖWAV) and a water-law framing that protects existing rights and protection zones. The limitation, as D3.1 highlights, is the lack of an explicit, nationally mandated "optimisation method" for inter-system thermal interactions; assessments hinge on protection of pre-existing rights rather than systematic neighbourhood optimisation. Still, the presence of clear temperature and spacing assumptions (including plume concepts and thresholds like small ΔT changes along plumes) makes Austria's approach operational—especially for practitioners who need fast, defensible calculations.

Germany (Munich): planning as city-scale resource management

Geo.KW is portrayed as a modern model: integrate hydrogeological layers, map exclusions, represent existing uses, and compute feasible well layouts and operational parameters. The value here is governance: the tool supports energy strategies, authorisation practice, and urban planning simultaneously. Its methodological backbone (TAP and optimisation methods) aligns with the report's thesis: thermal interference cannot be solved only by static setbacks; it needs spatially explicit, data-supported allocation of subsurface "thermal capacity."

Sweden: simple permitting, but formalised densification control

Sweden's permitting practice is deliberately light and fast, which helped mass adoption. The good-practice tool (Temperature Reduction 3000) addresses the predictable downside of success: crowded drilling in residential zones. The programme's assumption-driven structure is both a strength and a weakness: it enables uniform decisions and quick screening, but can oversimplify local variability. Still, it is an excellent example of a municipality-level tool that keeps approvals efficient while introducing long-term thermal stewardship (25-year impact logic).

Netherlands: data, certification, and national registration as a system

The Netherlands is depicted as the most systematised environment: legal requirements for registration and permits, certification schemes, and national databases that inform planning. ITGBES is especially relevant because it directly tackles the common real-world issue: neighbouring system parameters are often unknown at design time. The tool's linkage to search radii and registries shows what "mature market governance" looks like—thermal interference becomes manageable because information is structured, accessible, and embedded in procedures.

Recommendations: toward a robust, scalable EU approach

The recommendations flow logically from the evidence:

- Use clear, shared definitions of interaction and interference, adaptable with local thresholds.
- Make key interference-prevention elements mandatory, but offset burden via incentives, streamlined permitting, and technical support.

- Require registries and reporting (drilling, geothermal data, production), because planning tools depend on data.
- Develop planning tools that are urban/rural adaptable, produce clear outputs, integrate databases, and can be transferred across jurisdictions. The report's most strategic message is that regulation and tools must co-evolve: rules without tools are slow and inconsistent; tools without rules lack authority.

Overall assessment: what the deliverable does best, and what remains open

This deliverable is strongest where it translates complexity into structure: definitions, parameter groups, regulation elements, and tool archetypes. It is also persuasive in showing that thermal interference is not only technical—it is a cumulative, spatial, long-term governance issue. What remains open (and would likely sit in follow-up work) is a more explicit pathway from "ranges and assessments" to standardised decision workflows: when to require modelling, which minimum datasets are non-negotiable, and how to scale requirements by system size and density. Still, as a framework document, it succeeds: it gives Europe a common language and a practical blueprint for harmonised, data-driven geothermal planning.

Table 2: SWOT Analysis - Scoring of Regulatory Elements

Weaknesses	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Thermal changes in the subsurface and/or groundwater	20	1	20	3	60	3	60	1	20	1	20	2	40
Subsurface interference impact on the ability to deliver heating & cooling power	20	3	60	3	60	2	40	3	60	3	60	3	60
Special legal obligations, restrictions, or technical requirements.	15	1	15	2	30	2	30	2	30	2	30	2	30
Higher energy consumption (Maintenance and Repair Costs, Control and Monito	10	1	10	1	10	1	10	1	10	0	0	2	20
Groundwater thermal short circuit or thermal breakthrough between systems	20	3	60	2	40	3	60	0	0	1	20	2	40
Space and availability for systems in different environments	15	3	45	1	15	2	30	0	0	2	30	2	30
	100		210		215		230		120		160		220
Ensure Energy balance of GHP systems	15	1	15	3	45	1	15	3	45	1	15	3	45
Optimization of heat exchange distribution of the systems over time.	10	1	10	3	30	2	20	3	30	1	10	1	10
Optimization of cost of the GHP systems	10	1	10	1	10	1	10	2	20	1	10	2	20
Total	100		191		241		193		239		157		252

Opportunities	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Improved monitoring techniques	15	1	15	3	45	1	15	3	45	2	30	2	30
Develop optimized planning software.	15	2	30	2	30	2	30	1	15	3	45	3	45
Development of future installations and/or heating districts	20	2	40	2	40	2	40	3	60	3	60	3	60
Encouraging and promoting research and development	15	0	0	0	0	1	15	3	45	2	30	3	45
Protecting ecosystems	15	2	30	2	30	2	30	1	15	2	30	1	15
Long term resource management	20	3	60	3	60	2	40	2	40	2	40	3	60
Optimise consumption of the heat pump	15	2	30	2	30	1	15	3	45	2	30	3	45
	100		205		235		185		265		265		300

Threats	Weighting (out of 100)	Score I1 Distance [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Extraction and discharge [0 to 3]	P x I3	Score I4 Seasonal performance of installation [0 to 3]	P x I4	Score I5 Size and layout of the GHPS installation [0 to 3]	P x I5	Score I6 Subsurface [0 to 3]	P x I6
Regulatory instability	20	1	20	1	20	3	60	3	60	1	20	1	20
High costs associated with complying with regulations	20	1	20	2	40	3	60	3	60	3	60	2	40
High operation costs	15	1	15	1	15	1	15	2	30	1	15	1	15
Unknown Environmental Impacts	20	1	20	3	60	2	40	2	40	2	40	3	60
Conflict with other subsurface users (subsurface infraestructure) causing possi	25	3	75	3	75	2	50	2	50	3	75	2	50
	100		150		210		225		240		210		185

AXIS				Distance		Temperature		Extraction and discharge		Seasonal performance of installation		Size and layout of the GHPS installation		Subsurface conditions		
100		0	200	210	191	215	241	230	193	120	239	160	157	220	252	WS
400	100	200	0	150	205	210	235	225	185	240	265	210	265	185	300	TO
				WT	SO	WT	SO	WT	SO	WT	SO	WT	SO	WT	SO	

Table 3: SWOT Analysis - Scoring of Planning tools

Strengths	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Germany [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Adaptability to urban and rural areas	15	2	30	3	45	3	45	3	45
Application for different GHP systems (open and closed systems)	10	3	30	1	10	1	10	3	30
Free access	20	3	60	1	20	3	60	3	60
Performance measurement	10	2	20	2	20	2	20	2	20
Detailed modelling results	15	2	30	2	30	2	30	2	30
Clear information on calculation results	10	3	30	3	30	2	20	2	20
Functionality for handling calculation or modelling errors	5	2	10	2	10	2	10	1	5
Incorporation of local norms and standards	5	3	15	3	15	3	15	3	15
Integrated geothermal databases	10	2	20	2	20	3	30	2	20
Total	100		245		200		240		245

Weaknesses	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Germany [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Difficult tool to understand and execute	20	1	20	1	20	1	20	1	20
Operational problems of the tool	15	1	15	1	15	1	15	1	15
Require advanced hardware	10	1	10	2	20	1	10	1	10
Large amount of required data for the calculations	15	2	30	1	15	2	30	2	30
Restrictive calculation results for future installation	10	1	10	1	10	2	20	2	20
Constraints and restrictions to upgrade and innovate	10	2	20	2	20	2	20	1	10
Limited handling/processing of information for large-scale or complex projects	20	2	40	2	40	2	40	2	40
Total	100		145		140		155		145

Opportunities	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Germany [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Consolidation of the planning tool to be used in mature markets	15	3	45	3	45	3	45	3	45
Transfer of tool usage to other regions/jurisdictions	15	3	45	3	45	3	45	2	30
Facilitates decision-making	20	3	60	3	60	3	60	3	60
Use of local and regional resources	10	2	20	2	20	2	20	2	20
Integration into energy action plans	15	3	45	3	45	3	45	3	45
Map and plan heating and cooling energy demand based on sub-surface resource data	15	3	45	3	45	3	45	3	45
Development of long-term energy supply	10	3	30	3	30	3	30	3	30
Total	100		290		290		290		275

Threats	Weighting (out of 100)	Score I1 Austria [0 to 3]	P x I1	Score I2 Temperature [0 to 3]	P x I2	Score I3 Sweden [0 to 3]	P x I3	Score I4 The Netherlands [0 to 3]	P x I4
Changes in European policies	15	2	30	2	30	2	30	2	30
Expensive regulatory requirements	15	2	30	3	45	3	45	2	30
Changing energy needs	10	3	30	2	20	2	20	2	20
New planning tools emerge	20	2	40	2	40	2	40	2	40
Requirement for constant updating and maintenance of planning tool	20	3	60	3	60	3	60	1	20
Lack of data availability in the area of future installation	20	3	60	2	40	2	40	2	40
Total	100		250		235		235		180

AXIS				Austria		Germany		Sweden		The Netherlands		
100		0	200	145	245	140	200	155	240	145	245	WS
300	100	200	0	250	290	235	290	235	290	180	275	TO
				WT	SO	WT	SO	WT	SO	WT	SO	

Deliverable D3.2 - Integration of GHPs into Energy Action and Spatial urban Planning

Executive overview

This deliverable frames geothermal heat pumps (GHPs)—open-loop groundwater systems and closed-loop ground heat exchangers—as technologies that must be planned "spatially," not only on a building-by-building basis. Its core contribution is a practical bridge between energy action planning (targets, funding, decarbonisation pathways) and spatial urban planning (zoning, infrastructure layout, land-use constraints). D3.2 proposes a repeatable workflow: quantify heating/cooling demand, map the current supply, assess shallow geothermal potential, define priority areas, translate priorities into measures, then monitor and adapt. The text also shows how this logic works in real administrations via good practices from Vienna (Heat Plan 2040 + Geothermie-Atlas) and Bavaria/Munich (Energie-Atlas Bayern + groundwater potential planning).

Strategic context and objectives

The report positions GHPs as a key renewable heating and cooling option for meeting climate goals (Paris Agreement, EU climate neutrality by 2050, Fit for 55). It argues that the heat transition is inherently local: geology, groundwater, building stock, and existing networks vary strongly across cities. Energy planning therefore needs bottom-up detail to avoid generic "one-size-fits-all" rollouts. The stated objectives are to (1) describe policy/requirements for spatial energy planning, (2) propose a workflow to integrate GHPs into spatial planning procedures, and (3) present methods for shallow geothermal potential analysis and good practice implementation. The ambition is not to replace engineering design, but to make geothermal "plannable" at city and region scale.

Planning scales and policy drivers

A key strength is the clear separation of scales. At European and national levels, planning is framed as target-setting, regulation, and large infrastructure strategy (e.g., renewable targets in heating/cooling, building renovation direction, governance and reporting). At regional and local levels, the emphasis shifts to spatially distributed datasets: demand density, building typologies, subsurface properties, and permitting constraints. The report highlights that spatial city planning and energy planning overlap in infrastructure siting, cost avoidance (early integration prevents expensive retrofits), resilience, and stakeholder coordination. In practice, this means geothermal is treated as part of a city's "energy morphology," like district heating corridors or grid reinforcement zones.

Stakeholder ecosystem and responsibilities

The stakeholder chapters distinguish policy actors (strategic and regulatory roles) from target groups (implementers and adopters). At European/national scale, governments, regulators, urban planning institutions, utilities, industry associations, and research bodies shape the enabling environment through standards, incentives, and administrative processes. At local scale, city departments, planners, consultants, universities, energy providers, and community organisations become decisive for data collection, zoning, permitting, and acceptance. This separation is useful because geothermal deployment often fails not on technical feasibility, but on missing coordination: who owns subsurface data, who approves wells, who pays for monitoring, and who manages thermal conflicts between neighbours.

Workflow for integrating GHPs into spatial planning

The proposed workflow is the backbone of the deliverable. It begins with demand analysis to understand what must be supplied, then maps the current supply to identify gaps and lock-ins. Next, renewable potential—especially shallow geothermal—is assessed with explicit methods and constraints. Demand, current state, and potential are overlaid to identify priority areas (where geothermal can deliver high impact and where fossil systems dominate). Measures are then defined (regulation, incentives, technical guidance, training, pilot projects, network development). Finally, monitoring and adaptation close the loop so planning remains dynamic rather than a one-off study. This sequence is realistic for municipalities because it mirrors how planning approvals, budgets, and infrastructure decisions are actually made.

Heating and cooling demand analysis

The demand chapter is method-rich and practical. At regional scale, it lists energy-balance approaches, GIS-based demand modelling, and statistical analysis of consumption data; for cooling, it adds Heating and Cooling Degree Days and simulation models. At local scale, it emphasizes building energy simulation, plus top-down and bottom-up approaches to allocate demand by typology and occupancy. A valuable "warning label" is included: many demand/capacity methods overestimate real needs, which risks oversizing geothermal systems and degrading performance economics. The report implicitly encourages municipalities to use demand analysis as a planning baseline, then progressively refine it with measured data (audits, smart meters, calibrated archetypes).

Current state analysis and baseline diagnostics

The "current state" section formalizes what cities often lack: a structured inventory of existing heating/cooling systems, their locations, and the share of demand they cover. It specifies data categories (consumption, supply mix, infrastructure condition, environmental emissions) and proposes procedures: validation across sources, GIS mapping, capacity/efficiency assessment, and stakeholder consultation. Importantly, it highlights system-temperature realities—GHPs perform best with low-temperature emitters—so a city must map not only fuels but also heat distribution readiness. The Trias Energetica framing (reduce demand, use renewables, minimize fossil primary energy) helps keep measures consistent across planning departments.

What "potential" means and why definitions matter

A major conceptual contribution is the insistence on defining "potential" clearly. The report separates theoretical potential (physical heat in the ground) from technical constraints, then from realizable potential (after ecological, social, and regulatory limits), as is seen in figure 10. It also recommends treating economic feasibility separately because prices, drilling costs, and financing conditions are volatile—meaning "economic potential" can change faster than geology. This structure prevents misleading maps that look impressive but cannot be permitted, accepted, or implemented. It also aligns well with spatial planning practice where exclusion zones, depth limits, and minimum distances are often the true binding constraints.

Methods toolbox for shallow geothermal potential

The potential analysis chapters offer a catalogue of methods by system type and scale. For open-loop (GWHP), it describes approaches that estimate extractable energy from groundwater flow and allowable temperature change, including the TAP method that formalizes drawdown, injection constraints, and hydraulic short-circuit prevention. For closed-loop vertical systems, it presents analytical sizing (e.g., ASHRAE-type equations) combined with GIS mapping and regulation limits, plus VDI-based tabular extraction rates. For horizontal collectors, it outlines soil- and climate-driven methods integrating soil properties, moisture, heating degree days, and DEMs. For geostructures (energy piles/tunnels/walls), it includes GIS suitability zoning, volumetric capacity estimates, and explicit attention to thermal interaction in dense urban settings. Overall, the toolbox is most valuable as a "method menu" for authorities deciding what level of complexity fits their data and budget.

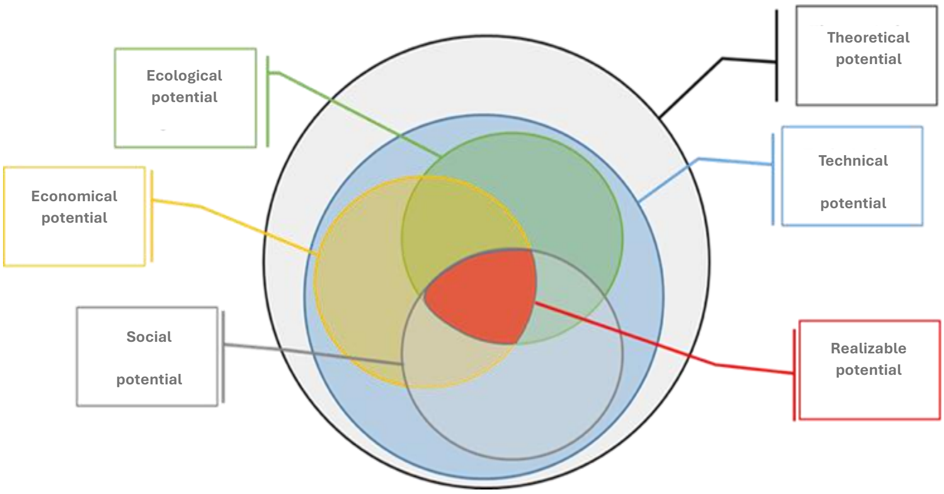

Figure 9: Potential terms from the results report of the 2018 Energy Summit

(Bavarian State Ministry of Economic Affairs, Regional Development and Energy, 2019).

From potential maps to priority areas

The priority-area concept is where planning becomes actionable. The report proposes overlaying demand, current system status, and potential (with constraints) to identify where geothermal can deliver high decarbonisation impact. Regional criteria include political targets, technical potential, demand deficits, economic feasibility, energy price/incentive context, and supportive policies. Local criteria add urban constraints (space, infrastructure conflicts), licensing rules, community participation, and joint planning with landowners and developers. The text strongly suggests multi-criteria decision frameworks supported by GIS, which is realistic because geothermal suitability is rarely determined by a single variable like thermal conductivity alone.

Defining measures at regional and local scale

Measures are structured as implementation packages rather than isolated actions. At regional scale, the report emphasizes coherent regulation, digitized permitting, subsidy/finance schemes, integrated planning across agencies, workforce training, and evaluation frameworks (installed capacity, emissions, savings, energy supplied, systems replaced, socio-economic impacts). At local scale, it recommends simplified licensing guidance, pilot projects and “geothermal zones,” citizen participation mechanisms, local incentives, and practical monitoring requirements. A strong message is that capacity building (installers, planners, authorities) is as important as mapping—because poor installation quality or inconsistent approvals can undermine market confidence quickly.

Monitoring and adaptation as an operating system

Monitoring is treated as essential governance, not an optional add-on. At regional scale, the report proposes KPI definitions, centralized databases, predictive analytics and IoT-enabled data flows, periodic reporting, compliance checks, and structured adaptation steps (identify needs, implement measures, evaluate effectiveness). At local scale, it emphasizes tailored monitoring objectives (subsurface temperatures, groundwater quality, efficiency, demand coverage), public reporting, and stakeholder feedback loops (see figure 11). This is particularly relevant for shallow geothermal because cumulative effects (thermal interference, long-term temperature drift) are spatial and time-dependent—meaning performance and sustainability must be managed like shared infrastructure.

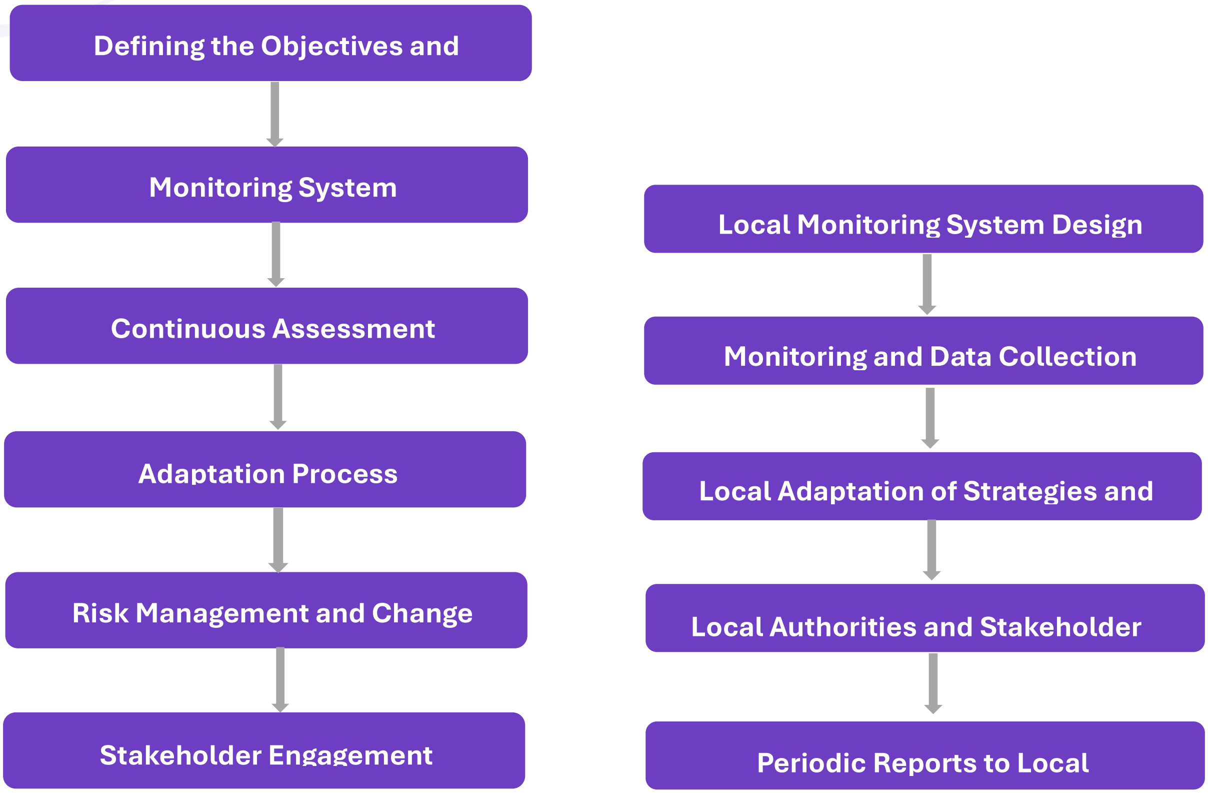

Figure 10: Monitoring and adaptation procedure at regional (left), and at Local scale (right)

Good practice synthesis: Vienna and Bavaria/Munich

Vienna Heat Plan 2040 demonstrates energy spatial planning in a form that residents and developers can use: mapped zones indicating district heating today/future and where local collective or individual solutions (including GHPs) are preferred. The Geothermie-Atlas* then operationalizes this with parcel-level tools that let users sketch borehole fields, set spacing/depth/hours, and obtain indicative heating/cooling potential with a multi-borehole thermal model and long-term temperature forecasts. Bavaria/Munich adds a second strong pattern: building-stock modelling and heat registers for demand, white-area mapping for exclusion zones, TAP-based groundwater potential at parcel and block scale, and an added economic feasibility filter so maps do not recommend systems likely to be uneconomic. Together, these cases show how “top-down zoning” and “bottom-up project planning” can be made consistent.

* https://www.lfu.bayern.de/geologie/geothermie/geothermie_tief/geothermie_atlas/index.htm

Figure 11: Different areas of the Vienna Heat Plan 2040.

Underlying data: City of Vienna – Energy planning (MA 20), Wien Energie, Wiener Netze. Base map: City of Vienna – data.wien.gv.at (left). Screenshot showing the main functionality and BHE potential results provided by the Geothermal Atlas (Geothermie-Atlas). Source: https://geothermieatlas.geosphere.at/ (right)

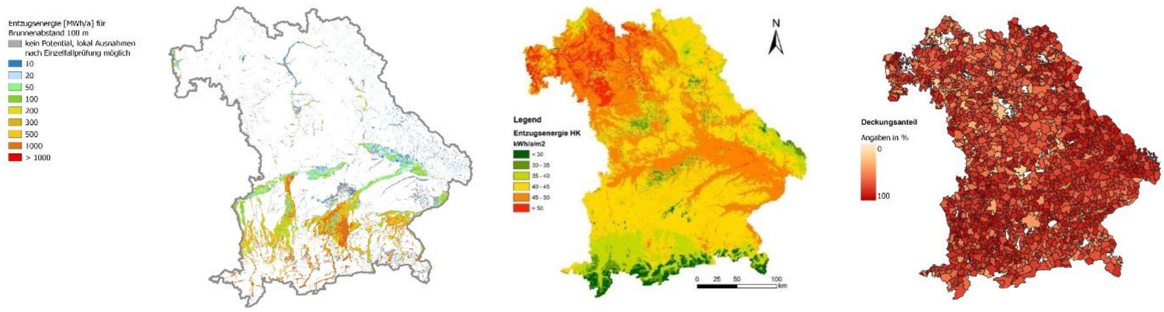

Figure 12: Bavaria-wide energy extraction (MWh/a) for groundwater heat pumps,

Well, spacing 100 m, (left). Calculated extraction energy for horizontal collectors, (middle). Wide potential for shallow geothermal energy per municipality after energy-efficient refurbishment (right).

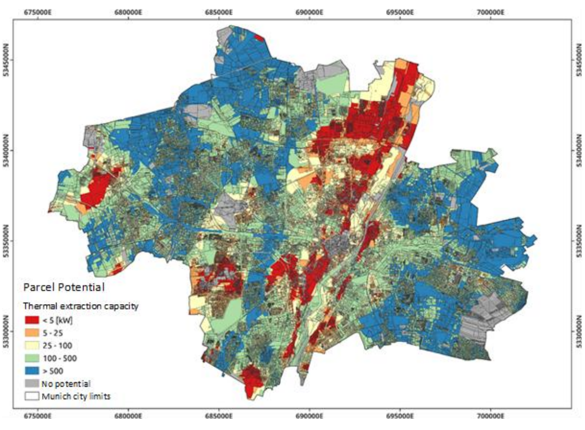

Figure 13: Result of the parcel-specific potential analysis,

The technically realizable thermal extraction capacity on the respective parcel was calculated.

Review highlights and improvement points

The deliverable is strongest where it turns abstract climate targets into a practical planning sequence and where it insists on clear definitions (potential, constraints, scale). It also rightly treats data and governance GIS layers, validation, stakeholders, monitoring—as core infrastructure for geothermal rollout. The main limitation is that older method catalogues can seem like parallel options, lacking a clear rule for selecting the "right" method given specific data availability, uncertainty, and budget constraints. A second gap is deeper treatment of uncertainty management (confidence levels on maps, sensitivity ranges, and how to communicate them to non-experts). Finally, while thermal interference is acknowledged, it could be tied more explicitly to permitting thresholds and to shared governance mechanisms in dense cities (rules for spacing, load balancing, and mandatory reporting).

The text argues convincingly that scaling GHPs is less a question of single-building design and more a question of planning systems: rules, maps, workflows, and feedback loops that let many projects coexist safely in the subsurface. Its workflow and good practices offer a realistic template for municipalities: build a demand and baseline picture, map realizable potential with constraints, steer development via priority zones and measures, and keep the plan alive through monitoring and adaptation.

Deliverable D3.3 - Guidelines and procedures for reducing licensing barriers

Purpose and audience of the guideline

This deliverable positions licensing reform as a practical lever to accelerate geothermal heat pumps (GHPs) in Austria, Germany, Ireland, Poland, Spain, Sweden, and the Netherlands. It targets public authorities (local–national regulators, permitting offices, technical monitoring bodies) while also serving the private sector (developers, drillers, designers) by clarifying expectations and reducing "process risk." The stated ambition is not just faster permits, but clearer, more consistent procedures and stronger compliance capacity. A key strength is the explicit linkage to wider EU relevance, aiming to convert "country lessons" into transferable patterns. The text reads as a bridge between policy principles and operational workflow design, with a strong emphasis on actionable simplification rather than abstract advocacy.

Why licensing is the bottleneck (not the technology)

The motivation chapter frames GHPs as mature, efficient, and climate-relevant, yet unevenly adopted because administrative friction often dominates project timelines and costs. The report argues that "zero-risk" regulation is unrealistic and can unintentionally block a technology that brings system-level public benefits (decarbonisation, energy security, local value creation). It identifies the typical pain points: multiple approvals, inconsistent requirements, unclear thresholds, and slow or unpredictable timelines especially acute in dense urban settings and protected zones. This is a convincing framing because it treats permitting as a cost driver and an investment signal, not merely a legal formality. The guideline implicitly promotes a risk-managed enabling approach: protect groundwater and subsurface assets while keeping procedures proportionate.

Analytical lens: turning RED principles into checkable criteria

A solid methodological move is operationalising the Renewable Energy Directive (RED) "streamlining" intent into concrete assessment criteria: one-stop shops, online submission, maximum deadlines, tacit/automatic outcomes, small-project pathways, and identification of suitable areas. The report strengthens this by adding a structured evaluation grid (legal basis → licensing steps → approval entities and documents → monitoring/decommissioning → decision-support tools). This converts policy ideals into auditable features of real permitting systems. It also anchors the analysis in prior EU projects (GRETA, GeoDH, GeoPLASMA-CE, etc.), which helps continuity and reduces "reinventing the wheel.

Open-loop systems: the sharpest cross-country contrasts

For open-loop systems (OLS), the tables show large divergence in timing, institutional complexity, and monitoring. The Netherlands stands out with short processing (weeks) and strong monitoring obligations, while Spain and parts of Germany can reach many months. Austria and Sweden appear less time-defined. Across countries, OLS tends to trigger stricter scrutiny because of abstraction/reinjection and perceived groundwater risk, and this drives heavier documentation (hydrogeology, risk plans, EIAs). The review usefully highlights that fragmented institutional involvement is often the real delay mechanism, not the technical study itself. A key takeaway: OLS frameworks need clearer national thresholds and integrated workflows, otherwise the same project may face different burdens depending on region.

Closed-loop systems: faster, but often "under-governed"

Closed-loop systems (CLS) generally face lighter licensing than OLS, but the report reveals a structural trade-off: easier approvals sometimes mean weaker traceability and poorer system governance. Austria's notification approach in non-sensitive areas accelerates deployment but may miss thermal-interference and planning issues if no water right/registry safeguards exist. Germany's federal variability can lead to differing interpretations and uneven monitoring expectations, especially in urban contexts where additional simulations may be required. The Netherlands again appears as the most systematised (protocols, interference concepts, performance/impact studies). The guideline correctly implies that "simpler" should not mean "blind"; it should mean proportionate, standardised, and well-instrumented.

Best practices by country: what "good" looks like in practice

The best-practice section is most valuable when it specifies mechanisms, not slogans. Austria's mapping and clearer published requirements reduce early-stage uncertainty; Germany's partial digitalisation and integrated reviews in some states reduce duplicative checks; Ireland's abstraction thresholding provides a crisp trigger for licensing; Poland's fast-track and indefinite permits can cut bureaucracy (though governance gaps remain); Spain's regional one-stop experiments and online portals show workable pathways despite fragmentation; Sweden's simplified residential approach supports uptake; and the Netherlands demonstrates an end-to-end model portal-based procedures, interference zoning, strong monitoring, and defined technical requirements. The report also highlights "soft infrastructure" best practices: applicant support, accessible guidance, and authority responsiveness. A useful improvement would be to rank these practices by transferability (easy to copy vs. dependent on national legal structure).

Country lessons: five patterns that matter most

Across the comparison, five recurring "system design" patterns emerge. First, digital one-stop shops reduce transaction costs and improve transparency. Second, tiered risk-based procedures (small/low-impact vs large/sensitive) prevent over-regulating routine projects. Third, explicit time limits (and clear consequences) reduce investor uncertainty. Fourth, zoning/decision tools (maps, interference zones, restricted areas) shift conflict detection to the pre-application phase, saving time for both applicants and authorities. Fifth, monitoring and registries determine whether the sector becomes governable at scale without data, policy learning and interference management remain weak. The document makes a strong case that these patterns can be mixed and adapted even in federal or decentralised systems, as long as minimum national standards and interoperable processes exist.

Barrier anatomy: licensing, administrative, regulatory (and why it matters)

A central strength is the three-part barrier classification. Licensing barriers capture applicant-facing burdens (documents, permits, unclear validity); administrative barriers describe institutional workflow failures (multiple entities, lack of coordination, no deadlines, limited digitisation); regulatory barriers cover unclear rules, missing geothermal-specific provisions, weak monitoring, and planning gaps. This separation helps avoid "blaming" applicants for problems caused by governance design. It also clarifies interventions: digitisation does not fix legal ambiguity; stricter technical standards do not fix inter-agency duplication; and faster deadlines do not automatically improve environmental outcomes if screening remains unclear. The tables make the pattern visible: many countries suffer less from a single bad rule than from inconsistent handoffs between authorities.

OLS barriers: uncertainty, documentation overload, and coordination drag

For open-loop, the recurring issues are predictable but well evidenced: long or undefined processing times, heavy hydrogeological documentation, multiple authorities, and inconsistent monitoring/data management. Germany's 3–12 month range and urban/protected-zone constraints illustrate how risk sensitivity translates into procedural friction. Spain's regional variability plus multi-permit structure amplifies uncertainty for developers operating across regions. Austria's limited online platforms and non-standardised monitoring data storage suggest that governance capacity can lag behind market needs; however, water authorities do grant scientists access to their datasets, enabling excellent analyses. Poland's case-by-case approach and lack of e-procedures create both delay and subjectivity risk. The guideline correctly emphasises that OLS needs clearer national frameworks, integrated permitting, and transparent reinjection/temperature rules otherwise every project becomes a bespoke negotiation.

CLS barriers: variability, missing registries, and "quality risk"

Closed-loop barriers are often about inconsistency and long-term governance rather than immediate environmental risk. Germany's state-by-state forms, non-mandatory standards, and varying monitoring expectations create a moving target for applicants. Austria's non-licensing in non-sensitive areas speeds deployment but weakens interference visibility and undermines sector statistics an important point for policy credibility. Sweden's permit validity limits and fragmented responsibilities increase rework and uncertainty, particularly in cities. Poland's additional mining-related requirements over 100 m and lack of monitoring rules highlight how depth thresholds can create administrative cliffs. The Netherlands shows the opposite risk: high technical and monitoring obligations can deter new entrants unless paired with applicant support. The report's implicit message is right: CLS should be simple for low-risk cases, but never "invisible" to planners.

Consequences: delays, stranded projects, and investment aversion

The impact section connects governance to real market outcomes. Delays and uncertainty can freeze projects, especially where multiple permits stack (hydrogeology, water use, EIA, construction). Developers may avoid urban/protected zones not only because of technical constraints, but because the permitting path is hard to predict. Investors interpret inconsistent rules as non-technical risk, favouring alternatives with clearer approvals even if performance is worse. Administrative costs studies, certifications, repeated submissions become a barrier for SMEs and residential-scale uptake. Authorities also suffer: manual processing, insufficient trained staff, and lack of monitoring databases reduce oversight quality and erode trust. The report is strongest here because it treats the permitting system as an ecosystem: if authorities are overburdened, the market slows, and climate targets get harder.

What "simplification" should mean (a critical reading)

The guideline consistently argues for simplification, but it also warns sometimes indirectly against oversimplification that removes safeguards or data. The best interpretation is: simplify the pathway, not the responsibility. In practice, that means: fewer duplicated steps, clearer thresholds, standardised templates, and digital workflows; plus proportionate monitoring, registries, and interference-aware planning. The text is also careful about automatic approvals: it notes deadlines are essential, but full "automatic permit" can be controversial in environmental contexts. A stronger editorial stance could help: propose "provisional/conditional approvals" with mandatory monitoring for low-risk cases, rather than binary automatic approval or indefinite waiting. This would preserve protection goals while eliminating paralysis.

General solution package for OLS: the minimum viable reform set

For open-loop, the proposed toolbox is coherent: national-level licensing procedures, tiered EIA triggers, integrated permits, digitised templates, and maximum deadlines. The one-stop-shop concept appears as the central enabler, because it reduces inter-agency friction and improves applicant experience. The recommended additions training officials, public awareness, and digital registries recognise that process reform needs capacity and legitimacy. The strongest elements are the risk-based tiering and coordinated permitting, which directly address the biggest cost and time drivers. A potential gap is operational detail: the report could specify "standard hydrogeology study tiers" (what's needed at what abstraction/setting) to prevent under- or over-study. Still, the direction is practical and aligned with the RED's administrative barrier removal intent.

General solution package for CLS: keep it light, but keep it visible

For closed-loop, the recommendations aim to remove unnecessary burdens (especially for small systems) while strengthening consistency and data. Key proposals include national standard forms, digitised submissions, clearer rules for sensitive areas, tiered assessment, and deadlines with sensible review mechanisms. The monitoring/registry push is important: without basic installation records, authorities cannot manage interference, quantify climate contribution, or target incentives effectively. Training officials and providing applicant support appears repeatedly, and rightly. So, many "delays" are interpretation problems. A critical balance point is monitoring: the report suggests proportionate approaches (smart/risk-based monitoring) rather than blanket requirements. This is the most scalable approach for mass adoption: make compliance easy to do correctly, and make oversight data-driven.

Country tailoring: priorities implied by the evidence

The country recommendations largely follow the diagnosed weaknesses. Austria is pushed toward clear deadlines, online platforms, and centralised monitoring data storage; Germany toward national standardisation, full digitisation, and better urban rules; Ireland toward filling regulatory gaps with proportional geothermal-specific frameworks and online one-stop processes; Poland toward e-procedures, standardised criteria, and inter-institutional coordination; Spain toward national harmonisation frameworks that reduce regional variability and improve staff training; Sweden toward time limits, simplified renewals, and stronger cooperation mechanisms; the Netherlands toward reducing friction for small/low-risk cases and adding applicant support to match its technical rigour. The strongest aspect is realism: it does not propose identical reforms everywhere, but modular upgrades matching administrative maturity. A missing piece is prioritisation order ("do these three first"), which would help policymakers sequence reforms.

Implementation and monitoring: from recommendations to measurable change

The implementation chapter is a practical governance guide: define objectives, choose pilots, assign roles, assess staff and funding, and phase actions short–medium–long term. This is valuable because licensing reform often fails at execution, not design. The proposed success indicators are sensible: processing time, administrative cost, licences issued, share of digital processing, compliance outcomes, and stakeholder satisfaction. The emphasis on dashboards, benchmarking, and feedback loops makes the reform measurable and adjustable. The report also integrates change management, communication, incentives for early adoption, and public perception monitoring, which is often omitted in technical guidance. A strong addition would be a "minimum KPI set" that every country can adopt for EU-level comparability, even if local systems differ.

Austria

Austria combines a strong water-law focus (Water Act + "state of the art" via ÖWAV RB 207) with federal-state variability in how "sensitive areas" are defined. OLS are clearly treated as groundwater-use projects (permit + water right), while CLS can be very light-touch in non-sensitive areas (often notification or even no procedure), which accelerates deployment but can weaken visibility of thermal interactions and national statistics. Vienna's planning maps (e.g., geothermal/traffic-light style tools) are a practical strength, but the guideline highlights gaps in deadlines, digitisation, and central monitoring databases.

Germany

Germany's framework is shaped by the Federal Water Act (WHG) plus strong technical practice (e.g., VDI 4640), but real-world permitting is heavily influenced by the 16-state (Länder) structure. OLS typically face the toughest pathway: hydrogeology, risk plans, coordination with water/environment/urban planning authorities, and longer timelines (months). CLS can be quicker but becomes complex in urban areas (extra simulations, protected zones, deeper boreholes triggering additional rules). Best-practice examples include integrated reviews in some states and partial online submission, but variability and uneven digitisation remain major barriers.

Ireland

Ireland stands out for a threshold-based approach on water abstraction: larger abstractions (e.g., >25 m^3/day) clearly trigger EPA-related licensing, while CLS has historically been less explicitly regulated, which reduces friction but creates a regulatory gap (unclear geothermal-specific pathway, monitoring expectations, and long-term quality assurance). The guideline points to ongoing policy development and recommends building a geothermal-tailored framework with clear time limits, a digital one-stop portal, and proportional rules for small domestic systems, so simplification doesn't come at the cost of uncertainty.

Poland

Poland uses a mix of water well / water law logic for OLS and geology/mining rules that can apply to deeper drilling (notably around >100 m or in mining territories). A practical advantage is that some permits can be indefinite and there are fast-track tendencies for certain CLS cases, but the report flags major weaknesses: case-by-case handling, limited inter-agency coordination, and lack of e-procedures. Monitoring tends to focus on abstraction/reinjection quantities (where required), while broader thermal/efficiency monitoring and nationwide registries remain underdeveloped.

Spain

Spain is characterised by strong regional autonomy: permitting requirements and timelines vary significantly by autonomous community, and OLS projects often face multiple approvals (municipal + regional + basin authorities, plus EIAs in many cases). This fragmentation is the core barrier: developers face non-uniform rules, "administrative silence" risks, and long timelines (often many months). Best practices appear where regions implement one-stop approaches and online portals, and where geological/hydrogeological mapping (e.g., MAGNA 50, IGME data) supports early screening. The guideline's central recommendation is a more unified national framework (minimum standards + consistent templates) while keeping regional implementation flexibility.

Sweden

Sweden generally supports deployment through simplified handling for residential CLS, which helps market uptake, but OLS and “larger/complex” cases can escalate to Länsstyrelsen and environmental courts, increasing complexity and unpredictability. The report highlights weak points such as missing statutory time limits, fragmented responsibilities (Kommun → regional agency → court), and limited routine monitoring unless explicitly required. Strengths include growing electronic application options in some areas and strong attention to water protection zones in cities. The guideline proposes tighter deadlines, clearer national standards, easier extensions/renewals, and more structured inter-institutional cooperation.

The Netherlands

The Netherlands is presented as the most “systematised” model: WKOTOOL centralises parts of permitting/registration and provides maps (restricted areas, interference zones), while licensing can be relatively fast (weeks). A defining feature is the strong emphasis on interference management and monitoring (temperature/flow/energy balance reporting, especially for larger systems), which supports governance and long-term sustainability. The trade-off is that high technical and monitoring obligations can be burdensome, especially for smaller actors—so the guideline recommends simplified pathways for small/low-risk systems, clearer public guidance, and better applicant support (helpdesk, templates) to reduce friction without losing control.

Deliverable D4.1 - Ground Source Heat Pumps in Europe: An analysis of the Geothermal Heat Pumps market

Purpose and structure of the deliverable

This report aims to prove the financial value of ground-source heat pumps (GSHPs) using comparable evaluation schemes. It builds a portfolio of representative GHP typologies and "non-GHP" alternatives, then applies life-cycle cost analysis (LCCA) and related metrics. A practical output is an Excel LCC tool that computes NPV and LCOE for GSHP, ASHP, boilers, and district heating. The text combines technology benefits, market snapshots from several EU countries, and a deep dive into methodology. Overall, it is written as a bridge between engineering reality (drilling, SCOP, geology) and investor logic (CAPEX, OPEX, discounting).

Why GSHPs are positioned as a "strategic" heat technology

GSHPs are presented as a core decarbonization option because they can deliver high useful heat per kWh electricity (often COP/SCOP ~3–6). The ground provides a stable source temperature, so winter performance is typically more consistent than air-source systems. This converts into lower operating costs over time, especially where electricity is low-carbon and competitively priced. The report repeatedly frames GSHPs as a system solution: heating + DHW + potential cooling, not just a boiler replacement. A key narrative is resilience: local energy extraction reduces dependence on fuel logistics and price shocks.

Claimed advantages—strong, but not "free"

The advantages chapter emphasizes efficiency, low emissions (with clean power), quiet operation, safety, and long component lifetimes. It also highlights that the ground loop can last decades (often far beyond the heat pump unit), shaping long-term economics. However, the report is honest about the barrier: GSHPs are CAPEX-heavy, with drilling and financing as the biggest obstacles. It notes that ASHPs share many benefits but can suffer winter efficiency drops and weather exposure of outdoor units. The core message is: GSHPs win on lifecycle value, but only if upfront cost and financing friction are addressed.

Sweden as the "mature market" benchmark

Sweden is used as an example of sustained adoption: a very large installed heat-pump base, with GSHPs supplying a notable share of heat. The text links national heating trends to a long decline in primary heating energy despite growing heated floor area. GSHP penetration is presented not as a single cause, but as one part of a broader efficiency story (buildings, refurbishments, awareness). Importantly, Sweden is framed as instructive rather than directly replicable—climate, geology, institutions, and history differ elsewhere. Still, Sweden demonstrates that GSHPs can scale from single homes to larger buildings, not only niche projects.

The “perfect storm” factors behind Swedish success

Several mutually reinforcing drivers are identified: historically high oil dependence, shocks in the 1970s, and policy responses. Cheap electricity supported heat-pump economics, while public R&D helped professionalize design methods and software tools. Early subsidies accelerated household uptake, and a strong domestic industrial base (heat pumps + drilling equipment) lowered barriers. District heating expanded rapidly, but GSHPs still became dominant in many small-building segments as oil disappeared. The key lesson is systemic: markets mature when technology, finance, regulation, and supply chains align—not from one policy alone.

Geology, drilling practice, and permitting—where Sweden is unusually advantaged

Sweden benefits from widespread crystalline bedrock with good drilling conditions and favourable thermal properties. Standardized borehole diameters, efficient rigs, and a competitive drilling sector are described as direct cost reducers. High groundwater occurrence often reduces the need for extensive grouting, and shallow overburden limit the need for expensive casing. Permitting is portrayed as predictable and municipal, with straightforward reporting to the geological survey—low “soft-cost” friction. This chapter quietly underlines a big EU reality: drilling cost is not just geology, it’s also standards, bureaucracy, and market structure.

Recent headwinds—macroeconomics can override technical superiority

The report notes that higher interest rates penalize CAPEX-intensive GSHP investments more than cheaper alternatives. Electricity price increases (relative to district heating or gas) can weaken the operating-cost advantage that GSHPs rely on. Market signals after the Ukraine war are interpreted as a mix of real demand, inventory effects, and construction cycle slowdown. A key insight is that GSHP deployment is sensitive to the cost of capital and to energy price ratios, not only to COP. The Swedish case therefore becomes a warning: maturity does not mean immunity to macro shocks.

Country snapshots—Germany as a reference “mature” market

Germany is described as dominated by gas and oil in the existing stock, with heat pumps growing under policy pressure. The text provides indicative installed costs for gas/oil boilers, ASHPs, and GSHP systems, plus typical household energy prices. Hydronic distribution (radiators/underfloor) is standard, while residential cooling remains limited but is expected to grow. The narrative stresses that policy tools (incentives, CO_2 pricing) and building efficiency upgrades shape the replacement pathway. Germany’s snapshot reinforces the central tension: high electricity prices + high drilling cost can slow GSHP acceleration.

Transitional and emergent markets—shared patterns, different bottlenecks

The Netherlands appear more systemized, with strong hydronic norms and widespread interest in ground energy and free cooling. Ireland is portrayed as heavily shaped by oil/gas in the residential sector, with heat pumps rising but starting from a different baseline. Austria shows a mixed heating landscape (district heat, biomass, gas, and heat pumps) and strong regional variation. Poland's picture emphasizes solid fuels and price sensitivity, with heat pumps still small but growing alongside modernization. Spain is described as climate-diverse with increasing cooling relevance, where GSHP remains a minor share versus ASHP dominance.

Evaluation methods—why LCCA is central but not sufficient alone

The report lists multiple economic lenses: LCCA, NPV, simple payback, ROI, LCOE, IRR, TCO, CBA, and EPC. This is useful because stakeholders differ: households often think in payback, investors in NPV/IRR, policymakers in LCOE and emissions. The text argues that GSHPs are easily undervalued if only CAPEX or payback is used. LCCA is positioned as the fairest method because it includes renewals, maintenance, energy costs, and end-of-life effects. A practical strength of the deliverable is translating these concepts into an accessible tool rather than leaving them theoretical.

The LCC tool—design logic and key assumptions

The Excel tool outputs NPV and LCOE for four technology families: GSHP, ASHP, heat-only boilers, and district heating. To make countries comparable, it uses presets for climate and costs, while allowing user overrides because prices change constantly. System sizing is tied to installed peak capacity; delivered energy is linked to climate indicators (HDD/CDD) and EN 14825 climate zones. The tool does not calculate building physics from scratch; instead it uses simplified residential presets and typical meteorological year data. A major modelling choice is partial peak coverage (e.g., 60%), reflecting common practice to avoid over-sizing CAPEX-heavy GSHP fields.

Table 4: Result generated by the LCC-Tool

Cost Distribution in EUR Period of analysis: 25 Years	GSHP	ASHP	HO Boiler	District Heating	HO Boiler + Equivalent Cooling	District Heating + Equivalent Cooling
Initial Investment:	45693	19970	6040	9048	10540	13548
Future Renewal Cost:	7222	10368	3605	2186	8554	7135
Fuel:	48991	61477	124040	119359	125152	120472
Regular Service:	3626	3626	6593	1813	10219	5439
Major Repairs:	0	0	0	0	0	0
Decomission:	368	184	461	184	567	290
Residual:	-26959	-3456	-1202	-2936	-3008	-4743
Total NPV:	**78942**	**92169**	**139537**	**129654**	**152024**	**142141**
LCOE [EUR/MWh]:	65	76	119	111	125	117

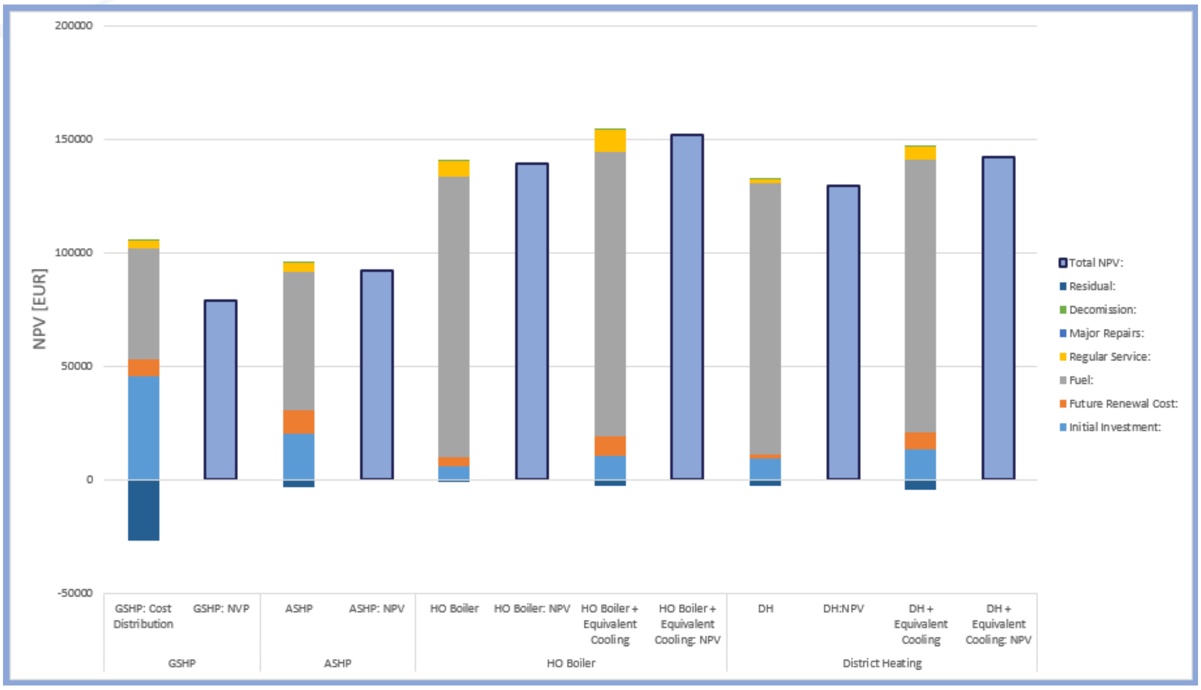

Figure 14: Illustration of heating and cooling solution cost presented by the LCC-tool.

NPV (Nett Present Value)

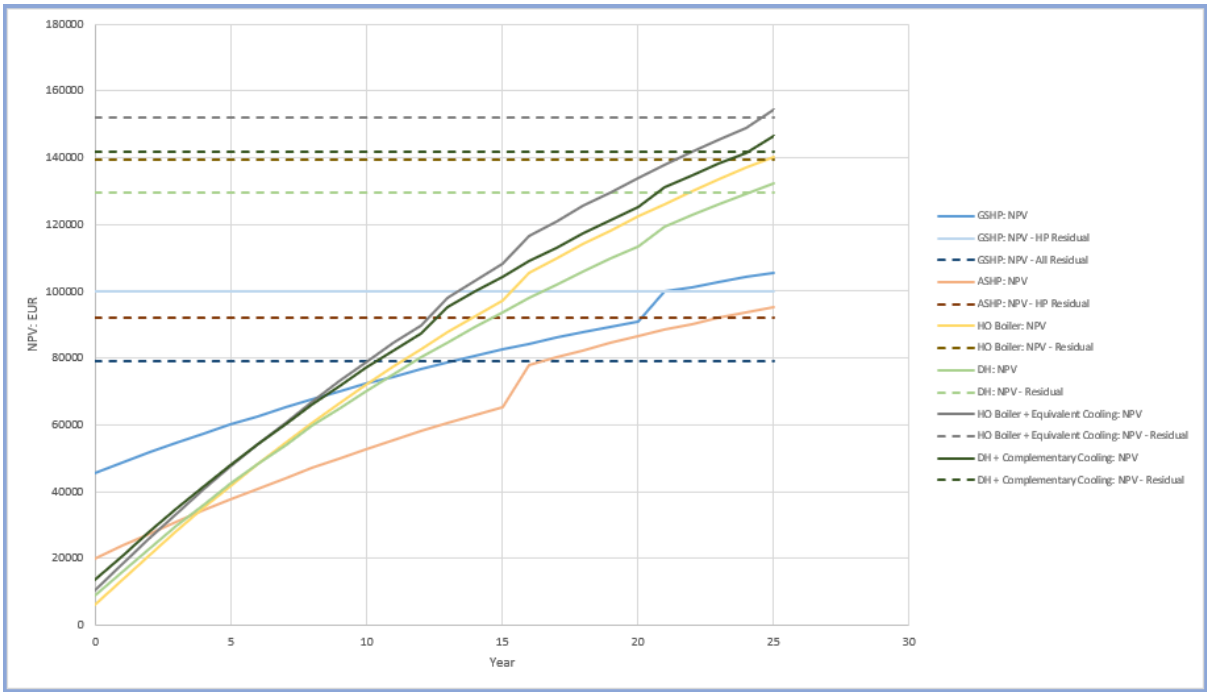

Figure 15: Progression of the NPV

The analyzed heating and cooling solutions is generated by the LCC-tool.

	ASHP	HO Boiler	DH	HO Boiler + Equivalent Cooling	DH + Equivalent Cooling
GSHP Paybacktime* [Years]:	38	10	10	8	8

*Without residual value

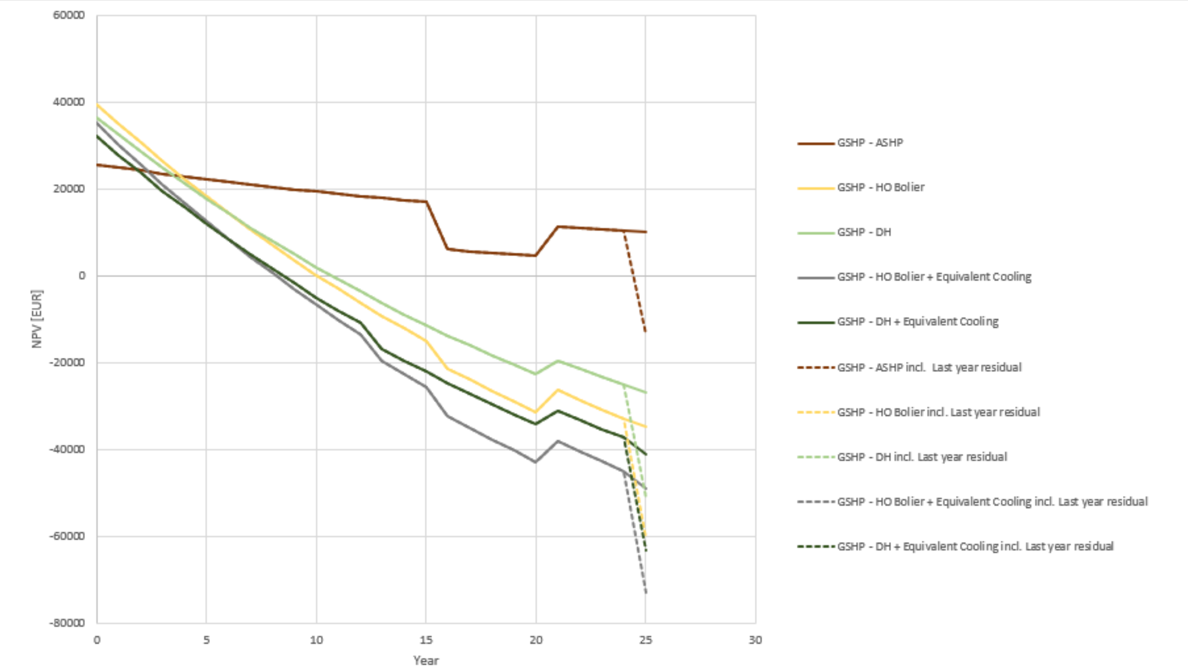

Figure 16: Illustration of the progression of the NPV:

It is used a cash -flow approach comparing GSHP to other heating solutions generated by the LCC-tool.

GSHP parameterization—where engineering drives economics

Borehole-field cost is computed from €/m drilling and total required depth, which is sensitive to conductivity and heat-pump SCOP. The tool allows thermal conductivity bands (e.g., 2–4 W/mK) and links SCOP to supply temperature (35 °C vs 55 °C). Borehole depth requirements are supported by Earth Energy Designer simulations across multiple scenarios (heating, DHW, cooling). Component lifetimes and major repairs are user-selectable, with minimum thresholds to prevent unrealistic inputs. This chapter makes the report's strongest point: GSHP economics are not generic—they depend on site, design, and operating strategy.

Reading results—why residual value and cooling change the ranking

Outputs include stacked cost allocation, NPV progression over time, and "payback vs alternative" cash-flow comparisons. Residual value can strongly favour GSHP when boreholes are assumed to retain value beyond the analysis horizon. ASHP and boilers can show NPV jumps when renewals occur within the period, highlighting lifecycle penalties of short equipment life. Cooling is treated carefully: GSHP/ASHP can provide it, while boilers and district heating need add-on cooling costs for fair comparison. The report's modelling philosophy is consistent: comparisons must represent equivalent service (heat + sometimes cooling), not only fuel use.

What the worked examples really demonstrate

The example tables show GSHP vs ASHP vs gas boiler outcomes under different drilling costs, electricity prices, and financing costs. A recurring finding is that high drilling cost + high WACC can erase GSHP's OPEX advantage, especially against ASHP. Another finding is that the electricity-to-gas price ratio is pivotal for GSHP competitiveness versus gas boilers. When electricity becomes expensive, GSHP often improves relative to ASHP (higher COP), but can worsen versus gas (cheap fuel + low CAPEX). The examples successfully turn a policy debate into a numeric one: if you want GSHP scale, manage drilling cost and cost of capital.

Discussion—policy and market levers implied by the report

The text argues that decarbonization logic alone will not drive adoption if consumers face high upfront costs and expensive financing. It suggests practical levers: low-interest loans, stable subsidies, predictable permitting, and competition-friendly drilling markets. Cross-country drilling costs are used to argue that lower cost levels are achievable (via better processes, standards, and market entry). CO_2 pricing is framed as a tool to rebalance OPEX comparisons versus gas, but electricity affordability remains essential. The closing takeaway is pragmatic: GSHPs are a high-value long-life asset—make the upfront pathway easier, and the lifecycle wins follow.

Overall assessment—strengths, limitations, and what to improve next

Strengths: clear value narrative, a concrete tool, and an excellent demonstration that CAPEX/OPEX trade-offs must be evaluated over time. The Swedish chapter is especially effective because it connects technology adoption to institutions, geology, and supply chains. Limitations: several country snapshots mix "hard data" with estimates, and comparability is uneven (especially for district heating). The preset approach is sensible for usability, but it risks overconfidence if users do not override outdated energy prices. Next improvement would be tighter, sourced datasets per country (cost bands, SCOP ranges, drilling scopes) and explicit uncertainty ranges.

Deliverable D4.2 - Report on the financial framework including a catalogue of strategies and measures for fostering future investments

Purpose and scope of The Deliverable

This deliverable focuses on the financial framework behind GHP uptake. It first maps national subsidy frameworks in seven partner countries using a structured questionnaire. It then introduces a new affordability score to compare heating/cooling options across countries and building types. Finally, it catalogues finance mechanisms beyond classic grants (on-bill, HaaS, performance pay, tariff reform, etc.). The intended readers are policy makers, investors/financiers, and market actors who need actionable levers. A consistent theme is bridging the CAPEX–OPEX mismatch that blocks GHPs despite strong lifetime economics. Overall, the report is both a stocktake and a proposal toolkit for scaling investment.

What the report does especially well

It separates “what exists today” (subsidy mapping) from “what would work structurally” (mechanism catalogue). The country narratives avoid getting trapped in short-lived exact grant amounts and instead stress program design. The affordability score is built to be replicable, with code referenced via Zenodo. Uncertainty is treated explicitly via Monte Carlo (input variability + disagreement on expert weights). The EPIC scenario is a clean sensitivity test: it isolates how an efficiency-tiered CAPEX grant would shift rankings. The discussion links finance design to real-world frictions: liquidity, bureaucracy, policy stop–go, split incentives. This makes it more useful than a purely descriptive subsidy overview.

Evidence base and data strategy

The subsidy mapping uses one questionnaire per country, plus follow-up clarification where needed. This creates comparability but also means national narratives reflect the completeness of partner inputs. For the affordability score, macro variables come from Eurostat (income, GDP/capita, employment, HICP, energy prices). Technology costs (CAPEX/OPEX/LCOE) come from GeoBOOST’s D4.1 LCC tool, with harmonised assumptions. Purchasing power differences are handled via Price Level Indices, improving cross-country fairness. A key boundary choice: the score excludes heat-distribution upgrades (radiators/pipework), which can be decisive. That keeps the model tractable, but it can understate retrofit complexity in older building stock.

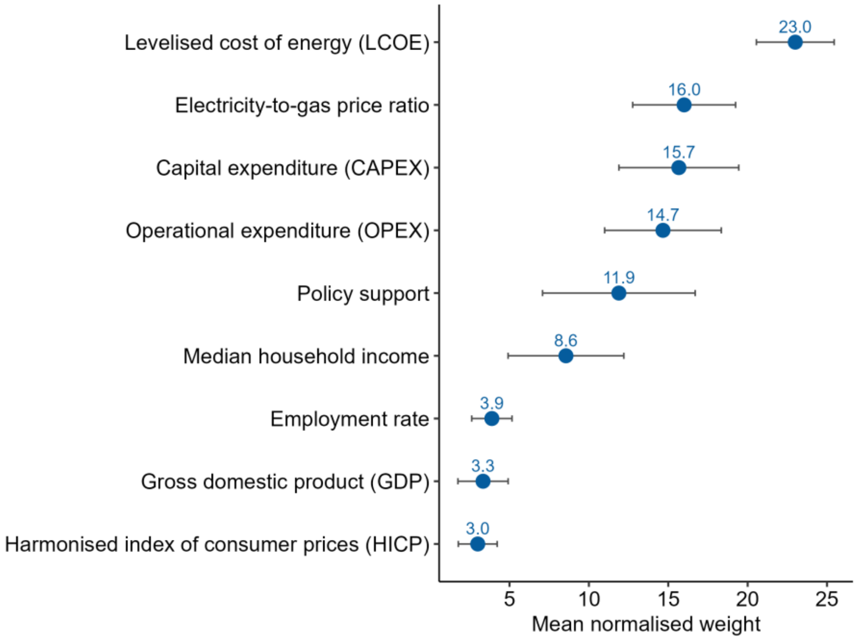

Figure 17: Mean normalised weights and variability for each factor.

This plot displays the average weight assigned to each factor (represented by blue points). Horizontal error bars denote the standard deviation, showing the variability in the weight assignments from the geothermal experts.

Austria's subsidy architecture and key frictions

Austria's framework is broad (multiple schemes) with strong grant rates and targeted support for low-income groups. The portfolio covers several renewable options, with drilling bonuses and technical quality conditions (EHPA seal, GWP limits). A notable strategic signal is district-heating prioritisation where feasible, with HPs supported as alternatives. The report highlights a core equity problem: most schemes are reimbursement-based, requiring full pre-financing. This can exclude precisely the households meant to benefit, unless bridge finance or invoice-level discounts exist. Another constraint is that schemes implicitly prefer direct ownership, limiting HaaS/leasing structures. The critique is balanced: accountability is preserved, but inclusiveness and business-model innovation are constrained.

Germany's support model and its structural trade-offs

Germany is presented through BEG (with layered bonuses + KfW financing) and progres.nrw for shallow geothermal. The design is robust: base rates plus bonuses (income, speed, efficiency) can raise funding substantially. As in Austria, reimbursement timing creates a liquidity hurdle, especially for households without savings/credit access. The report also flags the policy stance that often favours district heating in dense areas, with lock-in concerns. Administrative demands and the separation of envelope/emitters from heating support can increase transaction costs. Innovation (leasing/HaaS) isn't strongly enabled, even if not explicitly forbidden. The recommended direction is clear: hybrid disbursement, simplification, integration of "auxiliary upgrades," and model diversity.

Ireland's grants: performance logic with practical bottlenecks

Ireland combines non-domestic support (SSRH) and domestic grants plus a retrofit loan scheme. A strength is the SSRH logic: the grant rate links to SPF/COP, nudging quality and performance. But the report notes that applicants still face upfront costs and reimbursement delays, which hit low-income groups hardest. Feasibility studies and third-party assessments can add cost and depend on consultant competence in GHPs. Domestic applicants often need insulation first, creating multi-grant sequencing that can discourage participation. The assessment also points to imperfect reflection of GHP vs ASHP cost and significant efficiency differences not being reported accurately. Suggested improvement: simplify pathways, enable business models, and consider dedicated electricity tariffs for HP operation.

Netherlands: mature open-loop strength, mixed signals for small GHPs

The Dutch framework mixes purchase subsidies, tax deduction, and preferential loans (Warmtefonds). A distinctive driver is the "gas-less" transition, reinforced by seismic impacts from historic gas extraction. Large-building markets are shaped by ATES, which already holds a strong competitive position (especially for cooling). For small closed-loop GHPs, the report highlights a tension: ASHPs get substantial support despite lower CAPEX. Budget caps ("first come, first served") can produce stop–start cycles once funds are depleted. The narrative suggests subsidies help, but adoption also depends on regulation, performance assessment rules, and system value. Overall, the Netherlands shows how policy can support HPs broadly while still leaving GHP competing on upfront price.

Poland: ambitious targeting, but instability and quality-control gaps

Poland's framework centres on residential transition away from coal, via Clean Air, My Heat, and a tax deduction. The strengths are strong decarbonisation intent and income-tiered support, including (at times) pre-financing options. Digital applications reduce friction compared to paper-heavy systems, and regional add-ons can improve local fit. However, the report stresses policy volatility: suspensions and frequent rule changes undermine trust and planning. Administrative delays and strict eligibility can exclude older buildings without deep renovation capacity. A sharp critique concerns product listing and verification: reliance on the ZUM list without EU-style quality labels can be weak. The takeaway is that stability, fraud control without shutdowns, and stronger quality governance are decisive for credibility.

Spain: many instruments, but complexity is the tax on ambition

Spain combines classic grants (e.g., PREE), recovery funds, hybrid instruments, and CAE energy-savings certificates. The breadth supports many actors: homeowners, associations, firms, and public bodies across renovation and new build. A key innovation is monetising savings through CAE, but its value can fluctuate and adds "market risk" to support. The main weakness is bureaucratic load and rigid timelines, which are especially tough for geothermal projects. Upfront financing remains a barrier where invoice-level discounts or bridge finance are not built in. Targeted boosts for vulnerable households or regions can improve equity, but also add rules and navigation complexity. The report's message: Spain has the ingredients—now it needs simplification and better cash-flow design.

Sweden: why a mature market can live without GHP-specific grants

Sweden is portrayed as a case where dedicated GHP subsidies are largely unnecessary due to market maturity. Support comes mainly via tax deductions (ROT) and broad climate/efficiency programs rather than GHP targeting. A major strength in design is that some tax credits are effectively invoice-level, reducing the upfront pain. Klimatklivet is described as impactful but debated on cost-effectiveness, showing that "big" programs need scrutiny. The report frames Sweden as proof that once a market reaches scale, specialised subsidies can be phased out. But it also implies this is context-dependent (pricing, taxation, supply chain, consumer trust, geology).

Sweden becomes a benchmark for the "policy sequence": early support → scale → stable rules → lighter incentives.

Comparative synthesis: the shared bottlenecks

Across countries, the dominant pattern is reimbursement after installation, creating a liquidity wall for many households. Equity mechanisms are often weak: flat-rate support can be regressive if only cash-rich households can pre-finance. Technology signalling is inconsistent: grants often under-reward GHP lifetime efficiency compared with cheaper ASHPs. Stop–go budgets and sudden rule changes undermine supply-chain confidence and create installation cycles. Administrative friction persists even with digital portals, especially when upgrades are split across multiple schemes. "District heating first" approaches can create lock-in and spatial inequity if opt-out conditions are too rigid. The high-leverage fixes proposed are cash-flow reform, one-stop platforms, multi-year budgets, and model eligibility (leasing/HaaS).

The new affordability score: strong concept, careful boundaries

The score aims to answer a practical question: which technologies are easier/harder to invest in and run by country. It combines cost factors (CAPEX/OPEX/LCOE) with macro context (income, GDP, employment, inflation, energy price ratios). Weights come from an expert allocation survey, forcing trade-offs and making priorities explicit. The authors acknowledge double-counting risk (CAPEX/OPEX embedded in LCOE) and address it via weight logic. Purchasing power adjustment is a major strength for cross-country comparability. However, excluding building-side upgrades (emitters, insulation interactions) can shift real-world outcomes. Still, as a comparative, harmonised indicator, it's a credible decision-support layer—if not mistaken for a site-specific tool.

Monte Carlo uncertainty: a credibility booster

The simulation propagates two uncertainties: input variability (prices/costs) and weight disagreement among experts. Big-ticket costs are perturbed more (±20%) than macro factors

(±5%), matching real-world volatility intuition. Weights are sampled via a Dirichlet approach calibrated to survey dispersion—so disagreement widens uncertainty. The result: deterministic and Monte Carlo means correlate strongly, so the method is internally consistent. Uncertainty intervals often overlap for top options, discouraging over-confident "winner takes all" messaging. Importantly, HP options tend to show narrower uncertainty than combustion options in this framework. That supports a policy narrative: electrified solutions can be not only cheaper over life, but also more predictable.

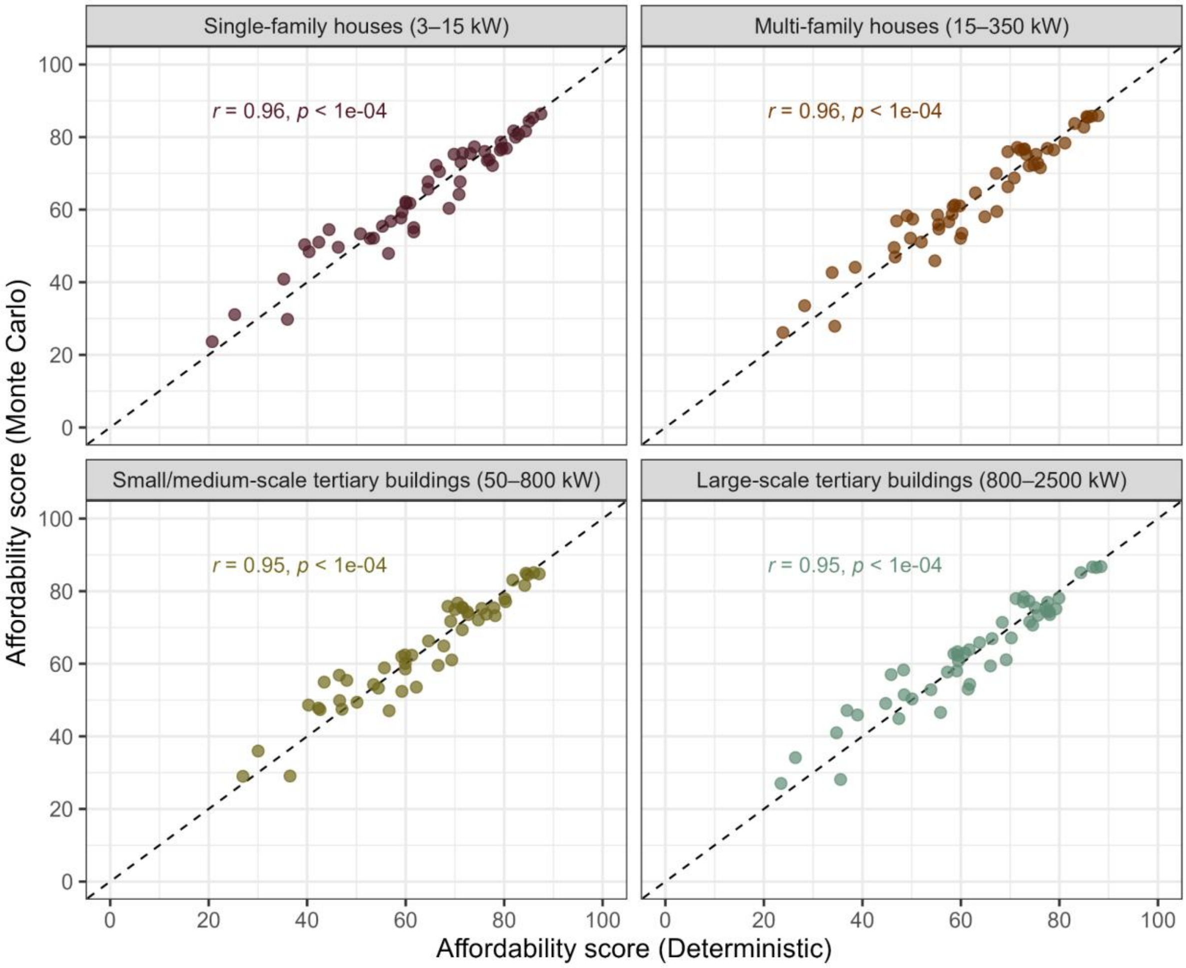

Figure 18: Deterministic against Monte Carlo affordability scores:

Each point is a country–system value, plotting the deterministic score (x-axis) against the mean Monte Carlo score (y-axis). Within each panel, the dashed diagonal is the 1:1 reference line indicating perfect agreement. Points above the line denote higher Monte Carlo than deterministic estimates; points below denote the contrary. The Pearson correlation coefficient (r, with p-value) is annotated in each panel, quantifying concordance within that building group.

Baseline results: the big story the score tells

Under baseline assumptions (no policy support), GHPs lead most country–building combinations, even at 55°C supply. ASHPs are close behind and sometimes win at mid-scale where low CAPEX matters most in the composite. District heating and pellets form a middle band; oil and gas boilers generally rank at the bottom. Germany is the key outlier where price ratios and drilling costs erode the HP advantage in this snapshot. Poland appears more "borderline," with positive GHP-vs-gas differences but sometimes overlapping uncertainty intervals. The report interprets this correctly: rankings are robust, but margins can be sensitive to tariff and CAPEX policy. A useful implication: banning gas in new builds does not automatically impose a lifetime "affordability penalty."

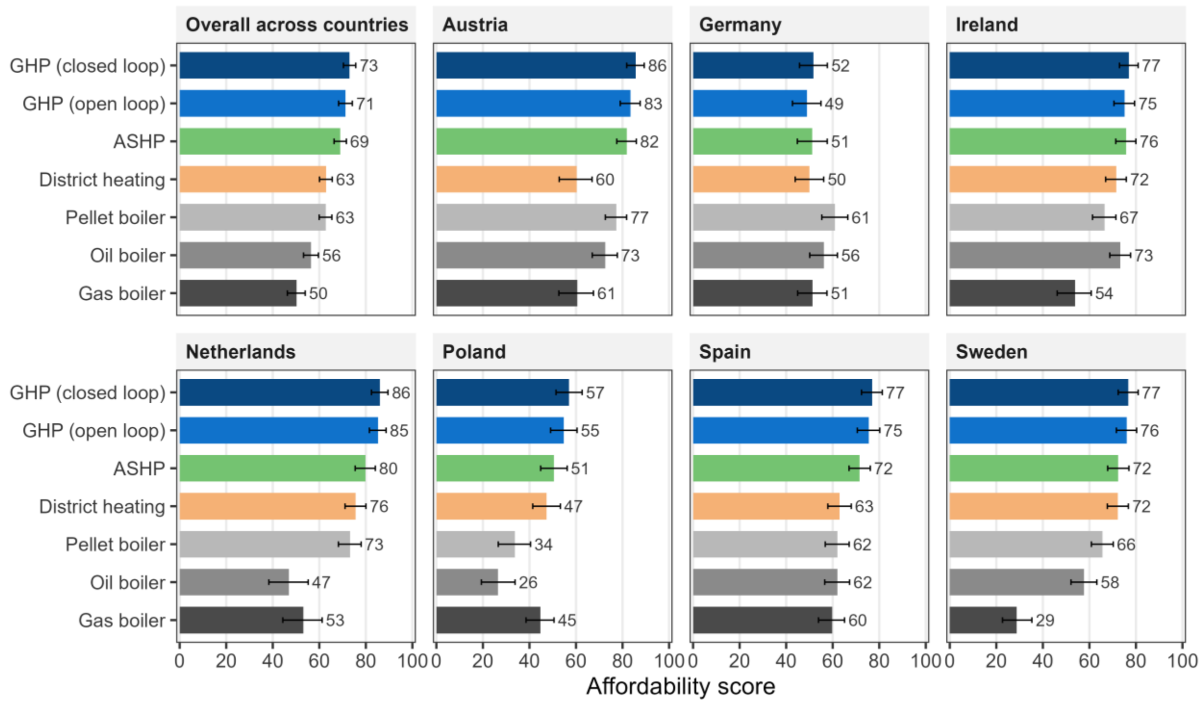

Figure 19: Affordability scores by technology and country

(baseline scenario, heating and cooling, 2023). Horizontal bars show Monte Carlo mean affordability scores for each system on the 0–100 scale from the Monte Carlo simulation (N_{sim} = 10,000); error bars indicate 95% uncertainty intervals (2.5th–97.5th percentiles). The "Overall across countries" panel reports scores averaged over all seven countries and four building groups, while the remaining panels show country-specific scores aggregated across building groups. Higher score values denote comparatively more affordable options. Policy support is not included in the baseline scenario.

Single-family houses (3–15 kW)

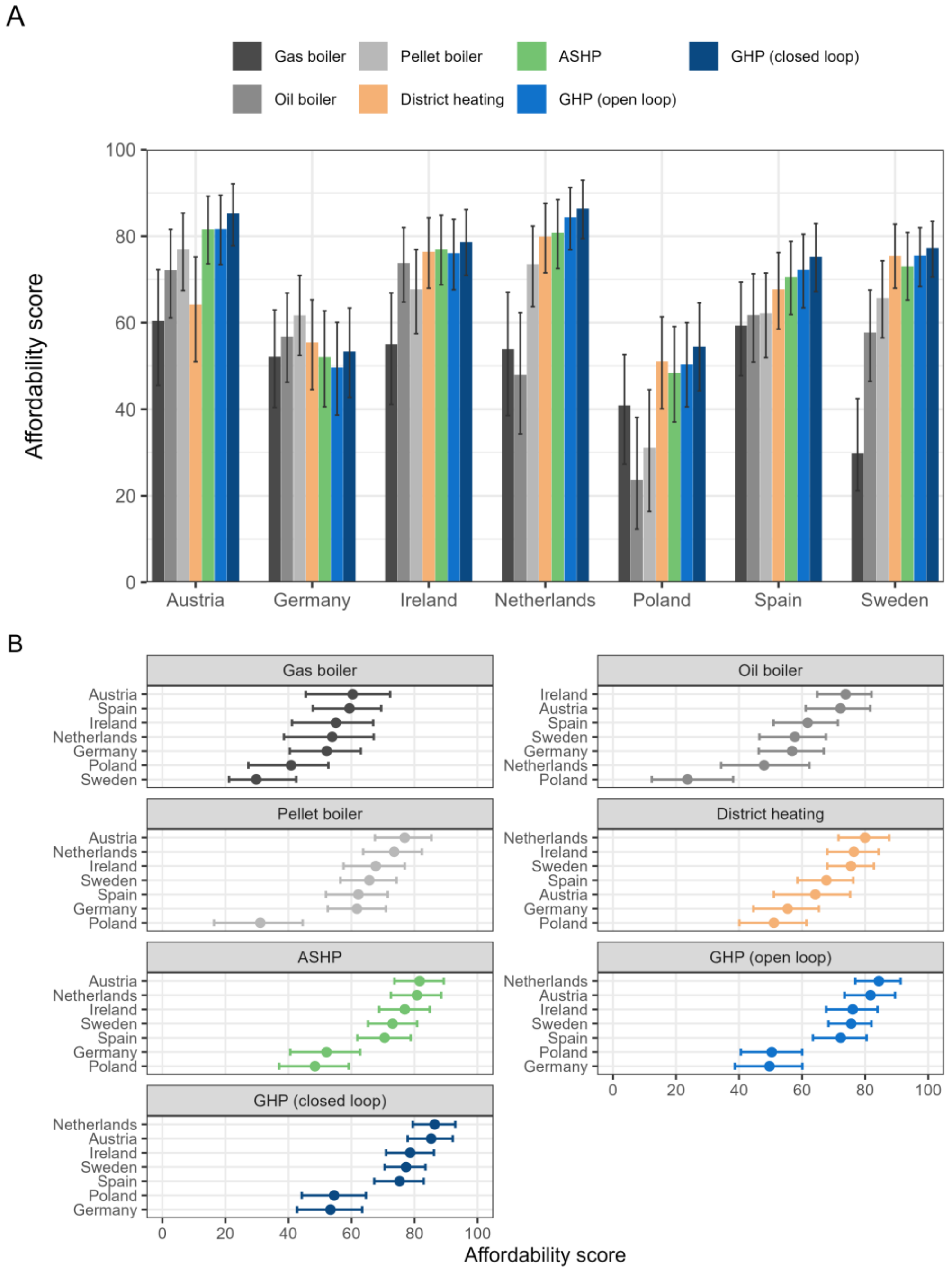

Figure 20: Affordability scores for single-family houses

(baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95 % UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation ($N_{sim} = 10{,}000$).

Multi-family houses (15–350 kW)

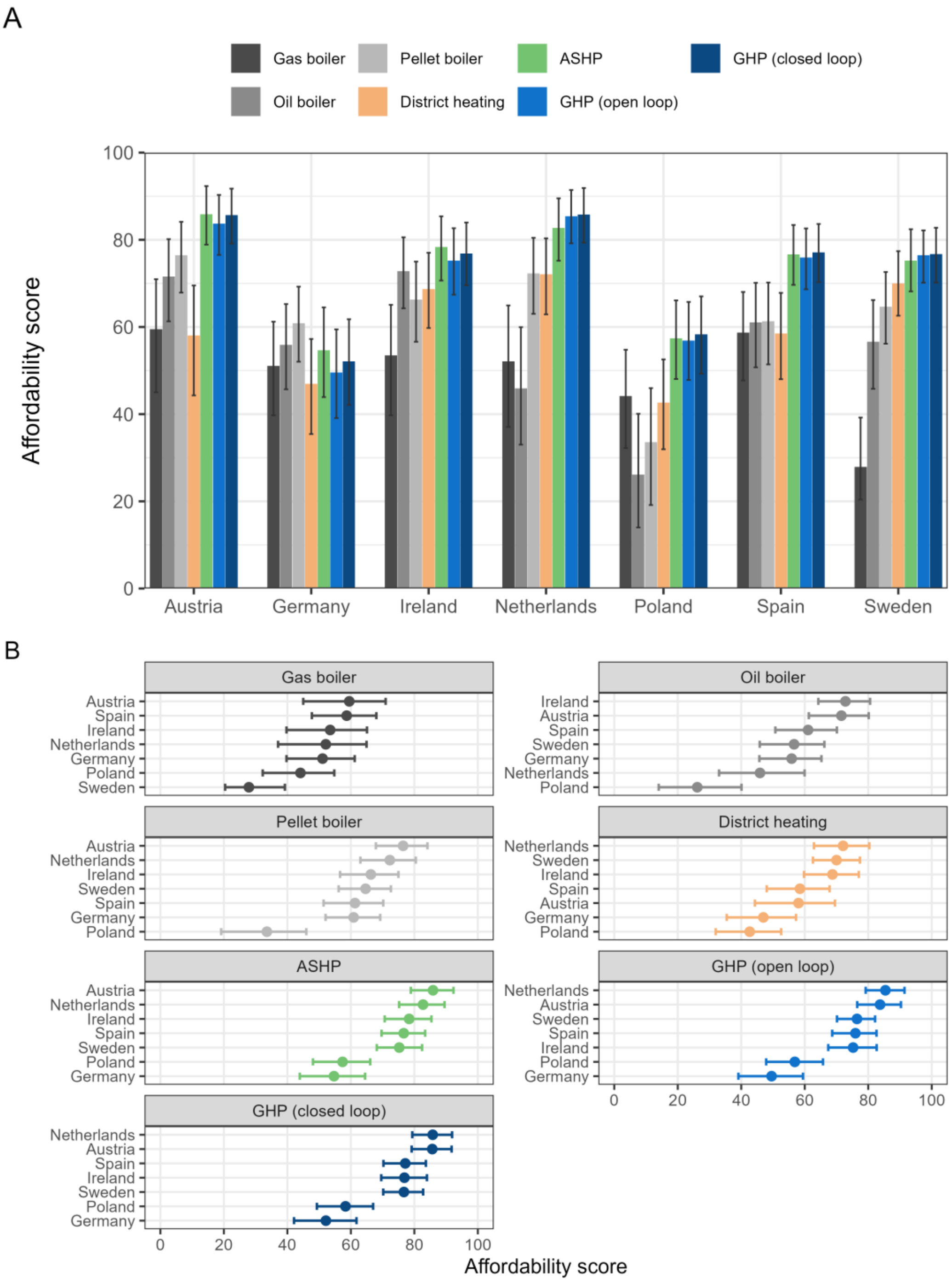

Figure 21: Affordability scores for multi-family houses

(baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation (N_{sim} = 10,000).

Small/medium-scale tertiary buildings (50–800 kW)

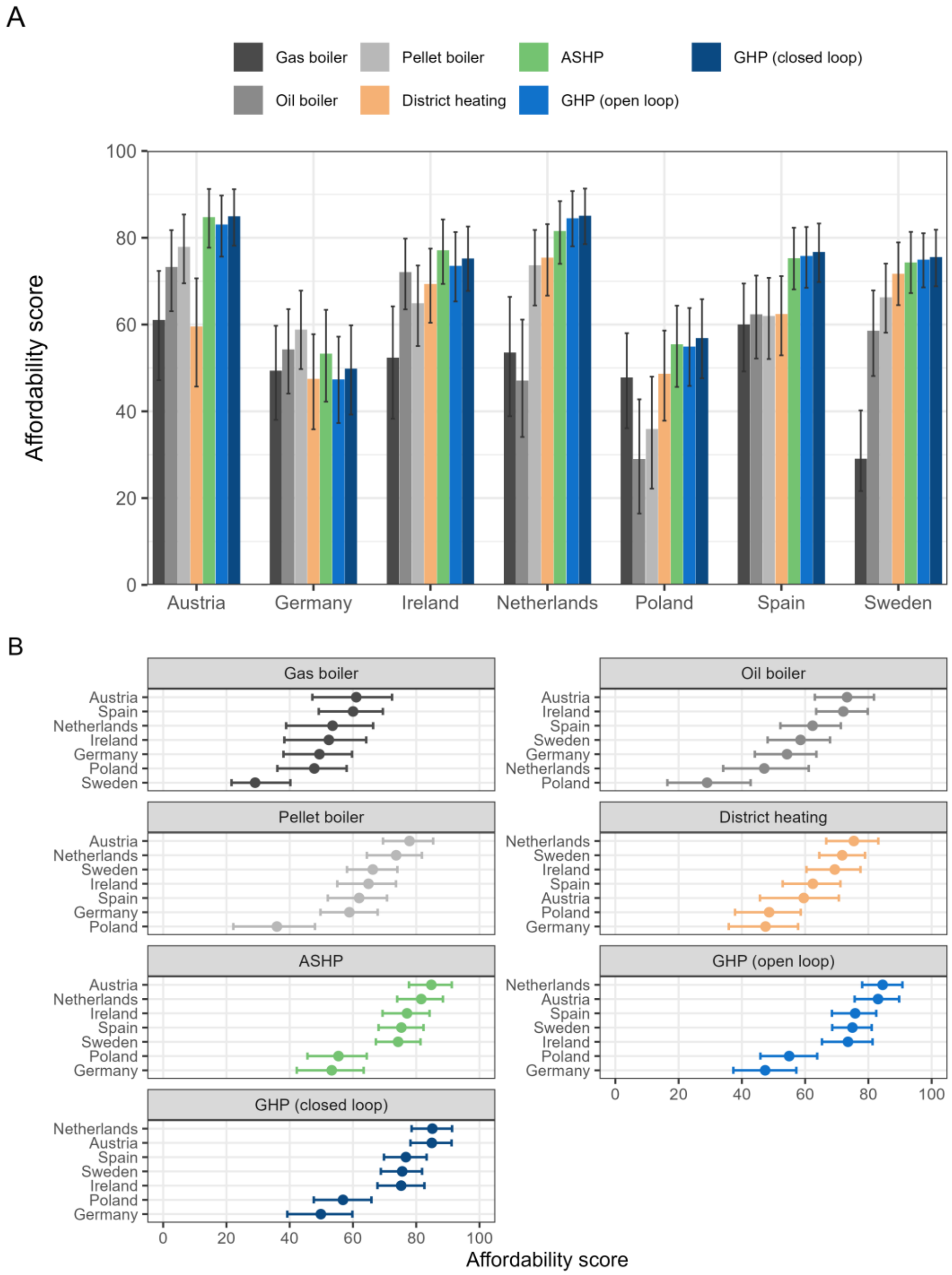

Figure 22: Affordability scores for small/medium-scale tertiary buildings

(baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation (N_{sim} = 10,000).

Large-scale tertiary buildings (800–2500 kW)

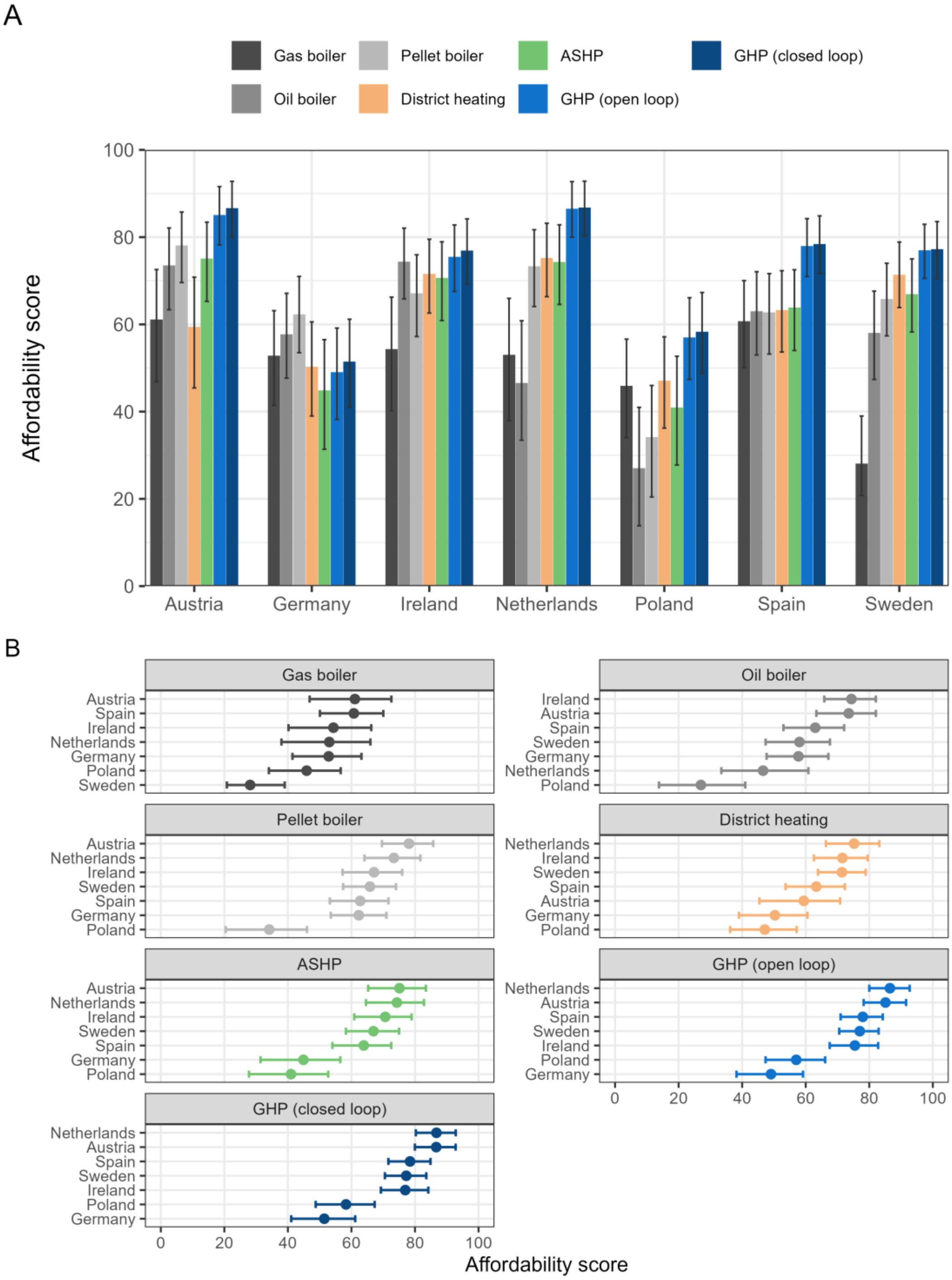

Figure 23: Affordability scores for large-scale tertiary buildings

(baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation (N_{sim} = 10,000).

EPIC scenario: what an efficiency-tiered grant changes

EPIC reintroduces policy support as a factor and models tiered CAPEX grants (highest for GHPs). It doesn't flip the table; instead it widens the gap between geothermal and ASHPs in a predictable way. Because the baseline already places GHPs near the top, closed-loop GHPs gain modestly (ceiling effect). Open-loop GHPs are the biggest "climbers," moving more clearly into second place across many panels. ASHPs can slip slightly in rank—not because they worsen, but because GHPs get a stronger CAPEX correction. The design choice to isolate EPIC to the policy-support factor avoids double counting, improving interpretability. Policy lesson: targeted grants can shape which HP gets chosen, not only whether an HP gets chosen at all.

The finance mechanism catalogue: practical levers beyond grants

The six mechanisms cover the main real-world barriers: liquidity, split incentives, risk perception, and OPEX competitiveness. On-bill "pay-as-you-save" targets upfront cost and can follow the meter, helping tenant/landlord alignment. Third-party ownership/HaaS turns capex into a service fee and reduces perceived risk through professional operation. Performance-based incentives pay for outcomes and can improve bankability—especially when paired with monitoring. Tariff and tax reform is framed as a "hidden finance tool" because it determines payback and loan comfort. Community/cooperative financing reduces unit cost via scale and can include renters/social housing. Risk mitigation (guarantees, insurance) lowers the cost of capital and tackles drilling/performance anxiety head-on.

Case studies: the report's most policy-relevant lessons

Sweden illustrates policy sequencing: carbon taxation + stable rules + quality infrastructure can mainstream HPs. US rural electric co-ops show how tariffed on-bill can finance long-lived ground loops with minimal credit barriers. Denmark's OK model demonstrates customer appetite for subscription/lease simplicity and predictable monthly costs. The UK Green Deal is used as a cautionary tale: poor terms and trust issues can sink property-linked repayment. EuroPACE in Spain shows promise but also highlights that enabling law and consumer protections are prerequisites. France/UK low-income targeting reinforces that equity requires intentional design, not leftover budget. Across examples, the success pattern is consistent: reduce upfront pain, align repayment with savings, and standardise delivery.

Overall verdict and the most actionable takeaways

As a review, this deliverable is strongest where it links program design details to predictable market outcomes. Its affordability score is a credible comparative tool, especially with uncertainty handling and transparent assumptions. The subsidy mapping makes a clear case that liquidity design matters as much as headline grant percentages. The mechanism catalogue is practical: it offers implementable routes when "more subsidies" is fiscally or politically constrained. The main limitation is scope: national averages and no distribution-system retrofit costs mean real projects can diverge. Still, the strategic direction is consistent: fix cash flow, simplify pathways, reward verified performance, and enable service models. If policymakers adopt only one message, it should be this: make geothermal affordable at the point of purchase, not only over 25 years.

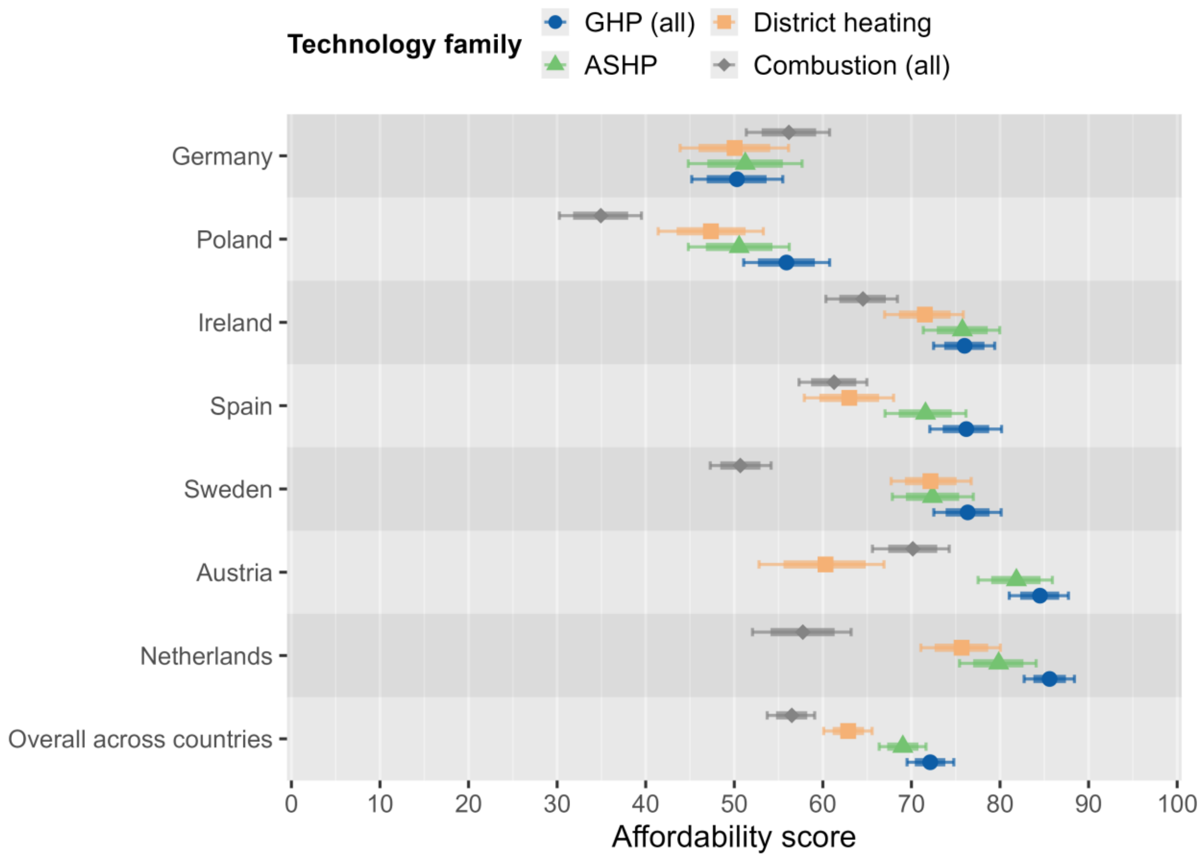

Figure 24: Affordability scores by technology family and country

(baseline scenario, heating and cooling, 2023). Points represent pooled average scores for each technology family aggregated across building groups. Families were defined as GHP all (geothermal heat pumps, combining closed- and open-loop systems), ASHP (air-source heat pumps), District heating, and Combustion all (combining gas, oil and pellet systems). The thick error bars are 80% UIs (10th–90th percentiles) and the thin bars denote 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation ($N_{sim} = 10{,}000$). The "Overall across countries" row reports pooled scores over all 7 countries; subsequent rows show country-specific results. Higher values denote comparatively more affordable options. Policy support is excluded in this baseline configuration.

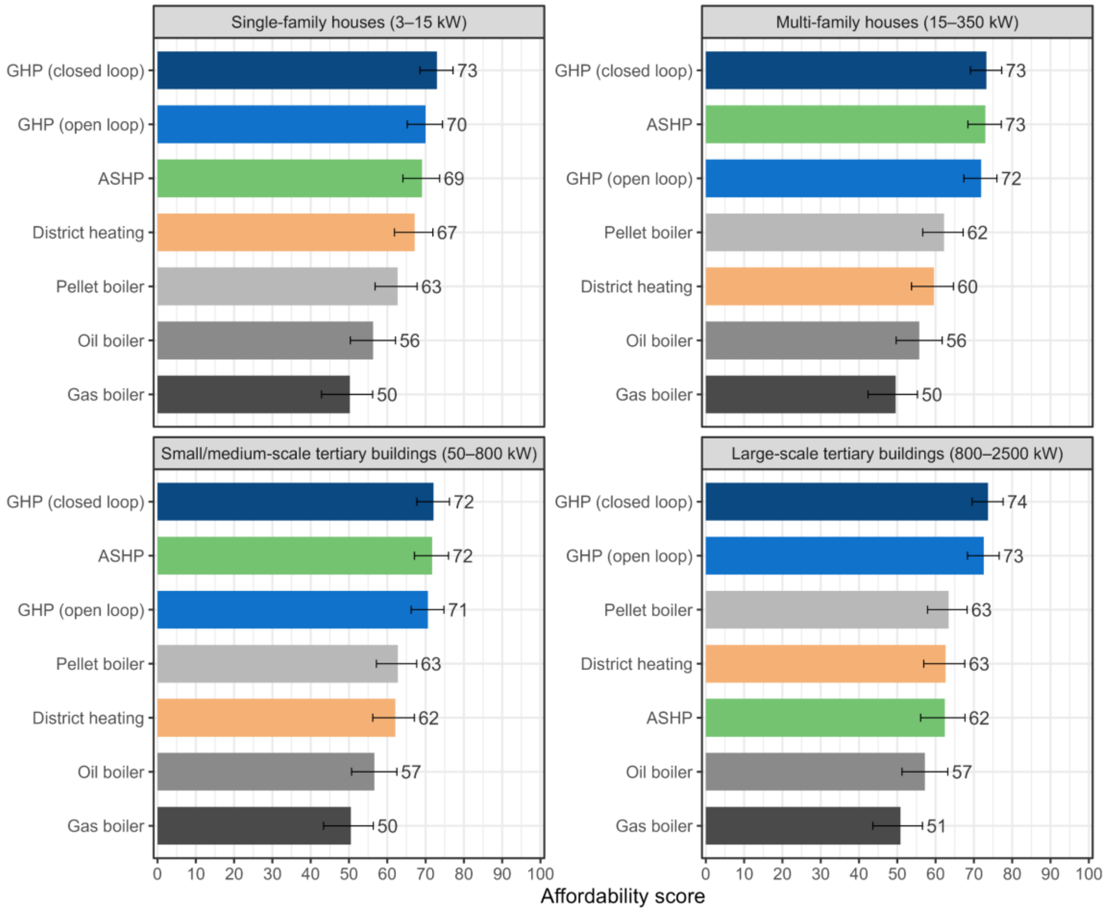

Figure 25: Affordability scores by building group

(baseline scenario, heating and cooling, 2023). Horizontal bars show Monte Carlo mean affordability scores for each system on the 0–100 scale from the Monte Carlo simulation (N_{sim} = 10,000); error bars indicate 95% uncertainty intervals (2.5th–97.5th percentiles).

Deliverable D5.1 - Catalogue of existing and promising technical solutions

Purpose, and scope of the catalogue

This deliverable compiles existing and promising technical solutions for harnessing geothermal energy, with a strong focus on ground-source energy systems for heating and cooling. It supports WP5 Task T5.1 by providing a structured technology inventory that can be used later for thermo-economic comparison, life-cycle thinking, and decision support for non-technical consumers and project developers. The catalogue is intended to be practical. It links technologies to boundary conditions, such as project type, geology, climate, and operating temperatures, as well as risk considerations that often determine project success or failure.

A key reason such a catalogue is necessary is that ground-source systems behave differently from many other heating/cooling technologies: the source and sink temperature can change over time due to extraction and reinjection, so the “resource” is dynamic and coupled to building load and operation. This creates feedback between the ground, the heat pump plant, and the building envelope/emission system, which makes technology selection less straightforward than choosing a boiler or an air-source heat pump. Accordingly, the deliverable frames selection as a systems problem—where design, operation, and local constraints are just as important as hardware.

The catalogue’s objectives are to describe technologies and references, set implementation boundary conditions, and provide qualitative assessment tools such as SWOT and risk perspectives (economic, environmental, operational). It also aims to define benchmarking parameters and KPIs that allow fairer comparison across very different concepts—e.g., open-loop aquifer systems, vertical borehole heat exchangers, borehole thermal energy storage, and hybrid solutions combining multiple sources and storage. In short, it is designed to be a “technology map” that supports consistent project screening and later decision frameworks within GeoBOOST.

To ground the catalogue in real innovation pathways, the text references a set of EU projects that explored improved heat pumps, collectors, drilling, controls, and integrated system concepts—ranging from Mediterranean GSHP demonstrations to lower-impact drilling and dual-source heat pump systems. These projects illustrate that progress is not only about better components, but also about whole-system integration, reduced installation cost, and improved controllability under real building operation and seasonal demand. The catalogue therefore treats “technology” broadly: equipment, interfaces, controls, installation methods, and operating strategies all matter.

Terminology, classification, and locality-driven suitability

Ground-source energy systems are described using different terms across countries, so the report starts by aligning classifications that otherwise cause confusion in markets, permitting, and statistics. Depth-based naming commonly distinguishes very shallow systems (roughly up to 5–10 m, e.g., horizontal collectors) from shallow geothermal systems (up to ~500 m, including borehole heat exchangers), while deep geothermal (kilometres) is out of scope. Temperature-based naming also matters: low-enthalpy systems operate around sub-zero to ~35 °C, while high-enthalpy systems start near 60 °C and above, with different technologies and regulatory contexts.

The catalogue also uses the IEA ECES terminology for underground thermal energy storage and related systems: UTES is the umbrella for underground energy storage; ATES refers to aquifer thermal energy storage; BTES refers to borehole thermal energy storage; and BHE describes borehole heat exchangers used primarily for extraction/injection without “storage intent.” This framing helps separate “open-loop” groundwater-based systems (often ATES/recirculation) from “closed-loop” ground heat exchanger systems. National practice varies: some countries classify by ground vs groundwater, others by collector type (topsoil, boreholes, groundwater, caves, water).

Locality is treated as a first-order boundary condition because available space and interactions between multiple nearby systems can limit feasibility. In dense urban areas with large buildings and small footprints, ATES can be attractive due to compact surface needs, but technical and maintenance risks are higher; BTES can be robust and low-maintenance but may be limited by capacity and the need for good seasonal balance, often requiring hybridization. In village settings with multiple single-family homes, individual BHE systems are common, while small collective solutions with low-temperature networks are also possible. In rural settings with ample space, horizontal/ring/spiral collectors become realistic options that are often impossible in cities.

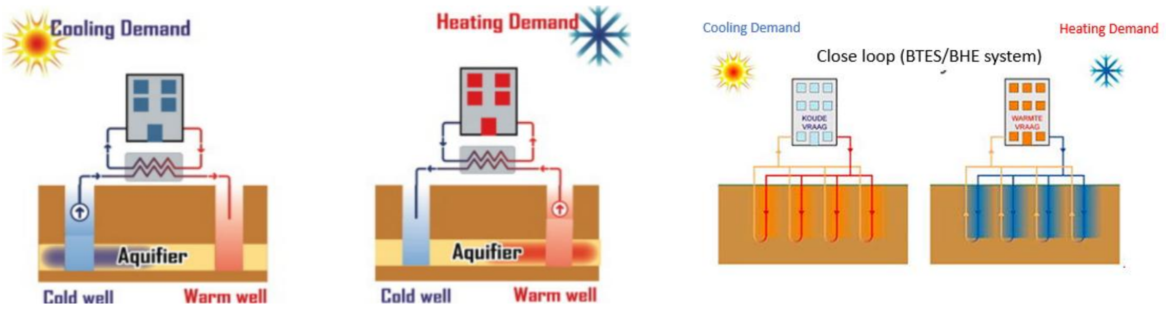

Figure 26: Basic principle of ATES and BTES

The open loop ATES is in the left hand picture (Bloemendal et al., 2015), and the closed loop BTES is right. (source: BodemenergieNL/Groenholland) - right.

The report provides indicative suitability matrices: in urban contexts, open loop systems are often “very suitable,” while horizontal and shallow collector options are usually constrained by space and logistics. In villages and rural areas, BHEs are typically highly suitable, with horizontal/ring collectors improving as available land increases; spiral/earth-basket concepts become most attractive where large surface area and easy excavation are possible. These matrices are not strict rules, but they encode typical European practice and can reduce early-stage screening errors when comparing options.

Table 5: Indication of types of geothermal systems per locality type.

Dark green (++): very suitable, light green (+): suitable; yellow (+/-): may be suitable; red (-): not or limited suitability. Open Loop : aquifer systems. Closed loop: BTES (Borehole Thermal Energy Store) systems, BHE (Borehole Heat Exchanger systems), Shallow horizontal heat exchanger systems, Ring: Shallow Ring collector heat exchanger systems (Slinky), Spiral: Spiral (including Earth-Basket) type heat exchangers.

	Urban	Village	Rural
Open Loop	++	+	+/-
Closed loop, BTES	+	+	+
Closed loop, BHE	+	++	++
Closed loop, HORIZONTAL	-	+/-	+
Closed loop, RING	-	+/-	+
Closed loop, SPIRAL	-	+/-	++

Table 6: Indication of type of application and different geothermal technologies.

Tertiary buildings: larger buildings such as offices, hospitals etc.

	Single family house	Multi-family house	Small tertiary	Large tertiary	Industrial & Agrifood	Heat/Cool networks
Capacity (kW)	3 - 15	15 – 350	50 – 800	800 – 2500	> 2500	> 2500
Open Loop	+	+	+	++	++	++
Closed loop, BTES	-	++	++	+/-	+/-	+/-
Closed loop, BHE	++	++	++	-	-	-

Closed loop, HORIZONTAL	+	+/-	-	-	-	-
Closed loop, RING	+	+/-	-	-	-	-
Closed loop, SPIRAL	+	+/-	-	-	-	-

Application scale and user type further steer technology choice. The report groups applications from single-family homes (few kW) through multi-family and tertiary buildings (tens to hundreds of kW) up to large tertiary, industrial, agri-food, and heating/cooling networks (often >2.5 MW). Open-loop systems become increasingly attractive at higher capacities because they can deliver large thermal power with small footprints, while closed-loop BHEs dominate typical building-scale projects and are less common for very large industrial/network-scale duties. BTES sits between these extremes, as a robust storage-oriented approach that depends on balancing and integration.

Subsurface constraints, climate context, and main heat-pump concepts

Geology and hydrogeology strongly influence both feasibility and cost: they affect drillability, required casing, grouting complexity, and long-term performance through conductivity, heat capacity, and groundwater flow. Key parameters include temperature profiles with depth, thermal properties, groundwater table level, hydraulic conductivity, aquifer layering and aquitards, porosity (including secondary porosity in fractured rock), and rock hardness. Horizontal systems need suitable unconsolidated overburden, while vertical boreholes in unconsolidated layers may require casing to avoid collapse. Certain geological settings (karst, subsidence zones) can create prohibitive risk or tight permitting restrictions.

The report summarizes important drilling-related risks that project teams must anticipate. Artesian confined aquifers can create high-pressure outflow and mobilize fines, destabilizing boreholes and even causing subsidence, so casing, barrier pipes, packers, and appropriate drilling fluids may be needed. Connecting multiple groundwater levels must be prevented to avoid undesired hydraulic and chemical mixing. Gas occurrences require detection and safety planning due to explosion/ toxicity/ asphyxiation risks. Karst, faulted rock, voids, mining areas, and soluble rocks can cause tool drops, mud losses, and backfilling challenges. Swellable clays and anhydrite demand special care, as water contact can generate damaging swelling pressures; landslide zones are strongly discouraged for shallow geothermal drilling.

Climate context is introduced using EN 14825, which defines three reference climate zones (average, cold, warm) for seasonal performance calculations. Typical meteorological year profiles, heating degree days, and cooling degree days are used to normalize performance expectations and compare solutions across Europe. This matters because the same hardware can behave very differently when the heating season is long and cold versus short and mild, or when cooling dominates and the ground acts as a seasonal heat sink. Climate therefore connects directly to sizing, balance, and the value of passive cooling, storage, and hybridization.

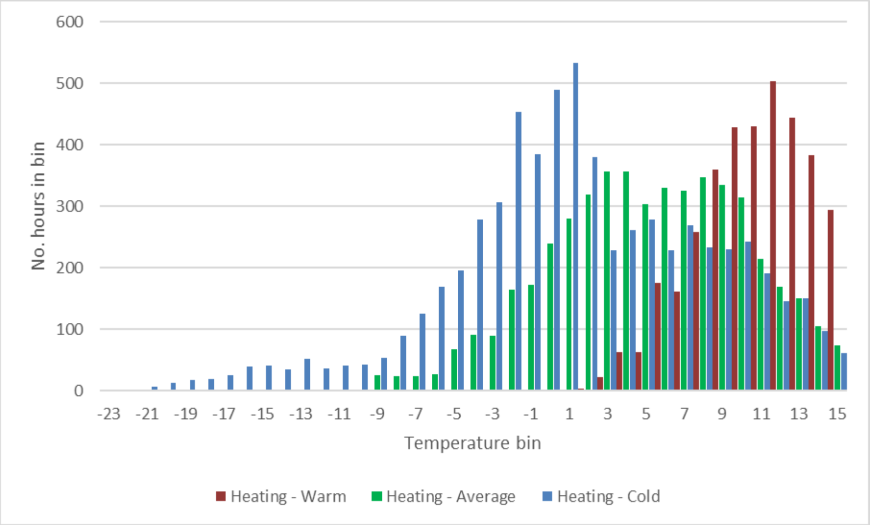

Figure 27: Bin hour distribution heating operation:

The graphs show three different climate zones (limit temperature 16 oC).

Heat pumps sit at the centre of most ground-source systems because ground temperatures often require "lifting" for heating or "lowering" for cooling. The report distinguishes instantaneous performance metrics (COP/EER) from seasonal metrics (SPF or seasonal COP/EER), and stresses that boundaries matter: some definitions include only the compressor, while others include ground-source pumping, user-side pumping, backup heating, and auxiliaries. This boundary clarity is essential for fair benchmarking and for preventing misleading comparisons between projects with different hydronic layouts. Operating temperature is a major driver of efficiency: lower emission temperatures (e.g., floor heating) generally yield higher COP than high-temp radiators or domestic hot water production.

The vapour-compression heat pump is described as the dominant technology, with compressor, condenser, evaporator, and expansion device forming the core cycle. Performance drops as temperature lift increases, which is why system design aims to minimize temperature differences across heat exchangers and in distribution. The report also highlights transcritical CO_2 cycles for higher-temperature duties, noting benefits when large temperature lift is required and limitations due to very high pressures and the need for adequate heat rejection conditions. Compressor choice (scroll, screw, centrifugal) and staging/inverter control are linked to application size and part-load needs.

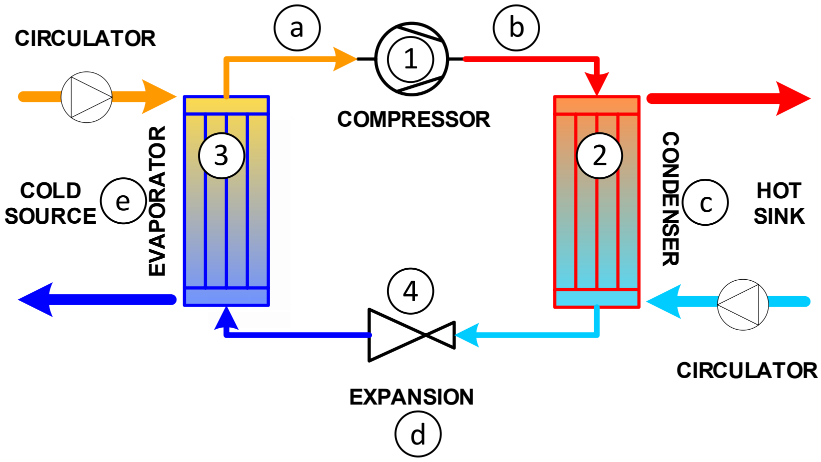

Figure 28: Simplified schematic of vapor-compression cycle

(source: Groenholland)

Refrigerants, controls, circulation media, and practical integration levers

Beyond vapour-compression, the text briefly covers absorption and adsorption heat pumps (liquid-sorption vs solid-sorption), and notes thermo-acoustic heat pumps as an emerging concept with modulation advantages and wide temperature flexibility. These alternatives are relevant where electricity use, waste-heat driving sources, noise, maintenance profiles, or high temperature requirements reshape the best-fit solution. For most buildings, however, compression systems remain the practical baseline, so innovation focus shifts to refrigerants, controls, exchangers, and integration with sources/storage.

Refrigerant selection is framed as a multi-criteria decision: thermodynamic performance, chemical stability, material compatibility, safety (toxicity and flammability), and environmental impact. The report distinguishes natural refrigerants (CO_2, ammonia, water, hydrocarbons) from synthetic families (CFC/HCFC/HFC/HFO) and explains why regulation has driven successive phase- outs—from ozone depletion to high GWP constraints. Safety classification follows ASHRAE toxicity/flammability classes, and practical deployment is tied to standards that govern charge limits, ventilation, siting, and leak detection. Environmental impact is discussed using GWP and TEWI, emphasizing that both leakage and electricity consumption over the lifecycle matter.

Table 7: ASHRAE Safety Classification for Refrigerants

ASHRAE Safety Classification **	A. Low toxicity Not-toxic for concentration up to 400 ppm by volume	B. High toxicity Toxic for concentration below 400 ppm by volume
3. Higher flammability Flame propagation at 60°C and 1 atm and either heat of combustion > 19 MJ/kg	A3 Propane, isobutane and other hydrocarbons	B3

or LFL* < 0.10 kg/m³		
2. Lower flammability Flame propagation at 60°C and 1 atm, heat of combustion < 19 MJ/kg and LFL* > 0.10 kg/m³	A2 R152a, R1132a	B2 R40, R1130(E)
2L. Mild flammability Flame propagation at 60°C and 1 atm, heat of combustion < 19 MJ/kg, LFL* > 0.10 kg/m³ and Burning velocity ≤ 10 cm/s	A2L R32, R1234yf, R1234ze(E), and most of HFOs	B2L Ammonia
1. No flame propagation No flame propagation at 60°C and 1 atm	A1 R134a, R410A, R404A, CO_2	B1 R123, R514A

* LFL: Lower Flammability Limit, ** (source: ANSI/ASHRAE 34-2022)

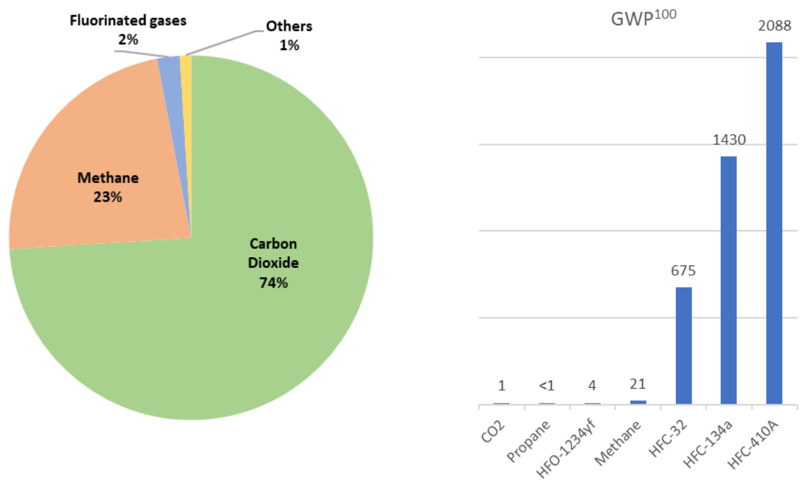

Figure 29: Global warming effect and GWP of refrigerants

Global warming effect per fluid (left), Example of GWP comparison among refrigerants (right)

Heat exchangers are presented as key interfaces: plate heat exchangers are common, with brazed types inside heat pumps (high pressures/phase change) and gasketed types where cleaning and low-pressure operation are important. Control systems are then positioned as a major performance lever: simple thermostat/hysteresis and PID approaches are contrasted with supervisory control systems that coordinate operating modes (heating, cooling, passive cooling, DHW), manage hybrid plants, enforce safety limits, and log data for diagnostics and optimization. The report notes that high thermal mass systems often suffer from poor tuning due to response lag, motivating more advanced strategies in some projects.

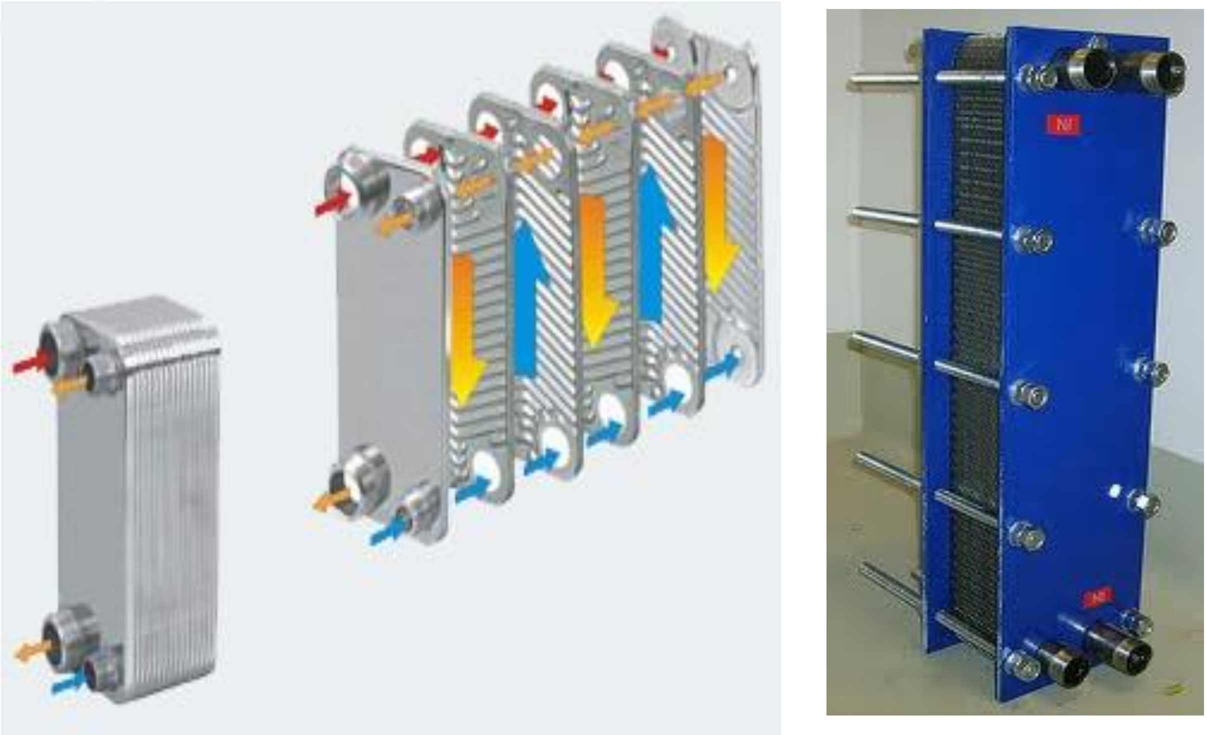

Figure 30: Examples of plate heat exchangers.

Brazed (left) and gasketed (right) configuration

Machine learning and artificial neural network control are described as newer options that can improve source switching, part-load behaviour, and robustness when classical controllers struggle. The text also mentions alternative control approaches such as genetic algorithms, fuzzy logic, and model predictive control (digital-twin style), stressing that control choice should match plant complexity and available data/commissioning capacity. The practical message is that controls are not an “add-on”: they strongly influence SPF, comfort, and equipment lifetime, especially in hybrid and networked systems.

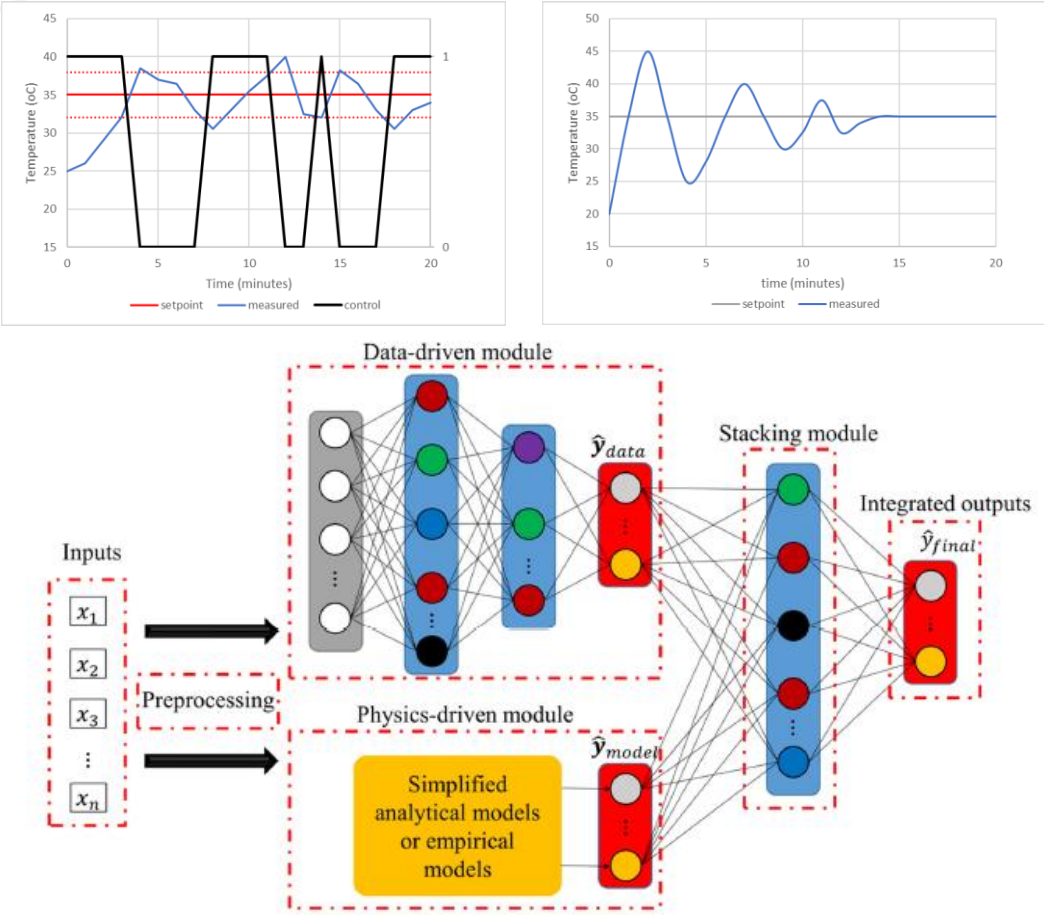

Figure 31: Examples of different control systems

On/off control with thermostat and hysteresis (source: Groenholland). (top left), PID control (source: Groenholland).(top right), A Machine Learning data-processing control algorithm (source: Wang & Chen, 2023) (bottom)

Finally, the report summarizes circulation media for ground loops and the role of additives. Water is the baseline heat transfer medium but often requires antifreeze in cold/average climates to avoid freezing damage and to satisfy local rules on minimum loop temperatures. Antifreeze agents discussed include propylene glycol, ethylene glycol, ethanol, methanol, calcium chloride, and others, compared by viscosity, freezing point, heat capacity, toxicity, and environmental behaviour. The text highlights that additives (corrosion and scale inhibitors, biocides, pH stabilizers) can be essential for durability but may raise environmental concerns if leakage occurs—so "fluid chemistry" becomes a risk-management topic as much as a thermal-design topic.

Table 8: Thermal properties of circulation media

(sources: The Engineering ToolBox, and Safety Data Sheets, the prices are from different on-line stores)

	Thermal conductivity	Specific heat capacity	Dynamic Viscosity at room temperature	Dynamic Viscosity at 0°	Freezing Point	Price
	W/mK	J/gK	mPa s	mPa s	°C	€/kg or €/ton
Water	0.606	4.18	1.0 (0.89)		0	0.003 €/kg
Monopropylene glycol	0.37	2.5	60		From -57 to -60	9.84 €/kg 983 €/ton
Monopropylene glycol – Water solution 25%	0.435	3.96	1	6.18	From -13 to -15	
Monopropylene glycol – Water solution 33%	0.415	3.86	1.3	12	From -17 to -20	
Ethyl alcohol	0.167	2.44	1.2	7	-114	3.6 €/kg
Ethyl alcohol – water solution 25%	0.44	±4	2.45	6	From -12 to -16	
Monoethylene Glycol	0.28	2.51	60		-13 Below -50 (55-72%)	3.59 €/kg 760 €/ton
Monoethylene Glycol 25% solution	0.49	3.93	1-2	3.1	From -12 to -15	
Methyl alcohol	0.22	2.51	0.54		-97.6	450 €/ton
Methyl alcohol – water solution 25%	0.44	3.9	1.8	3.4	From -20 to-22	
Calcium Chloride 25% solution	0.57	2.80	From 2.5 to 7	5	From -27 to -30 (-51 at 29% sol.)	Pure CaCl 126 €/ton
Triethylene glycol	0.26	2.39	32		From -4 to -7.2	1000€/ton
Propane-1,3-diol	0.13	2.51	50		From -28 to -33	4.5 €/l 900 €/ton

Ground Source Energy Systems and Enabling Technologies (UTES, GHEX, Drilling & Hybridisation)

System classification

Ground source energy systems provide heating and cooling by exchanging thermal energy with the shallow subsurface. A broad classification distinguishes (i) single-use systems, where heat is extracted from or rejected to the ground without intentional seasonal storage (typical Borehole Heat Exchangers—BHE or groundwater recirculation systems), and (ii) Thermal Energy Storage (TES) systems, where heat and/or cold is stored in the subsurface and recovered later (Underground Thermal Energy Storage—UTES).

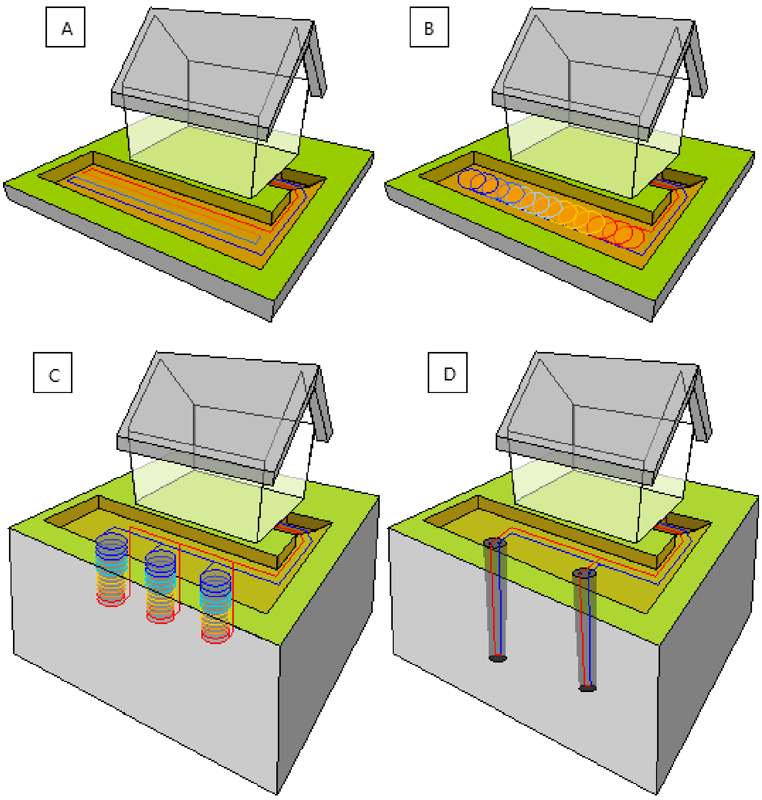

Figure 32: Examples of different ground heat exchangers.

A: horizontal ground heat exchanger, B: ring-collector (also called "slinky"), C: Earth basket/spiral and D: vertical borehole type ground heat exchanger (source: Groenholland/ISSO 73).

A secondary classification distinguishes open-loop and closed-loop systems:

- Open-loop systems exchange heat directly with groundwater that is abstracted and (usually) reinjected.
- Closed-loop systems circulate a heat-carrier fluid within buried pipes and exchange heat with soil/rock through temperature differences, without abstracting groundwater.

UTES can be divided into two main categories:

1. Aquifer Thermal Energy Storage (ATES)—storage in groundwater-bearing formations (aquifers).
2. Borehole Thermal Energy Storage (BTES)—storage via arrays of borehole heat exchangers (BHEs) in soil/rock with or without groundwater.

Other UTES concepts exist but are less widespread or more site-specific, including Cavern TES (CTES), Mine TES (MTES) and Energy Piles. Their feasibility is strongly influenced by geological and hydrogeological conditions (e.g., availability of suitable aquifers, rock mass stability, groundwater chemistry, and regulatory restrictions).

Open-loop: ATES and recirculation principles.

In an open-loop system groundwater is pumped from an aquifer, passes through a heat exchanger (and possibly a heat pump), and is reinjected into the subsurface. When the system is operated explicitly for seasonal storage (warm and cold wells), it is termed ATES. Thermal energy is stored and recovered by producing and injecting groundwater through wells. The ATES configuration typically comprises one or more doublets (pairs of wells), with extraction and infiltration occurring simultaneously (Bloemendal et al., 2015). The basic operating principle is shown in.

A recirculation system works similarly, but commonly uses one well for production and a second for injection, typically without establishing a seasonal warm/cold store. Both ATES and recirculation can also be configured as mono-well systems where warm and cold screens are placed within one borehole.

Closed-loop: BHE/BTES principles.

A closed-loop system circulates a heat carrier through pipes installed horizontally in trenches or vertically in boreholes. Heat is harvested when the circulating fluid is colder than the surrounding ground, and heat is rejected when it is warmer (Preene and Powrie, 2009).

BTES uses the subsurface itself as storage medium. It is typically implemented as a closely spaced array of boreholes (commonly 50–200 m deep) equipped with U-pipes or other exchanger geometries. Boreholes can be connected in series or parallel strings and arranged on a grid. BTES systems are widely used for heating and cooling of buildings ranging from single dwellings to large commercial complexes (Cabeza et al., 2015).

CTES and MTES.

Cavern TES stores heat in a large insulated underground volume (hot water or gravel/water stores) (Kalaiselvam and Parameshwaran, 2014). Mine TES can utilize flooded or partially flooded mine workings; however, long-term water treatment and environmental liability may become decisive constraints (Chicco et al., 2022; Menéndez et al., 2019).

Finally, each ground energy system can be described by three interacting elements:

1. Source side (subsurface infrastructure: boreholes, wells, ground loops, headers, grouting, etc.)
2. Load side (building demand, controls, users and operational profiles)
3. Heat transfer system (heat pumps, heat exchangers, pumps, and control strategy)

Open-loop systems: requirements, risks, and ATES operation

Hydrogeological requirements and operating constraints.

Open-loop geothermal heat pump systems depend on the availability of suitable shallow groundwater bodies. A productive aquifer typically requires sufficient saturated thickness, adequate transmissivity (hydraulic conductivity and effective porosity), and acceptable groundwater quality. Economic operation also depends on pumping lift and achievable yields.

A key distinction between open-loop variants is the preferred natural groundwater velocity:

- Recirculation systems benefit from higher groundwater velocities, which can replenish thermal conditions more quickly.
- ATES systems generally prefer low groundwater velocities, because advective transport can displace the stored warm/cold volumes, lowering recovery and increasing losses.

In most countries, reinjection is required to protect groundwater resources and avoid long-term depletion. Infiltration can be challenging in low-permeability aquifers and in unconfined systems with high groundwater levels. Both high and low water levels must be considered: high levels can reduce injection capacity, while low levels constrain pump placement and screened intervals. Screened sections and the pump should remain submerged to reduce oxidation and chemistry changes during operation.

Thermal plumes and interference

Thermal reinjection creates a warm or cold plume whose geometry is governed by pumping rates, temperature differences, and hydrogeology. Low hydraulic conductivity tends to create broader, shorter plumes; high conductivity and strong flow elongate and narrow plumes. Plumes can affect downstream users or neighbouring geothermal installations, so some jurisdictions limit permissible temperature change at the next water right. Proper well spacing and alignment relative to groundwater flow reduces risks of thermal breakthrough. Typically, the extraction well is located upstream of the injection well, or wells are placed side-by-side depending on local flow conditions.

Groundwater chemistry: scaling, clogging, and corrosion

Water chemistry is often a primary feasibility constraint in open-loop systems:

- Iron and manganese: in reduced groundwater, exposure to oxygen (through heat exchanger contact or reinjection structures) can trigger precipitation, clogging screens and filter packs.
- Carbonate scaling: CO_2 degassing and pressure changes can shift carbonate equilibria, causing incrustations, often during reinjection. Deposits can often be mitigated by mechanical and chemical cleaning.
- Microbially induced corrosion (MIC) and chemically driven corrosion can occur with elevated oxygen, sulphate, ammonium, chloride, CO_2, and unfavourable pH; copper heat exchangers are particularly vulnerable. Countermeasures include corrosion-resistant materials (e.g., stainless steel) and suitable design to minimize oxygen ingress.

ATES: principle, taxonomy, and flow schemes

ATES stores thermal energy seasonally in groundwater: excess energy (often summer heat) is injected and recovered later (typically winter heating) (Bloemendal et al., 2020). ATES characteristics across building demand, operational design, subsurface parameters, and system size are summarized conceptually in Fleuchaus et al. (2018).

ATES systems are commonly classified by operational temperature (Lee, 2013):

- LT-ATES: <30 °C (often constrained to injection <25 °C in several countries)
- MT-ATES: 30–50 °C
- HT-ATES: ≥50 °C (some classifications use ≥60 °C)

LT-ATES typically requires a heat pump to reach building supply temperatures (e.g., 35–45 °C), while MT-/HT-ATES may supply heat more directly depending on network/building requirements . ATES can also integrate external heat/cold sources (waste heat, solar thermal, or winter air cooling) to improve balance and seasonal performance (Nordel et al., 2015).

ATES performance and feasibility depend on aquifer properties (heterogeneity, mineralogy, permeability, porosity, stratification) and fluid properties (salinity, dissolved gases) (Kleyböcker et al., 2023).

Performance indicators and evaluation

Performance can be assessed using thermal, economic, and sustainability criteria; however, Fleuchaus et al. (2020) highlight that many evaluations remain theoretical and long-term monitoring datasets are scarce. Typical indicators include:

- Thermal recovery factor (ratio of discharged to charged energy) (Gao et al., 2017)
- Energy balance ratio (cooling vs heating extraction balance)
- Exergy efficiency (second-law performance)
- Seasonal Performance Factor (SPF) for the entire system (including pumps and heat pumps)
- Thermal imbalance measures based on injected cold/warm energy (Fleuchaus et al., 2020)

Common simulation tools for heat and mass transport in UTES are e.g., MODFLOW-MT3DMS, TOUGH2, COMSOL, FEFLOW, with selection depending on mesh type and coupling requirements (Regnier et al., 2022).

SWOT on regulation groups: priorities and weak spots

The SWOT/IFEM/EFEM approach is used to prioritise what belongs in a robust framework. The report concludes that temperature, extraction/discharge, and subsurface conditions sit in the high-relevance zone (big upside, big downside if missing). Distance, seasonal performance, and size/layout are moderately relevant but still beneficial and manageable. A particularly realistic insight is that extraction/discharge is where weaknesses and threats dominate: it is technically decisive but institutionally hard (monitoring costs, conflicts with other users, regulatory instability).

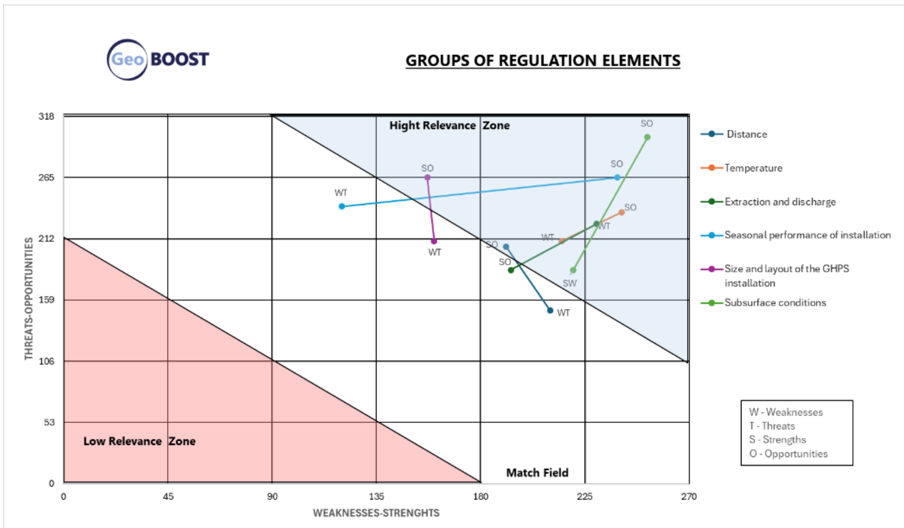

Figure 33: SWOT Analysis for Regulation element groups

Closed-loop ground heat exchangers: concepts, materials, and configurations

A ground heat exchanger provides the thermal coupling between the subsurface and the heat pump (active mode) or building system (passive mode). Heat transfer is driven by a temperature difference between circulating fluid and ground: heat is extracted in winter heating mode and rejected in summer cooling mode. GHEX can operate as:

- BHE (single-use): primarily extraction or injection without intentional seasonal storage
- BTES: deliberate diurnal/seasonal storage, typically using borehole arrays

Two performance descriptors are central:

1. Thermal performance, governed by the temperature difference and the thermal resistance between fluid and ground (mK/W), and the ground's specific heat extraction/injection rate (W/m).
2. Hydraulic performance, governed by pressure drop and pumping energy demand.

Drivers of thermal resistance

Thermal resistance is influenced by:

- Borehole/trench diameter and backfill/grout properties (thermal conductivity, density, heat capacity)
- Heat exchanger length and internal thermal short-circuiting between flow/return
- Pipe material conductivity and wall thickness; configuration (U-pipe, coaxial; pipe spacing, centralization)
- Contact resistance between pipe–grout and grout–formation interfaces
- Fluid properties (thermal conductivity, heat capacity, viscosity; temperature dependent)

Drivers of pressure drop

Pressure drop depends on:

- Number of parallel circuits and header/manifold design
- Pipe inner diameter, length, and roughness (PE pipes are typically very smooth; absolute roughness is commonly ~0.001–0.01 mm range depending on assumptions)
- Geometry (straight, slinky, spiral)
- Fluid properties and flow regime (temperature dependent)

GHEX configurations

A wide range of collector types exists, including:

- Vertical borehole exchangers (single-U, double-U, triple-U; coaxial/concentric)
- Horizontal straight collectors (trenches or directional drilling)
- Slinky/ring collectors
- Spiral/earth basket collectors
- Foundation-integrated systems (energy piles, diaphragm walls.

Vertical BHE performance is strongly affected by geological and hydrogeological conditions. Groundwater flow enhances advection and can replenish heat around boreholes, benefiting unbalanced systems but undermining BTES storage concepts. In stagnant groundwater settings, conduction dominates. Consolidated rocks often have higher thermal conductivity than unconsolidated sediments, while near-surface ground temperatures are influenced by climate and surface conditions.

Design variants (vertical)

Two main exchanger families are widely used:

- U-pipe exchangers, with downward flow in one channel and upward flow in the other (single/double/triple).
- Coaxial/concentric exchangers, with flow in an inner and outer channel; in competent rock, the borehole wall can sometimes act as the outer boundary, though liners may be required for hydraulic sealing.

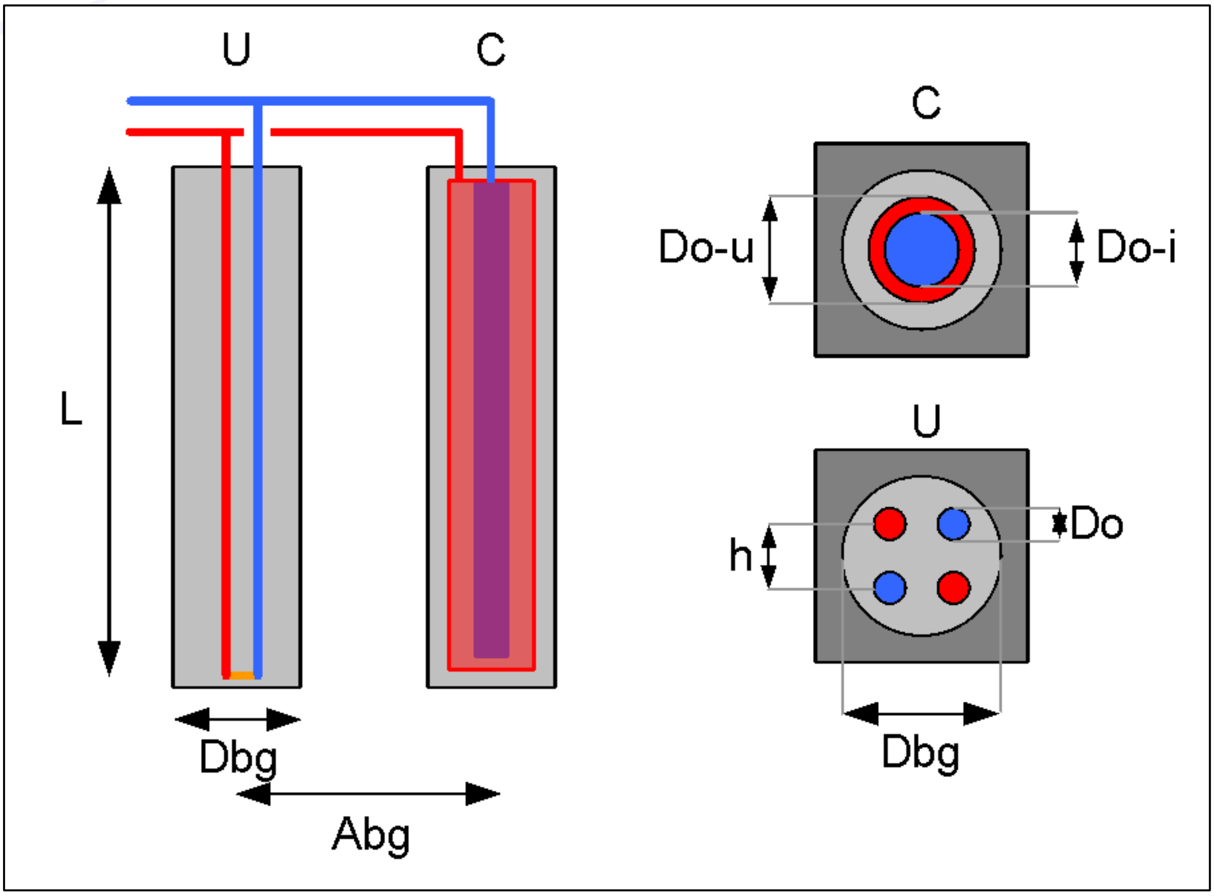

Figure 34: U-pipe and concentric heat exchangers

The main construction parameters for the heat exchangers (source: Groenholland/ISSO 73). L: active length of the ground heat exchanger. Dbg: Borehole diameter, typically between 0.1 and 0.2 m. Abg: Distance between adjacent boreholes, this depends on the depth of the borehole but in general it will vary from 3 meters (shallow boreholes, < 50 m) to 5 meters (borehole depth 50 – 150 meters) and 7 meters or more (deeper boreholes). Another factor affecting Do-u: outer diameter of the outer pipe.

Do-i: outer diameter of the inner pipe (and inner diameter of the outer channel) Do: outer diameter pipe (U-pipe heat exchanger) h: distance between the up- and downflowing channel in the U-pipe heat exchanger, when spacers are not used this is usually the average between touching pipes and the pipes touching the borehole wall.

Horizontal collectors and seasonal near-surface effects.

Horizontal collectors are installed at shallow depths (typically 1–2 m), benefiting from low excavation costs but being sensitive to seasonal temperature changes. Soil thermal conductivity and heat capacity depend strongly on moisture content; air-filled voids reduce performance. Freeze–thaw effects can provide latent heat during winter operation, but design must avoid creating persistent frozen blocks that delay spring regeneration.

Materials: polymer pipes and key mechanical parameters.

Most collectors are manufactured from plastics, primarily HDPE (PE100). Variants include PE-RC (crack resistant), PE-RT (high temperature resistant), and PE-X (crosslinked). Barrier coatings (co-extrusion or post-coating) can reduce diffusion (e.g., oxygen ingress).

Key durability parameters include:

- MRS (Minimum Required Strength): for PE100 typically 10 MPa (at 20 °C, 50 years)
- Stress crack resistance and rapid crack propagation resistance
- SDR (Standard Dimension Ratio) and MOP (Maximum Operating Pressure), typically:
- $MOP = 2 \cdot MRS / (C \cdot (SDR - 1))$
- Example (corrected): PE100, OD 32 mm, SDR 11, MRS 10 MPa, design factor C = 1.25 → MOP ≈ 1.6 MPa ≈ 16 bar.

Temperature reduces allowable pressure (typical reduction factors ~0.87 at 30 °C and ~0.74 at 40 °C), which constrains high-temperature operation over long lifetimes. U-pipe systems also rely on factory-welded footers (U-bends), where both mechanical strength and local pressure loss are important.

Advanced collectors and niche concepts

Recent developments include high-conductivity coaxial collectors (e.g., stainless steel outer pipes and enhanced plastics), improved grouts, and installation methods that reduce drilling time (e.g., GEO4CIVHIC concepts). Other concepts include direct expansion (refrigerant in copper ground loop), thermo-siphons, and freezing-based systems exploiting latent heat near 0 °C (Eslami-Nejad and Bernier, 2012). Each concept requires careful compatibility checks with corrosion risk, local regulations, and long-term durability.

Drilling technologies, hybridisation pathways, and performance frameworks

Drilling is a key cost and schedule driver for ground source projects. Classification can be made by tool type, drive mechanism, purpose, geology, cuttings transport, borehole construction (cased vs open), diameter, and precision (including steerable drilling). In practice, selection depends on the expected lithology, groundwater conditions, target depth/diameter, site constraints, and local contractor capabilities.

Traditional and widely used methods (shallow geothermal relevant).

- Impact drilling (shell/rope): simple and robust but slow; still used in some geotechnical contexts.
- Rotary auger drilling (bucket/tube augers; continuous spiral augers): fast in soft to medium materials, limited in hard rock; often used for shallow manifolds.

- Mud rotary drilling: the most common method for BHE installation; direct circulation is common for BHEs; reverse circulation supports larger diameters and better sampling.
- Down-the-hole (DTH) hammers (air or water): high penetration in rock; water-powered hammers (e.g., Wassara) provide an alternative flushing approach.
- Sonic drilling: high core recovery and speed in overburden; increasingly relevant for constrained sites.
- Simultaneous casing systems: single-head and double-head solutions stabilize difficult formations and reduce collapse risk.

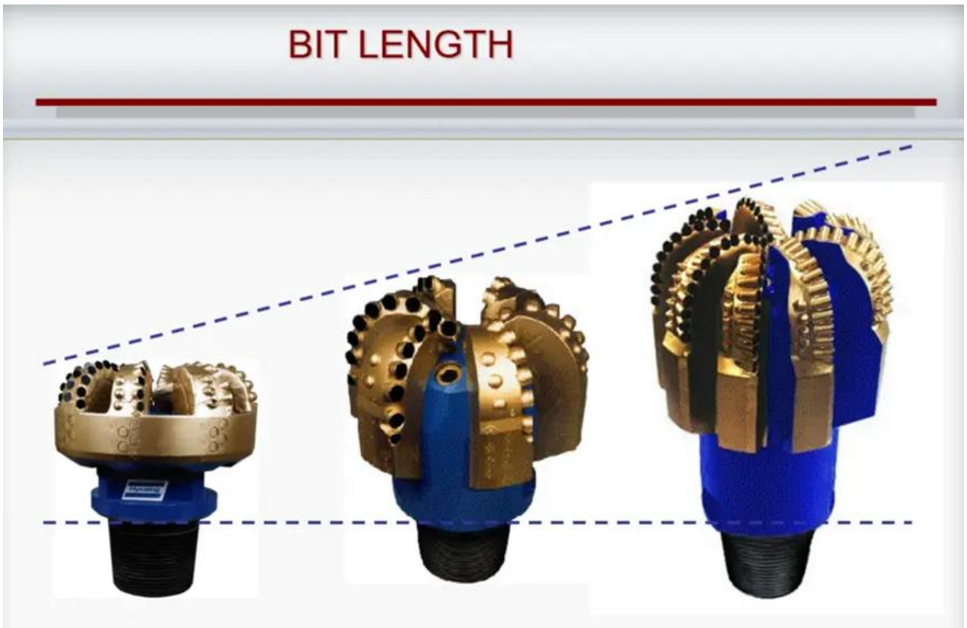

Figure 35: Types of diamond drill bits.

(https://www.drillingmanual.com/pdc-drilling-bit-design-guide-components/)

Novel and emerging methods

Several technologies are under development or niche deployment: plasma drilling, water jet drilling (geoJETTING), "Easy Drill" / EEDT piling-integrated approaches, geothermal radial drilling (GRD), VibroDrill (GEO4CIVHIC), and high-energy concepts such as electric impulse technology (EIT), millimetre wave drilling, melting drilling, and bio-inspired methods. These approaches aim to reduce drilling time, energy use, noise, and spoil generation, but often face cost and scale-up barriers.

*Drilling technologies and those used for installation of geothermal energy systems. *: in use for geothermal*

+: potential use for geothermal.

All Drilling technologies	Used for Closed loop geothermal systems	Used for Open loop geothermal systems
Impact drilling / shell and auger	•	
Spiral (hollow stem) auger drilling	•	
Mud rotary straight flush	•	
Mud rotary reverse circulation	•	•
Ramming		
Down the hole hammer, air hammer	•	•
Down the hole hammer, water hammer	•	•
Sonic drilling	• (+)	+ (?)
Plasma drilling		
Water jet drilling		
"Easy drill" and "Enlarged Easy drill" method	•	?
Geothermal radial drilling	•	?
Vibrodrill method	•	?
Fire Jet drilling		
Erosional drilling		
Electric impulse drilling		
Millimetre wave drilling		
Melting drilling		
Earthworm-like drilling		
Explosive drilling		

Hybridisation of ground sources (source-side and user-side)

Hybridisation can reduce CAPEX, improve seasonal balance, and mitigate long-term ground temperature drift.

- User-side hybridisation: GSHP combined with ASHP, boilers, DH networks, or solar-assisted systems to cover peak loads and improve operational economics.
- Source-side hybridisation: coupling ground systems with additional heat sinks/sources (surface water, dry coolers, solar thermal regeneration, PVT, waste heat) to improve thermal balance and long-term performance.

Surface water hybrid GSHP

Surface water heat exchangers can reduce ground heat rejection in cooling-dominated buildings, mitigating long-term heat build-up and COP degradation, case study is described by Liu et al., (2014).

Solar/PV/PVT coupling

PV systems can provide electricity for heat pumps and auxiliaries; solar thermal can support DHW, space heating, and ground regeneration during excess production. Design requires careful sizing based on load, insolation, available area, and economic assumptions (payback, incentives, O&M).

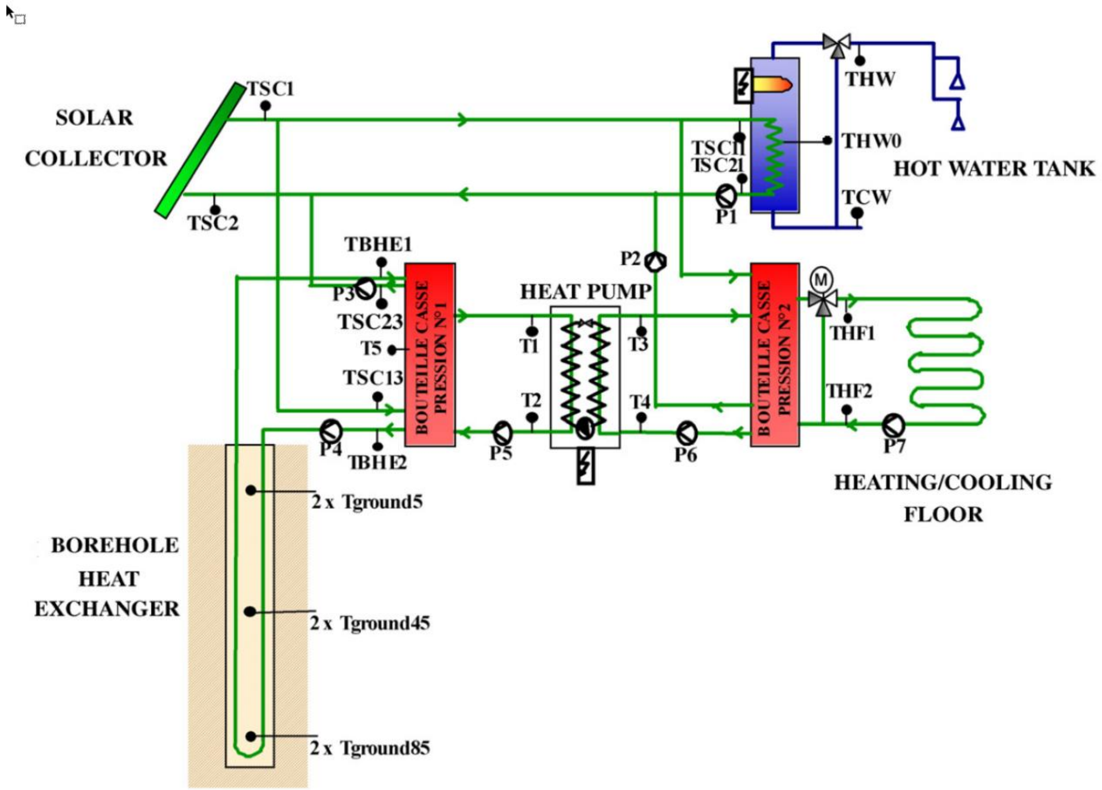

Figure 36: Geothermal heat pump with solar thermal collector

District heating/cooling networks and storage

Low-temperature district networks (e.g., 5GDHC) and Power-to-Heat concepts enable broader integration of shallow geothermal, thermal storage, and bidirectional energy exchange. Ground and groundwater storage (ATES/BTES) can support seasonal balancing; pit thermal storages and other TES options can reduce peak capacity requirements.

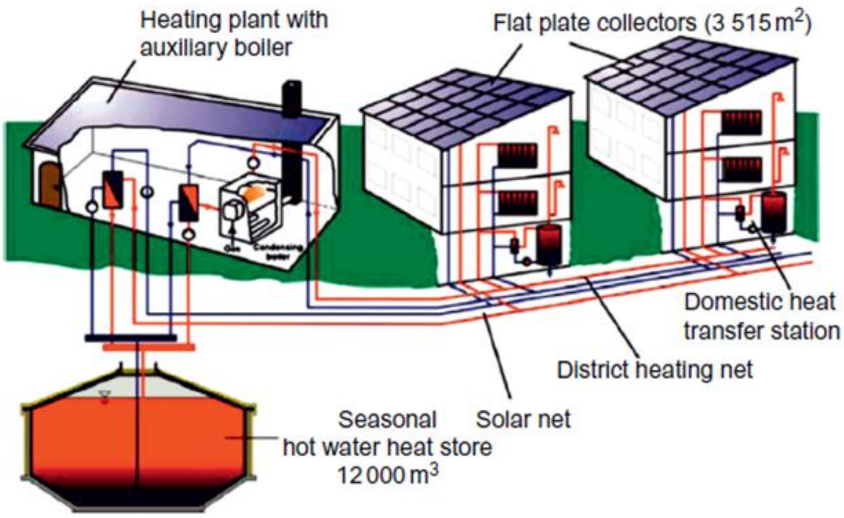

Figure 37: Schematic layout of hot water cavern TES system

(Kalaiselvam and Parameshwaran 2014)

Phase Change Materials (PCMs)

PCMs can increase storage density by leveraging latent heat during phase transitions. Potential benefits include load shifting, improved heat pump cycling, and reduced peak demand, but challenges remain in material selection, encapsulation, integration design, and cost.

Strategic assessment: SWOT and KPIs

The GeoBOOST SWOT framework evaluates technologies across delivery, permitting, CAPEX/OPEX, environmental impacts, replication potential, and market awareness. In parallel, an initial KPI inventory supports consistent comparison across locality types, climate zones (EN 14825), heat pump variants, control systems, application scales, storage integration, and drilling technologies.

Deliverable D5.2 - European Modular Course System for Massive Online Open Course (MOOC) to optimize and extend the existing GEOTRAINET training framework

GeoBOOST also launched a European Massive Open Online Course (MOOC) to deliver high-quality, standardized training on shallow geothermal energy and GHP technologies. The course targets a broad audience—drillers, planners, installers, designers, consultants, policymakers, students, and newcomers—progressing from fundamentals to applied practice.

Learning format includes:

- Video lectures,
- Technical reading materials,
- Interactive quizzes and exercises (multiple-choice, matching terms with definitions, true/false).

Expected outcomes for learners include a solid grounding in geothermal/heat pump principles; comparison of system types (borehole, groundwater, horizontal); integration into energy-efficient buildings and renewable systems; core geological and drilling considerations; EU-wide environmental/legal/permitting frameworks; and practical monitoring, maintenance, and troubleshooting skills—aligned with EU guidance on harmonized qualifications and best practices.

Participants learn GHP fundamentals, compare borehole/groundwater/horizontal systems, integrate GHPs into efficient buildings, understand site selection, drilling and legal frameworks, and gain basics of monitoring, maintenance, and best-practice operation. More information will follow.

MOOC Contents

- MOOC is Chronological: Content is organized in a sequential, step-by-step order. (6 Weeks - 1 Module per week (Module 1 = 2 weeks)
- A Support Forum (Q&A) is created where participants can exchange questions and knowledge

Learning Materials consist of Video Lectures: Core concepts of MOOC, Reading materials: PDFs/Reports and quizzes after each submodule (e.g., Multiple choice questions, True or false questions, Matching exercises)

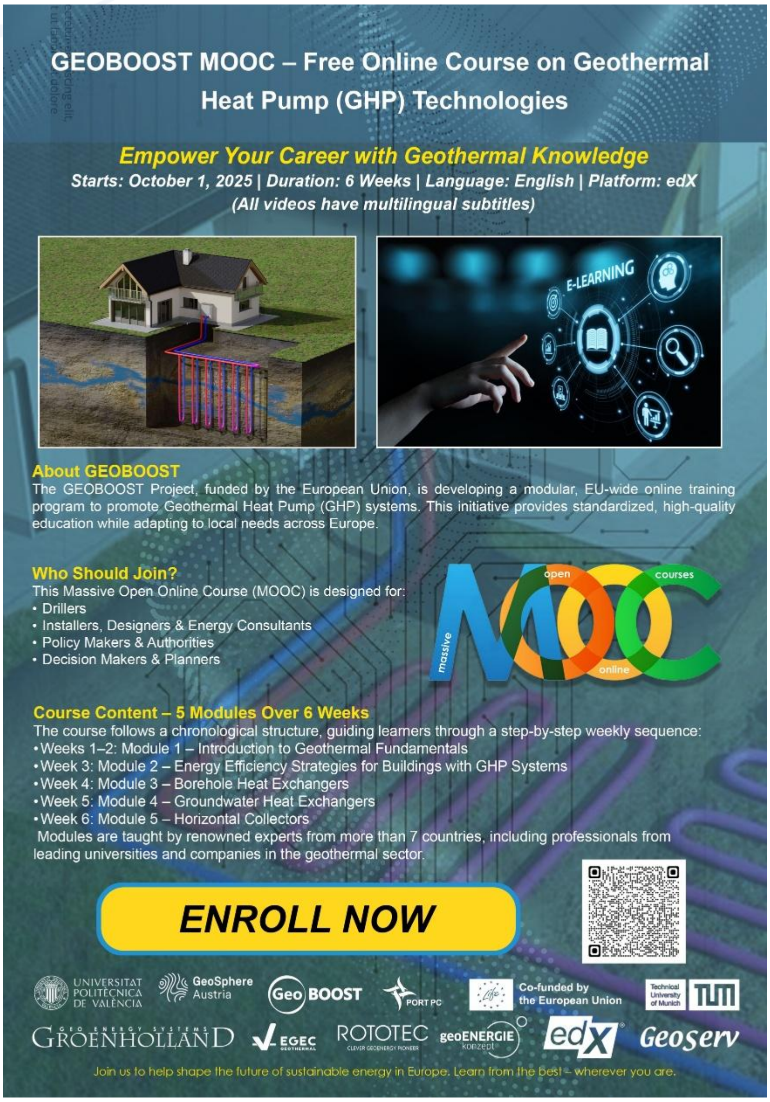

Figure 38: The poster for the MOOC

- Module 1: Introduction to Geothermal Fundamentals *(11 Submodules)*
- Module 2: Energy Efficiency Strategies for Buildings with GHP Systems *(3 Submodules)*
- Module 3: Borehole Heat Exchangers (BHE) *(5 Submodules)*
- Module 4: Groundwater Heat Exchangers (GWHE) *(5 Submodules)*
- Module 5: Horizontal Collectors *(4 Submodules)*

All course content, including modules and submodules, are fully accessible to all participants (after release), regardless of their target group or profile. A questionnaire is included during the enrolment/registration process to help identify the participant’s profile.

The MOOC “Specialization in Shallow Geothermal Energy: Skills Development and Training Across the EU”, launched on the edX platform on October 1st, has achieved encouraging participation figures during its first weeks. As of now (Mid Nov), the course has reached a total enrolment of 365 learners, of which 58 have paid for the verified track to receive a certificate. Participants represent 64 different countries or regions, reflecting the strong international outreach of the program. The top three countries by enrolment are Spain (15%), Portugal (12%), and the United States (10%).

Regarding educational background, the course attracts a highly qualified audience: 4.8% of learners hold a high school diploma or less, 34.5% have a college degree, and 60% possess an advanced degree. These indicators confirm that the MOOC is successfully engaging professionals and students with a solid academic foundation who are interested in deepening their knowledge of shallow geothermal energy technologies across Europe and beyond.

Deliverable D5.3 - User-tailored catalogue of good practice business models to implement geothermal heat pumps systems at different scales

The aim

This deliverable responds to a central barrier to shallow geothermal deployment: not technology, but business and financing models. It compiles a user-tailored catalogue of proven and innovative business models for geothermal heat pump (GHP) systems at different scales, from single houses to district energy networks. Using real cases from partner countries and the Business Model Canvas framework, it translates scattered experiences into structured guidance. The catalogue is intended as a practical tool, not a theoretical exercise, helping stakeholders see who invests, who owns, who operates, and who pays in each model. Ultimately, it shows how GHPs can be turned from technically mature yet niche solutions into mainstream, bankable options in the heating and cooling market.

GHPs in the Energy Transition and Current Barriers

Heating and cooling represent roughly half of Europe's final energy demand and remain heavily fossil-fuel based. GHP systems offer high efficiency, low emissions and long lifetimes by using the stable temperature of the ground for heating and cooling, often reaching seasonal performance factors far above conventional HVAC. They are particularly attractive where gas phase-out, climate targets and high fuel prices coincide. However, market penetration remains limited because of high upfront CAPEX, complex permitting, lack of awareness, and a shortage of clear, replicable business models. Traditional economic evaluations often undervalue long-term savings and resilience. GeoBOOST therefore links improved techno-economic analysis with business model design, integrating life-cycle thinking, risk management tools and new financing channels such as green bonds and climate funds.

Purpose and Scope of the Business Model Catalogue

The catalogue is meant as a structured reference for decision-makers—from homeowners to utilities and municipalities—who need to quickly understand which business model can work for their specific context. It covers three main capacity scales: small (<20 kW, primarily residential and small commercial), medium (20–150 kW, multi-family, commercial and institutional) and large (150 kW to multi-MW, district energy and industry). For each scale, it discusses typical applications, ownership and financing structures, stakeholders, revenue mechanisms and enabling policies. It also highlights best-practice examples and common challenges. Rather than promoting a single "best" model, the catalogue demonstrates a toolbox of options that can be adapted to local geology, regulation, energy prices, and customer preferences, making it easier to match projects with suitable investment approaches.

Benefits of GHPs as a Business Opportunity

Besides decarbonization, GHP systems deliver a bundle of business-relevant benefits. They significantly reduce CO_2 emissions by replacing fossil-fuel boilers and integrate well with renewable electricity, supporting net-zero strategies. High efficiency translates into 30–70% energy savings compared to traditional systems, making long-term operating costs predictable and attractive. Their scalability—from single houses to districts—opens opportunities for developers, ESCOs and utilities across many segments. Long lifetimes of underground components improve asset value and support long-dated financing. GHPs also contribute to grid stability by reducing peak loads and enabling thermal storage, especially when combined with UTES (ATES/BTES). Finally, they create local jobs in drilling, design, installation and maintenance, reinforcing regional value chains and aligning with ESG investment criteria.

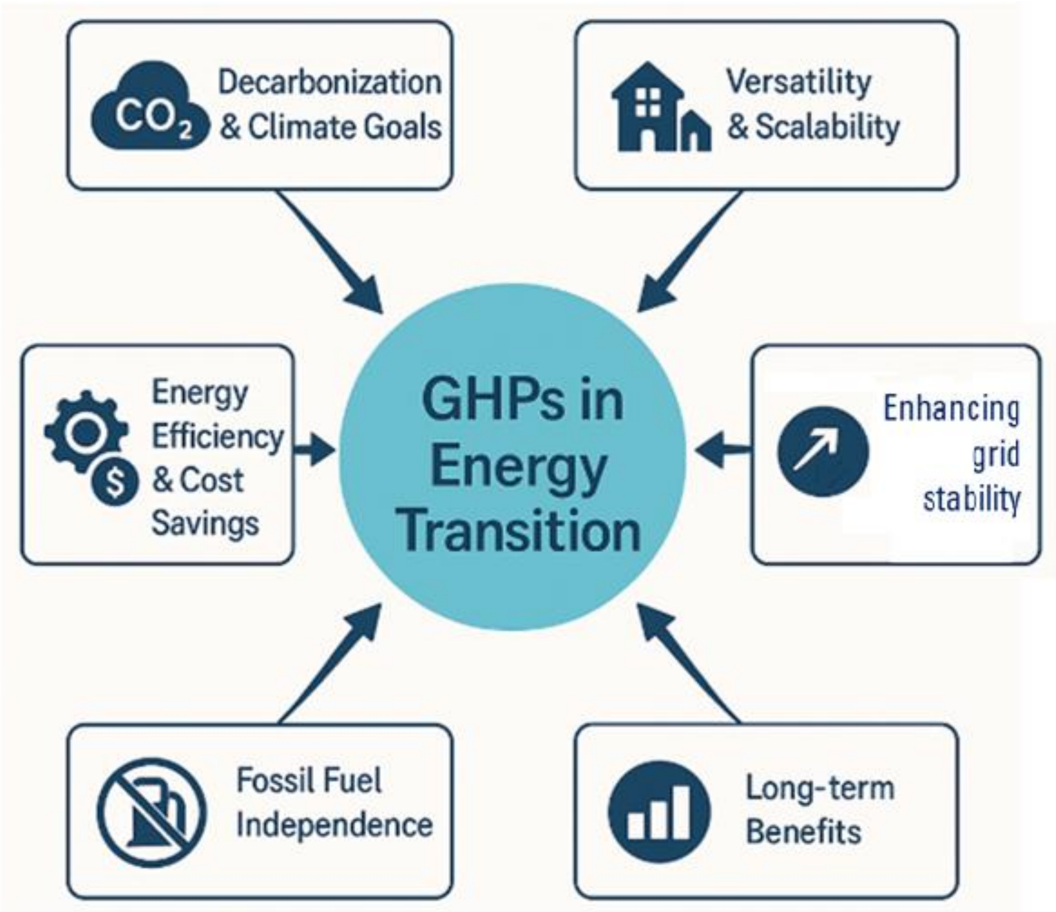

Figure 39: Main benefits of GHPs in energy transition

Key Stakeholders and Their Roles in GHP Deployment

Successful GHP business models require coordinated action from multiple stakeholder groups. Utilities and ESCOs can finance, operate and maintain systems, offering service-based contracts and taking performance risk. Financial institutions, from local banks to development banks, provide capital and risk-sharing instruments, sometimes via green bonds or climate funds. Policy-makers and regulators shape incentives, permitting rules and building standards that can either accelerate or hinder projects. Drilling companies, geologists and designers are crucial for site assessment, well construction and robust sizing of ground heat exchangers. Technology providers and installers deliver the hardware and ensure quality implementation. Finally, end-users—homeowners, businesses, municipalities, housing companies and cooperatives—decide whether to invest, lease, or buy "heat as a service", making their risk perception and awareness central to model selection.

Market Trends and Emerging Opportunities for GHPs

The GHP market is influenced by broader trends: decarbonisation, electrification, urbanisation and rising energy prices. Many countries tighten building codes, introduce carbon pricing and increase subsidies for efficient heating, which favours GHP systems. District heating and cooling networks, especially low-temperature "5th generation" grids, create new niches where GHPs and UTES act as backbone technologies. Technological progress—better drilling methods, smart controls, hybrid systems with PV or waste heat—reduces costs and broadens applicability. Emerging opportunities include retrofits in existing buildings, industrial process heating/cooling, energy communities and geothermal sharing grids. Globally, developing regions with growing demand begin to explore GHPs, supported by organisations like IRENA. These trends expand the room for innovative business models that bundle technology, financing and digital services.

Figure 40: Market trends

Overview of Core Business Model Archetypes

The catalogue identifies several recurring business model patterns across scales. Traditional ownership models see the end-user buying and owning the GHP system, often supported by subsidies. Rental and leasing models shift CAPEX into predictable monthly payments, sometimes with buy-out options. Energy-as-a-Service and Heat-as-a-Service models let customers pay for delivered comfort or heat, while a third party owns and operates the system. Utility-led on-bill models integrate repayment into the electricity or heat bill, tied to the meter. ESCO models use performance-based contracts where repayment is linked to verified energy savings. At larger scales, Public-Private Partnerships, district geothermal networks, community/co-operative ownership and green-bond-financed infrastructures become prominent. Carbon credit and climate-finance mechanisms add additional revenue or risk-mitigation layers for large projects.

Characteristics of Successful GHP Business Models

Effective GHP business models share several core characteristics. They start from a clear, customer-centric value proposition—cost savings, comfort, climate impact, resilience or property value—and tailor the offer to residential, commercial or public clients. Financial feasibility is addressed through suitable mixes of CAPEX, OPEX, incentives and financing tools, with transparent payback and ROI. Scalability and replicability are supported by standardised processes and modular system designs. Strong stakeholder integration is crucial: roles and responsibilities of utilities, ESCOs, drillers, designers, and financiers must be clearly defined. Robust risk management covers technical uncertainty, financial risk and regulatory changes, often via guarantees or performance contracts. Successful models also leverage digitalisation, smart controls and monitoring to guarantee efficiency and support long-term customer relationships.

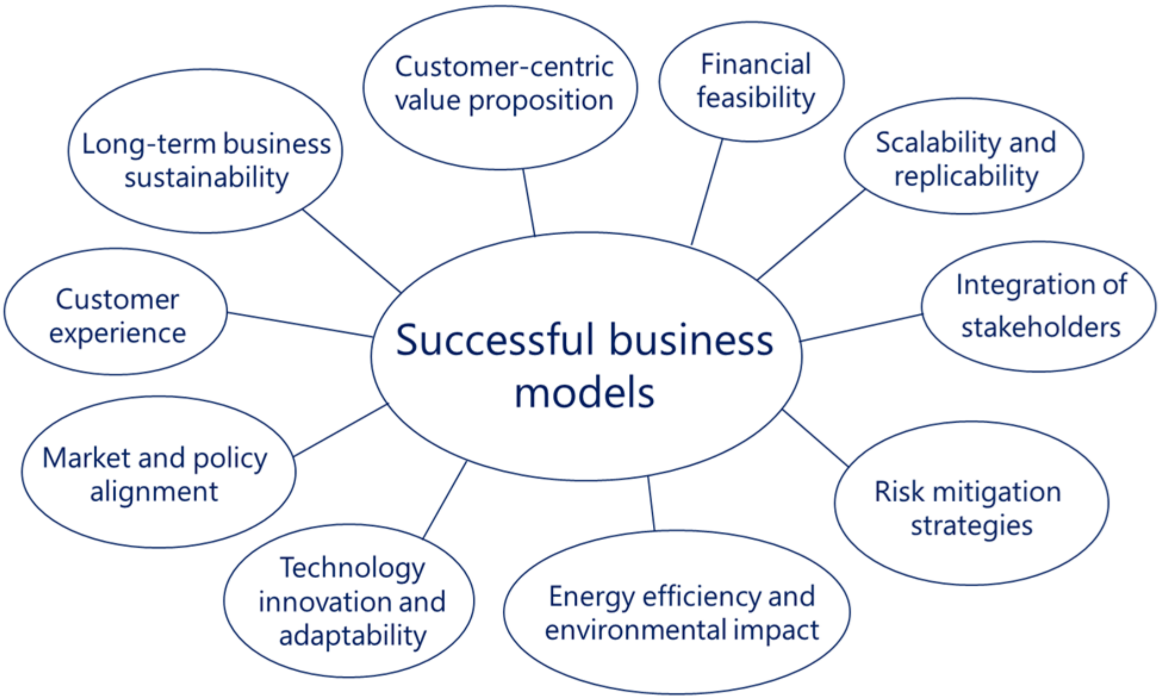

Figure 41: Key characteristics of successful business model

Factors Shaping the Choice of Business Model

Selecting a suitable business model depends on a combination of technical, financial, market and policy factors. Site conditions (geology, groundwater, drilling complexity) and project scale influence CAPEX, system design and risk allocation. The availability of subsidies, tax credits, grants or carbon pricing heavily affects payback times and bankability. Different customer segments have distinct risk appetites: homeowners tend to prefer simple, low-risk offers, while institutional or industrial clients may accept complex ESCO contracts in exchange for guaranteed savings. Market maturity and awareness determine whether advanced models like HaaS are accepted or whether more traditional ownership is still needed. Regulatory frameworks shape what utilities, municipalities or private companies are allowed to do, including on-bill recovery, third-party ownership and access to public land or data.

Business Model Canvas as Analytical Framework

To systematically capture and compare business models, the catalogue uses Alexander Osterwalder's Business Model Canvas. Each case is analysed through nine building blocks: customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partners and cost structure. This provides a common language to describe very different actors—retailers, manufacturers, ESCOs, utilities, project developers and municipalities—on a comparable basis. The canvas makes visible where models are customer-driven, which resources are critical (e.g. drilling expertise, capital, data platforms), and how revenue and costs flow. It also highlights gaps, such as missing partners, unaddressed risks or weak customer relationships. The method thus serves both for documenting existing good practice and for designing new, more robust business models around GHP systems.

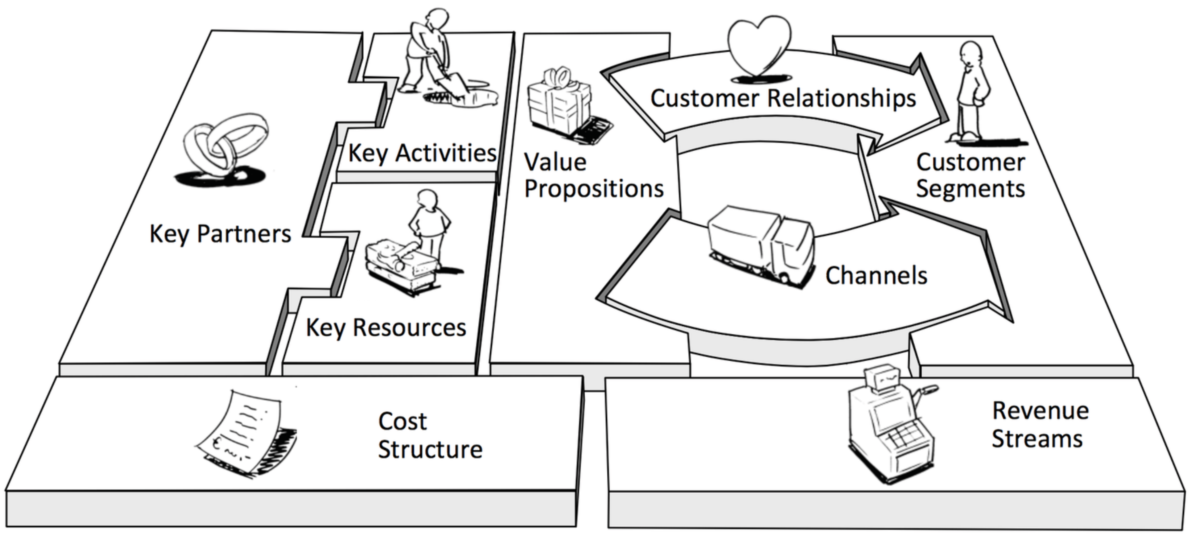

Figure 42:Business Model Canvas by Alexander Osterwalder (Pereiera, 2024)

Small-Scale Models: Retailers, One-Stop Shops and Leasing

At small scale, the dominant pattern remains the traditional retailer model, where homeowners or small businesses purchase GHP systems from HVAC or renewable energy suppliers. Customers coordinate drilling, permitting and subsidies themselves, often relying on separate installers and consultants. An evolving variant is the manufacturing "one-stop shop", where a single brand or group offers design, permitting support, drilling, installation, financing and after-sales service under one roof. Rental and leasing models further reduce upfront barriers by turning CAPEX into monthly payments, sometimes bundled with maintenance. Small-scale deployment faces specific challenges: high upfront cost relative to household budgets, limited awareness, complex permitting and space constraints. Solutions include turnkey services, better communication of payback, and innovative layout options such as inclined boreholes or shared fields.

Medium-Scale Models: Communities and ESCOs

For multi-family buildings, commercial blocks and institutional facilities, shared ownership and ESCO models become particularly relevant. Community-based or co-operative structures allow several buildings to share a central borehole field or geothermal network, spreading costs and risks while achieving economies of scale. Governance is often handled via co-ops, municipal companies or local utilities. ESCOs, meanwhile, provide comprehensive energy services—design, financing, installation and operation—under performance-based contracts where repayment depends on realised savings. These models are well-suited to medium loads but must deal with higher technical complexity, integration into existing buildings, and more demanding permitting. They benefit from careful feasibility studies, robust monitoring, and hybrid solutions that combine GHPs with other technologies to manage peaks and ensure ground thermal balance.

Large-Scale Models: Utilities, PPPs and Green Finance

At large scale—district heating, campuses, industrial parks—GHP systems require substantial capital and long planning horizons, making utility-driven and public-private structures central. Utility-led on-bill models finance customer-side systems and recover costs through energy bills over long periods, while still letting end-users benefit from savings. Heat-as-a-Service can be offered by utilities or specialised project developers who own the infrastructure and sell guaranteed comfort or heat supply. Public-Private Partnerships combine municipal policy goals and public land with private capital and expertise, especially for district networks. Green bonds and climate financing instruments provide attractive, long-term funding for such capital-intensive projects, provided that robust monitoring, reporting and verification frameworks are in place. Large-scale projects must also address complex permitting, system integration and political acceptance.

Innovation Vectors: Flexibility, Hybridisation and Digitalization

Future GHP business models will increasingly monetise flexibility, integration and data. Because of their thermal inertia and ability to store heat and cold in the ground, GHP systems can participate in demand response, capacity markets or virtual power plants. Business models may thus add “flexibility-as-a-service” revenues on top of heat sales. Hybrid systems that combine GHPs with PV, wind, waste heat or other renewables enable self-consumption strategies and net-zero energy concepts. Digital technologies—IoT sensors, AI-based control, digital twins and customer apps—support predictive maintenance, dynamic pricing and HaaS models focused on comfort rather than kWh. Policy and regulation can accelerate these innovations through sandboxes, standardised contracts and incentive schemes that reward flexibility, emissions reductions and life-cycle performance.

Target Groups and Tailored Recommendations

The catalogue offers differentiated guidance for key audiences. Homeowners and small businesses are encouraged to use leasing, on-bill or HaaS models to overcome upfront cost barriers and to participate in community projects where possible. Commercial developers and institutional owners should integrate GHPs early in planning, using ESCO contracts, shared-loop systems or district networks to benefit from scale. Industrial facilities can exploit GHPs for process heating and cooling, often combined with PPP or carbon-credit-supported models. Governments and municipalities are advised to provide stable policy frameworks, streamline permitting, support district-scale projects and invest in capacity building for planners, drillers and installers. Financial institutions are invited to develop tailored products—green loans, bonds, guarantees—that reflect the long lifetimes and low operating risks of well-designed geothermal systems.

Business Model Selection Toolkit and Overall Conclusions

To make the content actionable, the catalogue concludes with a Business Model Selection Toolkit—a recommendation matrix that links project type, scale, capital availability and sustainability goals with appropriate business model options. For example, small residential projects with limited capital may favour leasing or HaaS, while district networks with strong public involvement may combine PPPs, utility-led models and green bonds. Across all scales, the central message is that business model design is as important as technical design for GHP success. Tailored, well-structured models can overcome cost, risk and knowledge barriers, turning GHPs into mainstream contributors to Europe's climate neutrality, energy security and local job creation. The call to action is clear: stakeholders should actively adopt and adapt these models to accelerate geothermal deployment now.

Conclusion

The GeoBOOST project confirms that GSHPs—including closed-loop ground heat exchangers and open-loop groundwater systems—are a mature, high-efficiency pathway for decarbonising Europe's heating and cooling sector and a strategic solution for improving energy security and enabling low-temperature buildings and networks. Despite this, European deployment remains uneven, not because GSHP technology maturity, but because market scaling depends on a coordinated "enabling system": reliable data, predictable permitting, strategic energy planning (interference-aware) planning in dense areas, finance that addresses upfront CAPEX, and consistent quality in design, installation, and operation.

One of the common European market outcomes of GeoBOOST is that data governance is a market accelerator. In mature markets where registration, reporting, and monitoring are comprehensive (with clear definitions and usable datasets), planning and deployment of GSHPs is faster, investment risk falls, and public authorities can manage cumulative impacts. In less mature markets, where data remains fragmented, countries struggle to benchmark performance, improve rules, or confidently deploy systems, especially in dense urban environment such as cities. The project therefore reinforces a simple lesson: if the GSHP market share to grow at scale, the technology and it's potential to decarbonise heating and cooling must be visible through system registers, through local and municipal energy planning layers, and in long term performance monitoring—at least to a level proportionate to risk and system size.

A second core outcome is that thermal interference is not a niche engineering detail, but a governance challenge. GeoBOOST clarifies the practical distinction between interaction (within one system) and interference (between systems and other users). This distinction is translated into operational regulation elements and real planning-tool archetypes. This enables a shift away from "case-by-case uncertainty" towards a regulated, tool-assisted decisions making process that remains efficient whilst protecting groundwater, avoiding performance losses, promoted sustainable subsurface use as a shared resource over decades.

Thirdly, GeoBOOST shows that financing models underpin the economic viability of the technology and define the most appropriate subsidy levels that are required to accelerate the deployment of the sector. A recurring barrier across EU countries is the CAPEX–OPEX mismatch. The lifecycle assessment of GSHPs demonstrates that the technology performs better due to lower operational and maintenance costs as well as significantly reduced carbon emission and electrical inputs. However, reimbursement-based support schemes often create a cashflow problem to the investor or end user as they do not mitigate for the high capital cost outlay requirement. The project's affordability logic and financial mechanism catalogue, point to practical solutions that reduce the CAPEX-OPEX mismatch and improve bankability through on-bill repayment, Heat-as-a-Service, performance-based incentives with monitoring, tariff and tax reforms that reward efficiency, and risk-mitigation instruments that lower the cost of capital.

From a technical point, the project emphasizes a realistic message based on real-world project experience and delivery. Successful shallow geothermal systems are complex, not single-component choices. Subsurface assessment, collector/storage selection, heat pump and refrigerant choices, hydraulics, controls, and fluid chemistry are critical to project success. When technical aspects are not adequately addressed (e.g., poor hydraulics, inadequate controls, unmanaged additives), these can aversely affect performance, resulting in reduced SPF and lifecycles. In parallel, the technology catalogue and the business-model catalogue together clearly highlight "what works" by demonstrating that a local and application specific approach is required. These methods demonstrate that replication and scalability can be achieved through both robust engineering and delivery structures that allocate risk and responsibility credibly.

GeoBOOST's dedicated training and education platform (MOOC) addresses a final, decisive constraint: supply chain and capacity. Even the best policies and tools fail if authorities cannot assess projects consistently and if installers and designers cannot deliver reliable performance at scale. The harmonised training MOOC and shared terminology support a common market language—essential for quality, consumer trust, and promotes EU-wide strengthening and development of a skilled workforce.

Priority actions emerging from the GeoBOOST evidence base are therefore clear:

- Establish (or upgrade) standardised registration and monitoring so markets can be measured, planned, and improved.
- Implement risk-tiered, digital, time-bound permitting that is predictable for investors while safeguarding groundwater and the subsurface.
- Deploy interference-aware and spatial energy planning tools and workflows to enable the safe and sustainable deployment of GSHPs in dense urban settings in cities and priority zones.
- Reform support schemes to improve cash flow at the point of purchase and enable service-based models (leasing/HaaS/on-bill), not only direct ownership.
- Promote and train a skilled workforce to deliver quality infrastructure through common training, standard methods, commissioning discipline, and clear performance boundaries, to underpin sustainable deployment and guarantee high SPF and system performance outcomes.

Overall, this Final Report consolidates GeoBOOST's central proposition: scaling the geothermal heat pump sector in Europe is not mainly a technology problem, but rather an alignment problem. When data, regulatory requirements, tools, finance, and skills are aligned, shallow geothermal can move from uneven adoption to a dependable, mainstream pillar of renewable heating and cooling in a sustainable and affordable way at scale.