Report on the financial framework including a catalogue of strategies and measures for fostering future investments

Deliverable 4.2

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Abbreviations

Abbreviation	Description
AAHP	Air-to-air heat pump
ABS	Asset-backed securities
API	Application programming interface
ASHP	Air source heat pump
ATES	Aquifer thermal energy storage
AWHP	Air-to-water heat pump
BEG	Bundesförderung für effiziente gebäude (federal support for efficient buildings, Germany)
BER	Building energy rating
CAE	Certificados de ahorro energético (energy savings certificates, Spain)
CAPEX	Capital expenditure
CEE	Certificats d'économies d'énergie (white certificate scheme, France)
COP	Coefficient of performance
CV	Coefficient of variation
ECO	Energy company obligation (UK)
Eco-PTZ	Éco-prêt à taux zéro (zero-interest eco-loan, France)
EEMI	Energy efficient mortgage initiative
EFSI	European fund for strategic investments
EHPA	European heat pump association
EIA	Energie-investeringsaftrek (energy investment allowance, Netherlands)
EIB	European investment bank
ELENA	European local energy assistance
EMD	Electricity market design
EN 14825	European standard 14825
EPC	Energy performance contracting / contract (via ESCO)
EPEX Spot	European power exchange
EPIC	Efficiency program to incentivise clean energy (policy scenario name)
ESCO	Energy service company
ESG	Environmental, social and governance (
ETS2	Emissions trading system 2
EU	European union
EuroPACE	Eu project piloting property assessed clean energy
GDP	Gross domestic product
GeoBOOST	Boosting geothermal heat pumps to mainstream cost-effective and efficient renewable heating and cooling in building
GHP	Geothermal heat pump
GWP	Global warming potential
HaaS	Heat as a service
HICP	Harmonised index of consumer prices
HP	Heat pump
HPSG	Heat pump system grant (Ireland)
IEA	International energy agency

ISDE	Investeringssubsidie duurzame energie (investment subsidy for sustainable energy, netherlands)
KfW	Kreditanstalt für wiederaufbau (german state bank)
LCC	Life cycle cost
LCOE	Levelised cost of energy
LIFE21	EU LIFE programme
NECP	National energy and climate plan
NWG	Non-residential refurbishment (Germany, part of beg)
OPEX	Operational expenditure
PACE	Property-assessed clean energy (financing mechanism)
PLI	Price level index
PPP	Purchasing power parity
PREE	Programa de rehabilitación energética de edificios (Spain)
PVGIS	Photovoltaic geographical information system (database/tool)
REFIT	Renewable energy feed-in tariff (Ireland)
RHI	Renewable heat incentive (UK)
ROT	Renovering, ombyggnad, tillbyggnad (renovation, conversion, extension, Sweden)
RVO	Rijksdienst voor ondernemend nederland (Netherlands enterprise agency)
SEAI	Sustainable energy authority of Ireland
SPF	Seasonal performance factor
SSRH	Support scheme for renewable heat (Ireland)
UI	Uncertainty interval
UK	United kingdom
VAT	Value added tax
VDI 4640	Verein deutscher ingenieure (German association of engineers) standard 4640
VVE	Vereniging van eigenaren (homeowners' association, Netherlands)
WG	Residential refurbishment (Germany, part of beg)
ZUM	Lista zielonych urządzeń i materiałów (list of green appliances and materials, Poland)

1. Introduction

1.1. Project background and scope of the deliverable

The LIFE21 GeoBOOST project, titled "*Boosting geothermal heat pumps to mainstream cost-effective and efficient renewable heating and cooling in building*", aims to accelerate the widespread adoption of geothermal heat pumps (GHPs) across the European Union (EU). This initiative addresses persistent barriers, including: the lack of comprehensive data and monitoring standards; high upfront capital expenditure (CAPEX) costs; operational expenditure (OPEX) uncertainties; insufficiently developed financial mechanisms and deficient business models; limited regulatory alignment and streamlined processes for authorisation certification, and licensing; workforce skill gaps; and the low awareness of GHP benefits.

To overcome these challenges, GeoBOOST brings together a multidisciplinary consortium of research institutes, companies, and organisations from Austria, Belgium, Germany, Ireland, Netherlands, Poland, Spain, and Sweden.

The present deliverable is developed under Work Package 4 of GeoBOOST. This deliverable concentrates on analysing existing financial frameworks (**Task 4.2**) and generating policy recommendations to reduce financial barriers and ensure more inclusive access to GHP technologies (**Task 4.3**). Ultimately, the deliverable seeks to enhance the economic accessibility of GHP technologies, build investor confidence, and support their broader, more equitable adoption across the EU.

1.2. Main objectives

This deliverable pursues the following main objectives:

- **Examine existing financial frameworks:** Identify and analyse existing national-level public subsidy schemes supporting distributed renewable energy solutions in the GeoBOOST partner countries, with a focus on GHP systems.

- **Establish a new affordability assessment methodology:** Create and implement a new affordability score for evaluating the relative affordability of GHP systems in comparison to alternative technologies, thereby facilitating more informed, evidence-based decision-making among stakeholders.

- **Propose inclusive policy recommendations:** Develop evidence-based policy recommendations to tackle financial barriers through incentive measures that promote long-term investments and business solutions aimed at reducing upfront costs and bridging the gap between CAPEX and OPEX interests.

2. Analysis of current financial frameworks

2.1. In-place subsidies

2.1.1. Background

This section examines the current financial frameworks supporting distributed renewable energy technologies in the following GeoBOOST partner countries: Austria, Germany, Ireland, Netherlands, Poland, Spain and Sweden. The focus is on public subsidy schemes that can foster the adoption of GHPs, specifically those operating at the national level. Aspects considered include, for example, the structure of the subsidies, the types of financial support provided, and accessibility for recipients.

By gaining a collective understanding of the different subsidy schemes, the analysis seeks to identify general strategies employed in each country, discussing their benefits and drawbacks. Also explored are any apparent tendencies or priorities, as well as the potential foundation underpinning subsidy designs.

While funding schemes for distributed renewable energy systems are constantly changing, this analysis will always retain historical value. Overarching insights about how subsidy schemes are structured, implemented, or prioritised can remain relevant for guiding future developments. For that reason, specific amounts are not the focus in the country narratives.

The analysis is based on responses gathered through a targeted questionnaire to the project partners (**Appendix 1**). Below, the questionnaire's methodology is outlined, followed by a narrative describing the situation in each country.

2.1.2. Questionnaire methodology

Structure

A structured questionnaire was prepared to collect information on GHP subsidies in the participating countries. It is divided into major sections, each focused on a specific subsidy (e.g., Subsidy 1, Subsidy 2, Subsidy 3) with each section further categorised into sub-sections covering key financial details, eligibility criteria, and stakeholder perceptions. This layout allows respondents to detail individual subsidy programmes in a systematic way.

The questionnaire included a mix of closed and open questions. This means respondents could choose from predefined options for some questions, while providing detailed explanations where needed. This way enabled collecting both quantitative data and qualitative information.

Application

The questionnaire was distributed electronically to the project partner network. Each country was represented by a single, completed questionnaire. To supplement initial responses, follow-up discussions were conducted if deemed necessary. The purpose was to clarify certain aspects and obtain additional context.

2.1.3. Austria

Austria's financial framework is discussed based on six reported subsidy schemes. Four of these subsidies target private individuals (including a special scheme for low-income households), while two are aimed for businesses. National-level subsidies can generally be supplemented by additional regional support, typically from Austria's nine autonomous federal provinces. **Table 1** outlines the main features of the reported subsides.

Table 1. Austria's outline of the reported subsidy schemes.

Main features	Description
General purpose	To accelerate the transition from fossil-fuel-based heating systems to renewable and energy-efficient technologies across various target groups.
Supported technologies	The subsidy schemes support a variety of technologies, including GHPs, air-water HPs, water-water HPs, wood-based heating systems (wood chips, pellets, and logs), and connections to climate-friendly or high-efficiency district heating networks. The use of air-air HPs is explicitly excluded.
Target groups	The subsidies are structured to cover different groups: • Private households: Subsidies for smaller-scale residential applications, including both single-family and multi-storey residential buildings. • Businesses: Specific programs for larger-scale commercial or public installations. • Low-income households: A special program targets the lowest-income third of Austrian households, offering enhanced support.
Funding model	Non-repayable grants is the main type of financial support. Grants are provided as a percentage of eligible costs or capped amounts. Subsidy amounts vary based on technology type and system size (capacity). Bonuses and tiered incentives further refine the basic funding model. The reported subsidies reimburse between 30% and 100% of eligible costs.
Bonuses	Bonuses are available in most schemes. For example: (1) geothermal drilling bonus; (2) centralisation bonus per residential unit in multi-storey buildings; (3) bonus for switching to a continuous low-temperature heat distribution system; (4) specific gratuities tied to solar thermal system integration and to the replacement of a gas stove with an electric stove; (5) for businesses using renewable electricity, low-GWP refrigerants or having environmental certifications (e.g., EMAS).
Eligibility conditions	Applicants must comply with specific eligibility standards, which vary by program. Common technical criteria for HPs are: (1) compliance with the EHPA quality seal; (2) compliance with refrigerant GWP thresholds; (3) the maximum flow temperature of the heat distribution system must not exceed 55 °C. In addition, a scheme targeting businesses, particularly those for larger installations (Wärmepumpen ≥ 100 kW thermische Leistung), require a minimum SPF of 3.8. Some programs exclusively support the replacement of fossil fuel-based heating systems in existing buildings, while others also allow for installations in new constructions. Income-based eligibility criteria are evidently set for the program targeting low-income households (Sauber Heizen für Alle 2024).
Subsidy names	(1) Raus aus Öl und Gas – Private, one or two-family houses or terraced houses; (2) Raus aus Öl und Gas – Private, multi-storey residential buildings or terraced housing complexes; (3) Raus aus Öl und Gas – Erneuerbare Wärmeerzeugung < 100 kW; (4) Wärmepumpen ≥ 100 kW thermische Leistung; (5) Sauber Heizen für Alle 2024; (6) Tausch erneuerbarer Heizungssysteme.

Interpretation & Critical Analysis

The considered subsidy programs demonstrate a strategic intent to accelerate the adoption of renewable energy technologies by addressing their high upfront costs for private households and businesses. The special consideration for low-income households reflect an effort to attain equitable distribution of benefits.

The technological portfolio reveals both strengths and limitations. While the programs support diverse heating solutions, including GHPs with higher subsidies and drilling bonuses, the absence of GHP-specific programs suggests they are not in the spotlight. Coupled with the exclusion of air-to-air HPs, there is an explicit prioritisation of district heating in feasible areas. That is, if a connection to a highly efficient or climate-friendly local district heating network is not possible, then subsidies for other technologies apply. This indicates a clear strategic preference for large-scale infrastructure over individual heating systems. This approach enables widespread decarbonisation and cost efficiencies through economies of scale. However, nothing is without limitations. The priorisation risks technological lock-in, affecting long-term flexibility. While technologies like GHPs also face lock-in due to upfront investments, consumers can still have the choice to replace components, e.g., the heat pump (HP) itself in the future while keeping the ground loops. Consumers of district heating are often bound to a monopoly, losing autonomy. Fossil fuel dependency until networks are fully decarbonised undermines immediate emission reductions. Finally, the constraint on technology choice may have some impact on the adoption of granular renewables like HPs, potentially contributing to geographic disparities. Yet, the emphasis on district heating remains a pragmatic strategy for large-scale decarbonisation efforts.

Current subsidy schemes impose structural restrictions that can hinder innovative business models. Current schemes favour direct ownership models, requiring end-users to own the systems outright. Moreover, one program for companies ("*Wärmepumpen ≥ 100 kW thermische Leistung*") specifies that subsidies are provided only if heating systems are operated for self-supply. These constraints inherently exclude innovative service-based approaches like heat-as-a-service or leasing models. These limitations merit review to avoid restricting beneficial market innovations. Modern energy transitions depend on innovative business models that can help overcome upfront cost barriers.

The financial disbursement mechanism poses a major challenge as well. Applicants are required to cover the entire upfront cost and only receive reimbursement after submitting the necessary invoices and documentation. The main advantage of this mechanism is accountability. However, it simultaneously introduces a key structural barrier to entry. The requirement inherently favours those who have sufficient savings, access to credit, or the ability to handle temporary cash-flow restraints. For lower-income households, coming up with the upfront cost is not trivial, perhaps even prohibitive despite targeted support. This effectively means that the very beneficiaries the programs aim to support may be locked out of participation, undermining their equity and inclusiveness. The absence of government-backed, low-interest green financing options compounds this challenge. Potential solutions include (1) implementing hybrid disbursement mechanisms combining partial upfront payments with later reimbursements; (2) establishing partnerships with financial institutions for bridge financing; (3) offering point-of-sale discounts through manufacturer/installer collaborations; and (4) providing full upfront payments for qualifying low-income households or homes in energy poverty.

The treatment of ancillary upgrades represents another significant point to be debated. While separate programs exist for retrofitting work (such as adapting radiators and pipework for low-temperature systems), their separation from the primary heating system subsidies creates additional administrative complexity. This fragmentation is particularly problematic given the technical requirement for heat distribution systems to operate at temperatures not exceeding 55 °C, which often necessitates upgrades in existing buildings. While suboptimal operation affects efficiency gains, installing renewable heat sources without upgrading distribution systems (e.g., old radiators) can still bring emission reductions. Integrating these complementary programs would streamline the application process and better support comprehensive system optimisation.

Applicants could also perceive the overall administrative requirements of the funding programs, from online registration through implementation and final invoicing, as burdensome. This perceived intricacy, combined with the structural challenges in financing and ancillary support, may affect the programs' effectiveness in achieving their principal goals. Naturally, some degree of documentation and verification is necessary for public fund management. The key would be finding the right balance rather than eliminating oversight.

Concluding remarks

The analysis finds that Austria's subsidy programs demonstrate clear commitment to energy transition. However, quite a few limitations may impede equitable implementation and their full potential to be achieved. The programs' emphasis on district heating shows strategic foresight especially for urban areas, but it may contribute to geographic disparities in adoption. The financial architecture of post-installation reimbursement, combined with the inherent exclusion of innovative business models and fragmented support for necessary building upgrades, creates hurdles to widespread adoption. To improve the programs' impact, future policy revisions should consider introducing more flexible financing mechanisms, integrating ancillary upgrade support, and accommodating diverse business models. Such improvements would better align the subsidy framework with its core objectives of accelerating widespread adoption, while offering equitable access across different socioeconomic groups and geographic locations.

2.1.4. Germany

Germany's financial framework is discussed based on two reported national subsidy schemes. Namely, the *Bundesförderung für effiziente Gebäude* (BEG) program, comprising four sub-programs, supports both refurbishment and new construction with a mix of debt and equity funding (including bonus elements). The *progres.nrw* Climate Protection Technology program provides non-repayable grants for GHPs, through unit-based financial support. That is, the financial assistance is calculated based on specific units or metrics related to the geothermal installation. **Table 2** outlines the main features of the reported subsides.

Table 2. Germany's outline of the reported subsidy schemes.

Main Features	Description
General purpose	Accelerate the transition to energy-efficient, climate-friendly buildings by replacing conventional, fossil-based heating with renewable and efficiency-enhancing measures in both existing and new constructions.
Supported technologies	• BEG: Supports a wide range of measures, including installation of renewable heating systems (e.g., HPs), upgrades to building envelopes (doors, windows, insulation) and other efficiency improvements applicable to both residential and non-residential buildings. • progres.nrw: Supports GHPs. It covers borehole heat exchangers (vertical and horizontal) and groundwater HPs).
Target groups	• BEG: Available to private companies, civic associations, and individuals for both residential and non-residential sectors. • progres.nrw: Open to a broad range of applicants (private individuals, property owners, companies, municipalities, and public or non-profit institutions).
Funding model	• BEG: Delivered via a combination of debt and equity instruments with a variable funding rate. Support is structured into a base funding (30%) plus bonuses, such as a climate speed bonus (up to 20% for replacing systems older than 20 years), an income-dependent bonus (30% for households with annual incomes below €40,000), and an efficiency bonus (5% for systems with natural refrigerants or geothermal energy). The maximum funding rate achievable is 70%, with eligible investments and supplementary loans (up to €120,000) determined by system size and cost. • progres.nrw: Provides non-repayable grants that vary by measure (e.g., €5–10 per drilling metre, per square metre, or per litre-hour capacity) with a cap of up to €100,000 per building and location.
Bonuses	• BEG: Offers bonus elements that increase the funding rate: a Climate Speed Bonus for replacing heating systems older than 20 years, an income-dependent bonus for lower-income households, and an efficiency bonus for systems with improved performance. • progres.nrw: Does not list separate bonus percentages; funding is determined on a unit-based calculation.
Eligibility conditions	• BEG: Applicants (private companies, civic associations, individuals) must meet technical standards (e.g., as defined by water authorities, VDI 4640, or local specifications) and, in cases where installations are older than 20 years, may receive bonus funding. Both new constructions and renovations are eligible. • progres.nrw: Eligible applicants include private individuals, property owners, companies, municipalities, and associations. Measures must not commence until a grant notification is received, and reimbursement occurs only after completed work with proper invoicing and documentation.
Subsidy names	(1) Bundesförderung für effiziente Gebäude (BEG), comprising: (i) BEG WG (Residential Refurbishment), (ii) BEG NWG (Non-Residential Refurbishment), (iii) BEG EM (Individual Measures on Residential/Non-Residential Buildings), (iv) BEG KfN (Climate-Friendly New Construction); (2) Program for Rational Energy Use, Renewable Energies and Energy Saving (progres.nrw) – Climate Protection Technology program area for near-surface geothermal applications.

Interpretation & Critical Analysis

The subsidy programmes considered for Germany evidence a clear strategy to promote energy efficiency and the substitution of fossil fuel-based heating systems, reducing direct cost for households and businesses, as well as accelerating the energy transition.

A central feature of the German approach is its strong prioritisation of district heating in densely populated urban areas, encouraging large, centralised infrastructures to take an economies advantage of scale in decarbonisation. This top-down approach has its drawbacks. District heating customers are often trapped in monopoly-controlled networks, losing autonomy as consumers. In addition, many district heating systems remain dependent on fossil fuels, limiting immediate emission reductions until full decarbonisation is achieved. By focusing on centralised heating, smaller-scale decentralised solutions may be slower to be adopted, especially in rural and suburban areas. This could contribute to regional inequalities in areas where technologies such as GHP would be appropriate.

Despite this situation, subsidies exist for individual technologies such as GHPs, particularly through the national BEG programmes. The structure of the BEG programme allows for broad applicability in both residential and non-residential buildings, combining a base percentage of funding with additional bonuses, such as those associated with the use of more efficient technologies or those that take household income into account, reflect an intention to improve accessibility and accelerate the modernisation of the building stock. In this context, the loans offered through the public bank KfW form part of the financial support model, extending the reach of subsidies through complementary instruments. However, as in other contexts, access to credit may not be guaranteed for all users, particularly those with limited economical resources.

The programme requires the applicant to make the initial outlay, with reimbursements conditional on correct execution and subsequent reporting. While this model ensures traceability and proper use of public funds, it also imposes a significant initial liquidity burden, which may exclude certain segments of population, even if they meet the technical or social requirements. The combination of this mechanism with administrative complexities and rigorous documentation can act as an indirect barrier to participation, especially for residential users without technical advice or previous experience in energy efficiency procedures. Hybrid disbursement models, partnerships with financial institutions for bridge financing or direct upfront grants for low-income households meeting the requirements could be used to address this shortcoming.

Another relevant point is the improvement of older systems. While separate subsidy programs exist for retrofitting older buildings- such as the upgrading of radiators and pipes for low-temperature heating- their administrative separation from primary heating subsidies creates unnecessary complexity. Since HPs operate more efficiently at lower temperatures, many buildings require distribution system upgrades to maximise energy savings. However, even without these improvements, HPs can already reduce emissions compared to fossil systems. A more integrated subsidy structure would simplify applications and better comprehensive energy efficiency upgrades.

At the business level, current programmes tend to favour direct ownership of the system, without explicitly mention any innovative model's promotion such as operational leasing. While no explicit restrictions on these approaches have been identified, their lack of consideration may limit the development of more accessible and scalable alternatives, especially in urban or multi-family contexts.

Concluding remarks

The analysis shows the German subsidy programmes reflect a strong commitment to the energy transition towards renewable heating systems through a balanced combination of grants and public loans. The inclusion of specific bonuses within the BEG reveal a robust and result-oriented design. However, significant structural barriers remain, such as: i) the prioritisation of district heating, ii) reliance on post-installation reimbursement mechanisms, and iii) the lack of explicit integration of innovative business models.

To enhance the effectiveness of the programmes, future policy revision should focus on:

- Introducing more flexible financing mechanisms, such as hybrid disbursement models.
- Simplifying administrative procedures to reduce bureaucracy, making the process more accessible to wider range of beneficiaries.
- Integrating auxiliary improvement grant to streamline the modernisation of systems, ensuring that heat distribution upgrades are aligned with the adoption of renewable technologies.
- Accommodating diverse business models that lower entry barriers, such as operational leasing or third-party ownership.

These improvements would better align the subsidy framework with its core objective-accelerating the transition to sustainable heating-while ensuring equitable access across different socioeconomic groups and geographic locations.

2.1.5. Ireland

Ireland's renewable heating framework comprises three nationally administered schemes designed to accelerate the transition to renewable and energy-efficient heating across non-domestic and domestic sectors. By providing performance-linked non-repayable grants and complementary loan options (debt financing), these schemes support the installation of renewable heating systems (including various HPs types, biomass, and biogas systems) while pursuing energy efficiency improvements. **Table 3** outlines the main features of the reported subsides.

Table 3. Ireland's outline of the reported subsidy schemes.

Main Features	Description
General purpose	Accelerate the adoption of renewable heating systems which can contribute to meeting Ireland's renewable energy targets, while reducing greenhouse gas emissions as well.
Supported technologies	The subsidies are structured to cover different groups: • SSRH: Comprises an installation grant for HPs (ground source, air source, and water source) and an operational tariff support (ongoing payment for up to 15 years) for biomass and anaerobic digestion (biogas) heating systems. • HPSG: Supports domestic HP systems (air-to-water, ground source-to-water, exhaust air-to-water, water-to-water, and air-to-air, with a lower grant for the latter). • Loan Scheme: Applies to installations eligible under associated SEAI grant schemes (typically the same HP types as in the SSRH and domestic grant scheme).
Target groups	• SSRH: Non-domestic users (commercial, industrial, agricultural, district heating, public sector). • HPSG: Homeowners and private landlords with domestic properties built and occupied before 2021. • Loan Scheme: Residential property owners undertaking retrofit projects to improve energy efficiency.
Funding model	• SSRH: Non-repayable grant of up to 40% of eligible costs (with the rate linked to system efficiency via SPF/COP, plus up to an extra 30% for approved energy efficiency measures). • HPSG: Non-repayable fixed grants per dwelling type (e.g. ~€4,500 for apartments and ~€6,500 for terraced/detached homes; air-to-air systems receive a lower amount). • Loan Scheme: Unsecured debt financing (€5,000–€75,000 per property, up to €225,000 per applicant) available only in combination with an SEAI grant.
Bonuses	• SSRH: The grant rate is performance-linked; higher design efficiency (SPF/COP) leads to a higher percentage of funding. While no separate "bonus" payments are listed, the integration of energy efficiency measures (with up to an extra 30% support) functions as a bonus. • HPSG & Loan Scheme: No explicit bonus is provided, but the differentiated grant amounts by dwelling type and the condition that the upgrade must deliver a minimum 20% improvement in energy performance serve as additional incentive measures.
Eligibility conditions	• SSRH: Eligible applicants must be EU/EEA nationals or established entities with a principal place of business in Ireland; the building must be non-domestic, permanent, and wholly enclosed; the system must be new, installed after a Letter of Offer, and compliant with SEAI technical standards (e.g., no use of air as a transfer medium, meeting specific SPF/COP values); and applicants must not receive other related funding (e.g., under the REFIT Scheme). • HPSG: Only available to homeowners/private landlords with domestic properties (with differences for properties built pre-2007 vs. post-2007); limited to first-time HP installations in dwellings with sufficiently low heat loss. • Loan Scheme: Restricted to residential property owners (not used for short-term letting or holiday purposes) who are simultaneously receiving an SEAI grant; projects must demonstrate at least a 20% improvement in Building Energy Rating (BER), and financing is subject to the applicant's credit approval.
Subsidy names	(1) Support Scheme for Renewable Heat (SSRH); (2) Heat Pump System Grant (HPSG), as part of the Home Energy Grants Scheme; (3) Home Energy Upgrade Loan Scheme.

Interpretation & Critical Analysis

Ireland's subsidy schemes are a key step in accelerating the adoption of renewable energy technologies by addressing the high upfront costs for both homeowners and non-domestic users. The grant schemes, promote sustainability by reducing fossil fuel reliance, supporting the country's renewable energy goals, and offering financial incentives to make energy-efficient systems more affordable. However, there are limitations to the existing schemes which should be addresses.

Despite the strengths of Ireland's HP grant schemes, there are several notable weaknesses that create roadblocks to widespread adoption. Although the schemes do offer a financial support which reduce initial costs, the post-installation reimbursement combined with upfront installation expenses still remain a significant barrier, particularly for low-income households. Financially, the grants do offer more supports for GHPs compared to ASHPs purely based on the capital investment costs of the geothermal collector; however they do not accurately represent the difference in costs between the two systems. In addition, the difference in operational efficiency between the GHPs and ASHPs is not accurately represented.

The complexity of the application process also poses some challenges with respect to the two main grant schemes: the SSRH and the HPSG. The application process for the SSRH, required a detailed feasibility and assessment to be completed by a third party, comparing the business case for different technologies, which is costly and relies of the level of knowledge of the consultant or third party in GHPs to accurately complete such feasibility. In the case of the domestic HPSG, most applicants also require building energy upgrades such as insulation which results in the applicant having to apply for multiple grants which is also discouraging.

Concluding remarks

Ireland's subsidy programs demonstrate an important step towards the country's commitments to the renewable energy transition. They have the potential to support a variety of stakeholders both domestic and non-domestic however, there are a number of limitations which may impede their implementation and accelerating the uptake of HPs in Ireland. Financial challenges such as high operational costs with increased electricity rates, higher capital investment and high costs combined with a complex application process and the need for additional works such as building upgrades create roadblocks to widespread adoption. Future improvements of the subsidies should focus on introducing more flexible schemes with streamlined application processes, diverse business models and the introduction of dedicated electricity tariffs for GHPs. These improvements will allow Ireland to accelerate the adoption of renewable energy technologies to better meet its energy transition goals. Improving the schemes would offer access to a wider group of stakeholders and better financial support.

2.1.6. Netherlands

The Dutch financial framework is discussed based on four reported subsidies. These schemes aim to accelerate the installation of HPs and other sustainable energy measures in both the residential and business sectors. The programs support both the purchase of new systems and complementary financing, tax relief, or loan options to lower the upfront cost barrier for homeowners and business users. Specific performance and installation criteria are included as an attempt to convey quality and long-term energy savings. **Table 4** encapsulates main features of the reported subsides.

Table 4. Netherlands' outline of the reported subsidy schemes.

Main Features	Description
General purpose	Accelerate the adoption of renewable heating technologies and energy-efficiency measures by replacing conventional systems with HPs and other sustainable solutions.
Supported technologies	• ISDE (Homeowners and Business): Focus on HP installations (including ground source, full electric air-source, and hybrid air-source systems) with performance tied to capacity (kW) and energy label. Additional support may cover related renewable or energy saving measures (e.g., solar boilers, insulation, connection to district heating). • EIA: Covers several energy-saving and renewable business assets, including HPs, as listed in the official Energy List brochure. • Energy Saving Loan: Available for financing energy-saving measures across technologies.
Target groups	The subsidies are structured to cover different groups: • ISDE – Homeowners: Individuals owning residential properties (with prerequisites on building age or permit dates). • ISDE – Business users: Legal entities, self-employed individuals, and commercial landlords. • EIA: Entrepreneurs and corporations paying income or corporate tax in the Netherlands. • Energy Saving Loan: Homeowners and *Vereniging van Eigenaren* (VVE's) looking to finance the remaining investment costs after applying for purchase subsidies.
Funding model	• ISDE (Subsidies 1 & 2): Non-repayable purchases where the granted amount varies by HP type, capacity, and energy label (e.g., €2,550 for a 4 kW hybrid ASHP, €3,150 for an 8 kW full electric ASHP, or around €4,425–€4,650 for a 6 kW GHP). • EIA: A tax deduction scheme that allows businesses to deduct 40% of the investment cost from their taxable profit, yielding an effective benefit of around 10% on average. • Energy Saving Loan (Subsidy 4): Debt financing up to €28,000, with preferential interest rates and tax advantages (e.g., zero interest for combined incomes below €60,000).
Bonuses	• ISDE – Homeowners: Additional bonus of about €225 may be granted for installations achieving an energy label A+++ (with a transitional rule for systems purchased in 2023 but installed in 2024); from 2024, only systems with energy label A++ or better qualify. • ISDE – Business users: The purchase amount varies by the brand and type of GHP, indirectly offering a bonus for more efficient or premium systems. • EIA & Energy Saving Loan: No separate bonus percentages, though the loan product offers favourable terms that can effectively reduce the overall cost.
Eligibility conditions	• ISDE – Homeowners: Individual homeowners with properties built before January 1, 2019 (or with a permit applied for before July 1, 2018) must install a new, RVO-approved HP by a certified installer. • ISDE – Business Users: Legal entities and self-employed persons qualify; for air-water HPs, annual consumption must remain below 50,000 kWh electricity and 25,000 m^3 gas unless disconnected from the gas grid. • EIA: Only businesses subject to Dutch tax with eligible investments within set thresholds.

	• Energy Saving Loan: Available to homeowners and VVE's for professionally installed new systems (no second-hand installations).
Subsidy names	(1) ISDE: Warmtepomp woningeigenaren (for homeowners); (2) ISDE: Warmtepomp zakelijke gebruikers (for business users); (3) Energie-investeringsaftrek (EIA) voor ondernemers (tax deduction for businesses); (4) Energiebesparingslening ("Energy Saving Loan") (favourable loan offered by the National Warmtefonds).

Interpretation & Critical Analysis

The Netherlands promotes energy efficient and renewable systems to reduce greenhouse gas emissions. Another important driver especially for domestic application is going "gas-less" due to seismic events in the Northern region, caused by the gas-extraction. The Netherlands offers home-owners and businesses subsidies for different renewable energy systems, including ground source HP systems. For businesses additionally, they are required to implement renewables if the payback time is five years or less.

For larger tertiary buildings ground source energy, specifically open-loop aquifer thermal energy storage (ATES) systems, are well established, as they offer a very high thermal capacity for passive cooling. ATES systems therefore have an excellent market position. For smaller GHPs (closed-loop) the situation is more complex, as substantial subsidies are offered also for ASHPs that have a much lower CAPEX. Also, competition with e.g. large-scale heating networks can be a limiting factor.

One of the problems with subsidies themselves is that there a limited budget is made available, distributed on a first come first served basis. Once the available budget has been exhausted, requests for new installations are significantly reduced.

Concluding remarks

In the Netherlands the HP market, and especially the GHP market, has shown a slow but steady growth over the past 30 years. Although subsidies are important especially for individual home-owners, in reality the subsidy has not been a main driver of adoption of the technology. For the government the main drivers are highly efficient systems for heating *and cooling*, reducing carbon gas emissions, as well as lower impact on the electrical grid. For project developers the Energy Performance Assessment has been important, especially as in the previous methodology over heating (due to high insulation) is factored in as an energy-penalty. Ground source systems, with passive cooling, do not incur such a penalty in the Energy Performance assessment. For building owners undeniably, the reduced cost of operation and maintenance is of importance.

On the other hand, in spite of much lower performance and high impact on the electricity grid, ASHPs are a main competitor in housing projects due to the much lower CAPEX. Also, competition by large scale heating networks, is becoming an issue. Backed by large companies, these large scale networks do not offer economic advantages to the end user and in practice suffer from engineering, construction and operational problems, but are still adopted as an easy solution to reducing energy use and carbon emissions.

2.1.7. Poland

The Polish financial framework is discussed based on three reported subsidies, which aim for thermal modernisation and renewable heating in existing houses and new build in residential buildings. In Poland, the government (with EU support) uses a mix of non-repayable grants, and tax deductions to help homeowners replace outdated, high-polluting systems (such as coal boilers) with renewable, energy-efficient technologies. The programs target individual homeowners (mostly single-family houses) and support many technologies from various types of HPs to biomass boilers and district heating connections. **Table 5** encapsulates the main features of the reported subsides.

Table 5. Poland's outline of the reported subsidy schemes.

Main Features	Description
General purpose	Accelerate the thermal modernisation of existing single-family homes by replacing old, polluting heating systems with renewable and energy-efficient solutions. Support HP investment in new-build.
Supported technologies	The subsidy schemes support a variety of technologies. They cover various HPs types – air-to-water (AWHP), ground source (i.e., GHP), and air-to-air (AAHP) – as well as biomass boilers, district heating connections, mechanical ventilation, and photovoltaic systems.
Target groups	The subsidies are structured to cover different groups: Individuals/homeowners, primarily of one-family houses undertaking renovation to replace old coal-fired or similarly inefficient heating systems.
Funding model	• Clean Air: A non-repayable grant with variable amounts based on both the HP technology and the applicant's income level (with tiers offering up to 100% of eligible costs for the most disadvantaged). • My Heat: A non-repayable grant for new construction of one-family houses with subsidy levels that vary by HP type and family size (30% or 45% of eligible costs). • Tax Exception: Offers a deduction of 53,000 PLN per homeowner (or 106,000 PLN per married couple) on eligible costs, deductible over 6 years.
Bonuses	• For Clean Air, bonus levels depend on income, with higher percentages available for lower-income households; the subsidy supports AWHPs with higher efficiency (A++ and higher) and GHP. • For Tax Exception, the benefit doubles in a marriage (each spouse can claim the deduction).
Eligibility conditions	• Clean Air: Open to individual homeowners renovating one-family houses (only investments replacing old coal boilers are eligible). • My Heat: Available for new constructions of one-family houses, with subsidy intensity adjusted for family size (standard 30% and higher level 45%) and depending on the HP type (GSHPs get the highest amount). • Tax Exception: Limited to individual homeowners who do thermos-modernisation of the existing house and install new, approved systems (no second-hand equipment), following all technical and installation regulations.
Subsidy names	(1) "Czyste Powietrze" – Clean Air subsidy (currently suspended with new rules under development); (2) "Moje Ciepło" – My Heat subsidy; (3) Tax Exception ("Ulga Termomodernizacyjna").

Interpretation & Critical Analysis

Poland offers several subsidy programs to encourage the adoption of HPs, aiming to enhance energy efficiency and reduce environmental impact. Subsidies in Poland are mainly aimed at homeowners, who do thermo-modernisation including exchange of old coal boiler or any other polluting heating system into new energy efficient heating system. There is also one subsidy dedicated for new investors in one-family segment promoting HPs. All subsidies refer to the residential market.

These subsidies are designed to reduce reliance on coal-based heating, which is still widespread in Poland, while simultaneously improving energy efficiency and lowering household heating costs.

Strengths of the subsidy system.

1. *Encouraging decarbonisation:*
   The programs align with the EU's Green Deal objectives, promoting cleaner alternatives to fossil fuels. Poland, historically dependent on coal, benefits significantly from incentivising HP adoption.
2. *Targeted financial support:*
   - The Clean Air Programme particularly supports lower-income households, ensuring accessibility for those who might struggle with high upfront costs.
   - The pre-financing option (introduced in 2022) is a crucial improvement, reducing the financial burden on homeowners before installation.
3. *Possibility to merge subsidy schemes:*
   The Clean Air program is dedicated for existing houses together along with tax exemption opportunity. The polish law enables end-users to merge both subsidies in the way, that remaining eligible costs that were not covered by the Clean Air program may still be deducted from the tax base within special tax exception for thermo-modernisation of the house.
4. *Regional customisation:*
   In addition to nationwide initiatives, individual provinces have regional programs of financial support for the purchase and installation of HPs. The conditions and the amount of funding may vary from region to region, so it is worth checking the current information on the websites of local marshal offices or provincial environmental protection funds.
5. *Digitalisation of the process:*
   All subsidies undergo a digital process for the applications – no paper work and face to face meetings with operators. The digitalisation simplifies and accelerates the whole process of application.

Challenges and criticism.

1. *Temporary suspension and policy instability:*
   - The suspension of the Clean Air Programme (December 2024) due to fraud concerns raises doubts about the long-term stability of the scheme. Such

interruptions can reduce public trust and slow down the transition to sustainable heating. The reopening of the program is announced to happen by April, 1st 2025.

- Frequent changes in subsidy conditions make it difficult for homeowners to plan investments in advance.

2. *Bureaucratic and administrative barriers:*
    - Many applicants report complex application procedures and long waiting times for approvals and fund disbursements (especially for Clean Air).
    - Strict technical requirements (such as minimum energy efficiency thresholds) may exclude many potential beneficiaries, especially in older buildings that require extensive renovation.
3. *Equity concerns:*
    - The My Heat Program focuses only on new buildings, leaving out many existing homes (with other fossil fuel driven heating systems like gas boilers or oil boilers) that may not qualify for Clean Air funding due to strict eligibility criteria.
    - The technologies do not undergo similar technical requirements to be listed on a special ZUM list (list of Green Appliances and Materials). There is no acceptance of quality labels like EHPA Q, Eurovent or HP Keymark, which are the standard requirement for subsidies in other European markets. Instead manufactures need to present special research reports for one appliance out of 5 in the range, with no control of the others, no need for third party control or no need of 10-year spare parts availability.
4. *Market impact and price inflation:*
    - Increased demand for HPs, driven among others by subsidies, has led to price inflation in some cases in years 2022-2023. Since the high saturation and stock-up in warehouses (strong imports from Far East) in the market in 2023, the prices of HPs have steadily decreased.
    - Some suppliers may exploit subsidies by raising installation costs, reducing the actual savings for homeowners.

Concluding remarks

Whereas Poland's HP subsidy programs are crucial for decarbonisation and energy efficiency, they face policy instability, administrative hurdles and equity concerns. Addressing these issues through stable policies, streamlined procedures and expanded accessibility could significantly enhance their impact. The government should avoid abrupt pauses or major policy shifts to maintain public trust and ensure steady adoption rates. Stronger anti-fraud measures should be implemented without disrupting the entire subsidy system. To counter price inflation, Poland could consider setting price ceilings on subsidised HPs or incentivising domestic HP production to reduce dependence on imports.

2.1.8. Spain

The case of Spain is discussed on the basis of five subsidies, from national grant schemes and hybrid instruments to a regional initiative and market-based energy savings certificates. The financial framework supports both thermal renovations and new construction projects through a mix of non-repayable grants, tax credits, hybrid support instruments, and market-based mechanisms, all designed to replace old, inefficient heating systems with modern, sustainable solutions. **Table 6** encapsulates main features of the reported subsides.

Table 6. Spain's outline of the reported subsidy schemes.

Main Features	Description
General purpose	Drive the energy transition by increasing the uptake of renewable and energy-efficient technologies in buildings.
Supported technologies	Covers a broad spectrum of renewable and efficiency measures including HPs (air-to-water, ground source, air-to-air), solar photovoltaic and thermal systems, biomass boilers, wind and hydropower, as well as energy efficiency improvements such as insulation, HVAC upgrades, and LED lighting.
Target groups	The subsidies cover different groups: Private individuals, homeowners' associations, private companies, public organisations, and other entities across both residential and non-residential sectors.
Funding model	Varies by program: • PREE: Non-repayable grants covering 35–70% of project costs (with variations based on technology, installation size, income level, building type, and region). • Recovery and Resilience Plan: Grants and tax credits that can cover up to 100% of eligible costs for green energy and digital transformation initiatives. • NECP: Hybrid instruments funding 20–50% of project costs based on technology type and project scope. For example, one model might blend a direct non-repayable grant covering a portion of the project cost (say 20–30%) with tax incentives that further lower the effective investment burden. Another common approach is to pair grant funding with access to low-interest loans, thereby leveraging both immediate capital support and affordable financing for the remaining costs. • CAE: A market mechanism that monetises energy savings at approximately 0.182 €/kWh (2024 value). This value changes each year based on market values. • Regional (Comunitat Valenciana): Grants of 35–70% (with additional incentives for small and medium-sized enterprises and projects in municipalities facing demographic challenges).
Bonuses	Some programs offer enhanced support: • PREE provides higher grants for lower-income households and additional bonuses (e.g., an extra ~€225 for installations achieving top energy labels). • Regional schemes may add extra percentages for small or medium enterprises and for projects in prioritized areas. • NECP funding can be adjusted based on strategic regional priorities.
Eligibility conditions	Generally require the replacement of outdated, high-polluting systems (e.g., coal boilers) with more efficient alternatives that meet specific performance standards (such as minimum SPFs or energy labels). While programs like PREE and NECP apply to both new and renovation projects, others (such as the CAE system) are limited to renovation measures. Applicants must comply with technical and installation requirements, and some programs have geographic or building-type restrictions.

Subsidy names	(1) Programa de Rehabilitación Energética de Edificios (PREE); (2) Spain's Recovery and Resilience Plan (Next Generation EU Funds); (3) National Energy and Climate Plan (NECP); (4) Certificados de Ahorro Energético (CAE) – Energy Savings Certificates; (5) Regional Subsidies for Thermal Renewable Installations in Comunitat Valenciana.

Interpretation & Critical Analysis

Spain's subsidy framework is designed to drive the energy transition by promoting the uptake of renewable and energy-efficient technologies in buildings. The framework employs a diversified approach by combining non-repayable grants, tax credits, hybrid funding instruments, and market-based mechanisms. This mix supports both renovation and new construction projects, reflecting a broad strategy that targets various stakeholders—from private individuals and homeowner associations to public organizations and private companies.

The diversity in funding models (ranging from grants covering 35–70% of project costs in the PREE program to tax credits in the Recovery and Resilience Plan that can cover up to 100% of eligible costs) provides flexibility and tailors support to different project needs. However, the variation in funding percentages and eligibility criteria may also introduce administrative complexity, potentially making it challenging for applicants to navigate the system. The inclusion of market-based instruments such as the CAE, which monetises energy savings at a defined rate (approximately 0.182 €/kWh for 2024), adds an innovative element, though it inherently carries the risk of fluctuations in market values that could affect support predictability.

One notable challenge within Spain's subsidy framework is the bureaucratic complexity that often impedes the timely development of projects. The process typically requires extensive documentation and adherence to strict deadlines that can be misaligned with the actual pace of project implementation. For instance, fixed timeframes for submission and reimbursement may not accommodate delays arising from unforeseen technical issues or regulatory hurdles, thereby risking disqualification or funding delays. This challenge is particularly acute for geothermal installations, where projects demand comprehensive technical verifications and adherence to stringent performance standards. The additional administrative burden for geothermal systems (often capital-intensive and reliant on detailed engineering assessments) can discourage smaller operators and complicate financing. Streamlining administrative procedures and introducing more flexible deadlines could substantially enhance the effectiveness of these subsidies, ensuring that innovative renewable technologies are deployed without unnecessary delays.

Moreover, while the wide range of supported technologies—from various types of HPs to solar, biomass, and wind solutions—enhances technological inclusivity, it also necessitates strict technical standards and quality controls. Promoting tailored subsidies, especially those targeted at lower-income households or regions with demographic problems, would be paramount to fostering equity. Yet, these nuanced conditions, combined with specific geographic and building-type restrictions, might create barriers for some applicants, particularly those lacking immediate access to upfront financing.

Concluding remarks

Spain's subsidy framework reflects a comprehensive and multifaceted strategy aimed at modernising the heating systems in both existing and new buildings. Its strengths lie in the flexible combination of financial instruments and the wide spectrum of supported technologies, which together encourage a broad adoption of sustainable practices across diverse sectors. Nonetheless, the framework faces challenges such as administrative complexity and potential inequities arising from the necessity for upfront financing and varying eligibility conditions. To maximise the effectiveness of these programs, it is essential to streamline application processes, simplify and make the justification of support more flexible and consider complementary financing mechanisms that alleviate the burden of initial costs, particularly for lower-income applicants. Overall, while the framework is well-positioned to contribute to Spain's energy transition, careful calibration of its administrative and financial aspects will be crucial to ensure broad and equitable participation.

2.1.9. Sweden

The Swedish financial framework is discussed based on four reported subsidies. These programs target different aspects of energy renovations mostly in the residential sector. Offered are non-repayable funds in the form of tax deductions and grants. The schemes support both traditional refurbishment work and investments in green technology to lower CO_2 emissions and reduce energy costs. **Table 7** provides a concise overview of the main features of the reported subsides.

Table 7. Sweden's outline of the reported subsidy schemes.

Main Features	Description
General purpose	Stimulate energy renovation and the adoption of renewable and energy-efficient heating systems in the residential sector.
Supported technologies	The subsidies cover different groups. More specifically: • ROT: Applies broadly to refurbishment, maintenance, and enhancement works on privately owned buildings. It covers HPs (geothermal, air-to-water, air-to-air) when replacing fossil-based systems. • Klimatklivet: Supports a wide range of CO_2-reducing measures across sectors, with funding proportional to emissions reductions. • Grants for energy efficiency in small houses: Targets energy efficiency upgrades in one- or two-family houses (or terraced houses) focusing on replacing fossil fuels and upgrading heating systems. • Tax credits for green technologies**:** A tax deduction mechanism for energy efficiency investments (e.g., solar cells installed to power HPs) applied to privately owned buildings.
Target groups	The subsidies cover different groups: • ROT: Private homeowners undertaking renovations on their houses (applies only to work costs, not materials). • Klimatklivet: Public and private organisations (not individuals) investing in CO_2-reduction projects.

	• Grants for energy efficiency in small houses: Private individuals owning one- or two-family houses or terraced houses, particularly those transitioning from electric or gas heating to more efficient alternatives. • Tax credits for green technologies: Private individuals (via tax deduction) in all privately owned buildings, where the focus is on achieving green technology installations.
Funding model	Varies by program: • ROT: Non-repayable tax deduction for labour costs in renovation work. For example, for GHP installations the work cost is considered at 35% of total cost and up to 30% of that value is deductible (capped at 50,000 SEK per person per year). The subsidy is a tax reduction for individuals, but companies apply for it and receive the funds. The amount is deducted from the customer's invoice, effectively passing the benefit up-front to them. • Klimatklivet: Non-repayable investment funding provided regionally (with decisions made by Naturvårdsverket) based on the amount of CO_2-reduction achieved, typically averaging 41% (up to 70%) of eligible costs. • Grants for energy efficiency in small houses: Non-repayable grant covering material costs (up to approximately 30,000 SEK cap) for energy efficiency measures in small houses. It should be noted that here only material costs qualify. • Tax credits for green technologies: A tax deduction scheme that allows a deduction (up to 50,000 SEK per owner, or 50,000 SEK each for co-owners) for labour costs in green technology installations. It should be noted that here only labour is eligible, and the rate is typically around 20% of the labour cost.
Bonuses	The reported subsidies do not offer additional bonuses for renewable technology specifically.
Eligibility conditions	• ROT: Only available for renovations on privately owned houses; applies exclusively to labour costs (not materials) and is capped by the taxpayer's paid income tax. The installation must be performed by a certified contractor. • Klimatklivet: Open to private and public organisations, but not individuals; eligibility requires projects that demonstrably reduce CO_2 emissions. • Grants for energy efficiency in small houses: Limited to homeowners of one- or two-family houses/terraced houses undertaking upgrades to replace fossil-fuel heating systems; eligibility is based on property type and transition criteria. • Tax credits for green technologies: Available for all privately owned buildings; companies apply for the tax deduction on behalf of individuals, subject to technical compliance (only labour costs qualify, and installation must meet regulatory standards).
Subsidy names	(1) ROT (Renovering, Ombyggnad, Tillbyggnad); (2) Klimatklivet; (3) Bidrag för energieffektivisering i småhus - Grants for energy efficiency in small houses; (4) Så fungerar skattereduktion för grön teknik - Tax credits for green technologies.

Interpretation & Critical Analysis

In Sweden, there are no dedicated grants or subsidies for GHPs. Instead, private homeowners benefit from a tax credit that applies to all types of property work. The ROT scheme offers a tax reduction of 30% of the labour cost. It is granted whatever the end result is, even if it makes the house less energy efficient. In practice, 30% of 35% is approximately 10% of the total installation cost, which is directly deducted from the invoice by the installer who reports the work to tax authorities. During the annual tax audit, it is confirmed that the homeowner has paid at least as much in tax; if not, the credit must be repaid. For a typical geothermal installation in a private house, this tax reduction usually does not exceed 30,000 SEK, and most homeowners have a higher tax liability.

ROT was primarily established to counter tax evasion. Previously, significant amounts of unreported work allowed contractors to avoid the 25% VAT, providing homeowners with the option of a cheaper "black" service. The introduction of ROT in 2008 significantly reduced this practice, with overall tax deductions amounting to approximately 50–60 billion SEK. To note, a separate tax deduction scheme, Gröna Avdraget, is available exclusively for solar panels and battery storage for self-produced electricity, but it operates on a similar framework as ROT.

Another notable initiative is Klimatklivet, launched in 2015. Administered by the Swedish Environmental Protection Agency (Naturvårdsverket), this program supports local climate investments to reduce greenhouse gas emissions. Financial assistance is provided to municipalities, companies, regions, and organizations for projects that contribute to a fossil-free future. By June 30, 2024, Klimatklivet had approved 25,565 applications, with a significant portion allocated to electric vehicle charging infrastructure. Supported projects are estimated to reduce greenhouse gas emissions by approximately 2.8 million tons of CO2 equivalents annually over an average project lifespan of 15 years. The total investment, including contributions from both Klimatklivet and local stakeholders, amounts to 40 billion SEK, with the program typically covering 41% of investment costs and granting up to 70% under specific conditions.

In 2019, the Swedish National Audit Office (Riksrevisionen) reviewed Klimatklivet and raised concerns. The evaluation found that the program was not cost-effective, citing inaccuracies in emission reduction calculations and additional costs linked to the supported measures. The audit also noted deficiencies in risk analysis and ambiguities in the distribution of responsibilities among authorities. Furthermore, the report criticised the overly positive governmental reporting, which may have overlooked certain shortcomings. While Klimatklivet has made significant strides in promoting local climate initiatives and reducing emissions, it faces challenges related to cost-effectiveness and administrative processes. Addressing these issues is crucial for enhancing the program’s efficiency and ensuring the optimal use of resources in Sweden's transition to a fossil-free society.

Concluding remarks

There are no specific subsidies targeting GHPs in Sweden, and the reasoning behind this is straightforward. GHP technology itself is well-established; this is true globally, not just in Sweden. The core technology has been refined over decades and reliably delivers efficient solutions for both heating and domestic hot water production. What distinguishes Sweden is that its market for this well-established technology has reached maturity. With widespread adoption across the country, GHPs have become a standard heating solution for Swedish homes, typically paying for themselves through energy savings over their operational lifespan.

While general-purpose schemes like ROT offer incidental support, Sweden deems dedicated subsidies unnecessary given the maturity level of its GHP market. In contrast, other countries might still subsidise GHPs where the market is less developed and the technology requires additional promotion. Sweden’s experience shows that once a technology reaches sufficient scale and expertise, it can thrive without specialised financial incentives. However, this does not imply that subsidies are unwarranted elsewhere: in markets with lower penetration or different economic conditions, targeted support can still be merited.

2.1.10. Cross-country synthesis of national GHP-relevant subsidy schemes

Finally, we distil the 9 country profiles into a set of common patterns, divergences, challenges and opportunities. We offer a concise, **country-agnostic synthesis** which keeps the focus on structural barriers and actionable fixes, purposely avoiding any unintended ranking of individual national programmes.

A) Patterns and nuances

Dimension	Broad pattern	Nuances
Financing architecture	Most schemes reimburse costs after the system is installed and fully paid by the owner.	A minority offer partial up-front payments, apply the grant directly to the installer's invoice, or combine the grant with publicly backed low-interest loans.
Equity mechanisms	Flat-rate support dominates; the subsidy percentage is the same for every household or business.	Only a few programmes scale the aid for lower-income applicants or raise the ceiling for vulnerable groups.
Technology signalling	Many schemes cover different HP types, but their grants do not fully price-in the lifetime efficiency advantage of GHPs. The geothermal solutions often receive only a "modest" uplift over ASHPs, steering cost-sensitive buyers toward the cheaper, less efficient option.	A few schemes offer explicit drilling or "geothermal efficiency" bonuses, yet even these might not be enough to close the CAPEX–OPEX gap entirely.
Market-maturity stance	Financial incentives are framed as market accelerators for still-growing markets and HP segments.	Where the GHP market is already mature, dedicated subsidies have been retired and replaced by broad renovation tax deductions.
Administration & delivery	Digital application portals are present, but documentation loads remain high.	A handful of schemes have introduced one-stop platforms that bundle equipment grants, building-fabric bonuses and financing in a single workflow, reducing paperwork.

B) Challenges and opportunities

Challenge	Description	High-leverage intervention	Implementation notes
Liquidity barrier	Reimbursement-only models require beneficiaries to pre-finance 100% of CAPEX, excluding households with limited savings or credit.	Introduce hybrid disbursement (e.g., a fixed portion paid when the contract is signed and the balance after commissioning) or guarantee bridge loans through public banks.	Reduces cash-flow strain without increasing headline grant rates.
Administrative friction	Eligibility checklists, mandatory energy audits and fragmented bonus programmes inflate transaction costs and deter applicants.	Deploy integrated one-stop digital portals that merge heating-system grants, building-fabric incentives and financing options.	Cuts the time and cost of multi-scheme applications.
Policy stop-and-go	Annual budget caps and sudden rule changes create stop–start installation cycles, undermining supply-chain confidence.	Move to multi-year rolling budgets with automatic carry-over.	Gives installers and manufacturers predictable demand.
Uneven access	Where "district heating first rules" exist, this can channel incentives away from decentralised GHPs, which might add some spatial inequity in the adoption of the technology.	Allow individual projects to opt out of mandatory district heating connections when they can demonstrate, e.g., at least equal carbon performance or better cost conditions with an individual geothermal solution.	Maintains technology diversity in dense areas and avoids technology lock-in.
Limited recognition of innovative business models	Most schemes assume outright ownership and self-supply; business models such as HaaS or leasing not often qualify for support.	Allow subsidy eligibility for service-based models (e.g., leasing, HaaS) that meet efficiency and consumer-protection standards.	Lowers entry barriers and opens the market to households that cannot or prefer not to own the equipment outright.

Performance-misaligned incentives	Because subsidy levels track upfront cost more than performance-based efficiency, buyers are nudged toward lower-CAPEX ASHPs even where GHPs would deliver bigger long-term savings and emissions cuts.	Link grant amounts to verified seasonal performance (SPF) or add a small top-up that is paid after the first year if monitoring confirms higher efficiency.	Aligns public spending with real energy and carbon savings.
Equity blind spots	Flat-rate grants give the same % to every household; low-income applicants often cannot capture the full benefit or even meet the entry costs.	Income-linked grant multipliers or invoice-level tax credits that apply the benefit instantly, regardless of tax liability.	Makes subsidies progressive instead of regressive.

2.2. Proposition of a new affordability score

2.2.1. Background

Achieving carbon neutrality in energy systems depends on scaling up localised renewable solutions, and GHPs are increasingly acknowledged as a promising technology to help meet this goal (Brancher et al., 2025). However, the affordability of heating and cooling systems has emerged as a central challenge in achieving equitable clean energy transitions. This issue extends beyond simple cost calculations to fundamental questions of fairness and social inclusion. Rising costs of living and climate targets are pushing stakeholders to better understand the true costs of these technologies. This includes individual consumers, policymakers, and industry leaders who need clearer ways to evaluate the economic viability of these technologies. Traditional affordability-related metrics often fail to capture the unique characteristics of heating and cooling systems and the complex interplay of factors influencing their viability. This creates a limitation in decision-making capabilities.

The IEA's special report on affordability and fairness in clean energy transitions notes that many clean energy technologies are becoming the most affordable options when considering lifetime costs. The report discusses elements such as investment and energy bills, policies promoting affordability, and the impact of price shocks. While this report provides strategic insights, it does not consider specific affordability indices tailored to heating and cooling systems.

Consumer research provides additional insight into the economic considerations driving renewable technology adoption. Recent works capturing homeowner perspectives on HPs suggest that while environmental considerations play a role, financial factors tend to be the primary drivers of purchase decisions. These works highlight the financial benefits of HPs, stressing their efficiency over traditional systems and the significant savings on utility bills they offer. Yet, surveys underpinning these studies primarily focus on consumer attitudes and awareness rather than developing comprehensive affordability metrics.

A number of established quantitative measures attempt to evaluate renewable energy affordability, each with distinct strengths and limitations. The Levelized Cost of Energy (LCOE) serves as a foundational metric, calculating per-unit heating or electricity costs across a project's complete lifecycle, including capital expenditure, operational costs, maintenance requirements, and fuel expenses. While LCOE provides robust cost comparisons, it fails to capture broader affordability considerations beyond direct costs.

The Energy Affordability Ratio, or energy burden, measures household energy expenditure as a proportion of income, particularly highlighting challenges faced by lower-income households. Related initiatives address affordability by capping utility costs at fixed income percentages, like the U.S. Percentage of Income Payment Plan. However, these metrics focus on overall energy costs rather than comparing specific technologies.

The HP Cost Burden Ratio compares the total cost of ownership (including installation, operation, and maintenance) of a HP to the median household income in a given area. Although appropriate for understanding direct financial impacts, this metric captures only a subset of relevant affordability factors, primarily focusing on the relationship between costs and income levels.

The Energy Affordability Gap quantifies the difference between actual energy costs and a predetermined "affordable" threshold, typically defined as a percentage of income. Like the Energy Affordability Ratio, this metric underscores overall household energy burden without distinguishing between technologies.

The Energy Insecurity Index offers a more comprehensive approach, incorporating multiple factors including energy costs, income levels, housing energy efficiency, and access to assistance programs. While thorough in its assessment of energy insecurity, it also does not specifically address the comparative affordability of different technologies.

These existing metrics are valuable for their intended purposes of looking into energy as a whole, including electricity. To the best of our knowledge, an affordability measure specifically designed for heating and cooling systems is therefore lacking. This new metric must address current limitations by factoring in a broader range of relevant factors, enabling meaningful technology comparisons across different contexts, and providing actionable insights for multiple stakeholders. By doing so, it will not only assist consumers in making more informed decisions but also support policymakers and industry stakeholders in effectively promoting and implementing renewable energy transitions. With energy costs soaring and increasing emphasis on sustainability, the development of holistic affordability assessments is also timely. We need a better understanding of which renewable technologies are the most suitable, both at implementation and over their long-term lifetime, to help drive broader adoption of renewable energy solutions.

Accordingly, the affordability score developed in the present work will be used to address the following question:

- *Given present-day prices, incomes and macro-economic context in each country, which heating and cooling technologies look comparatively easier or harder for consumers to invest in and operate?*

2.2.2. Methodology

This section presents the methodological approach created to compare the affordability of GHPs with alternative technologies, based on a so-called **affordability score**. This indicator aims to provide a quantifiable measure of the economic viability of selected technologies relative to one another and to compare different countries. It can encourage a basis for more informed decision-making by offering a direct and easily interpretable comparison.

To support transparency and reproducibility, the full implementation of the affordability score methodology is publicly available at https://doi.org/10.5281/zenodo.17716094 (Brancher, 2025).

The methodology has been developed taking into account the following key requirements:

i. The score must yield results not only for GHPs but also for various alternative heating technologies.

ii. The methodology should facilitate direct, quantitative comparisons across technologies, providing results that are presented on a common, easily interpretable scale.

iii. The spatial resolution of the analysis is at the national level, thereby allowing the results to reflect country averages.

In order to meet these requirements, a structured method has been devised. The following sections detail the steps taken to build the affordability score.

Step 1: Definition of system and building types

The first step involves defining the systems and building types that will be included in the analysis. This is the foundation of the methodology. The goal is to design the assessment to be comprehensive enough and applicable to a wide array of technologies currently available in the market, by considering both conventional and renewable options. The analysis focuses exclusively on electric HPs and compares them with conventional alternatives. It only considers the deployment of new systems, excluding any ancillary costs associated with modifying or installing the building's heating/cooling delivery infrastructure (e.g., radiators, pipework).

Table 8 shows the selected systems and building types considered. All systems listed are considered technically applicable across all building categories, in principle. This reflects the intention to capture the full range of feasible options, rather than limit the scope to only the most commonly used systems. However, this does not imply equal prevalence across all target groups; only that the systems are technically possible in theory should a project choose to pursue them.

Table 8. Heating and cooling systems considered in the affordability score calculation across different target groups. "*All listed*" includes GHP (closed and open loop), ASHP, gas boiler, oil boiler, pellet boiler and district heating.

Building type	Capacity range	Applicable systems
Single-family houses	3–15 kW	All listed
Multi-family houses	15–350 kW	All listed
Small/medium-scale tertiary buildings	50–800 kW	All listed
Large-scale tertiary buildings	800–2500 kW	All listed

The capacity ranges in **Table 8** are taken from previous work (Witte, 2023) and are in line with commonly cited values across different building types. In practice, a variety of factors (e.g., climate, building thermal envelope, retrofit *vs.* new build, occupancy patterns) can influence the specific capacity needed in a given project. Hence, it is more accurate to think of these ranges as indicative or rule-of-thumb references rather than strict thresholds. Namely, stating that a single-family house usually requires a 3–15 kW capacity is a reasonable short-hand for typical scenarios. But it does not exclude situations where the capacity might be larger. Likewise, a large tertiary building (commercial) could need even more than 2500 kW in some cases. Therefore, we treat these ranges as guidelines rather than absolute upper and lower limits for both reasonable and practical reasons.

Step 2: Selection of affordability factors

The next step is to identify factors that affect the affordability of the selected systems. The final list of factors is defined based on their relevance to consumer costs, their impact on the overall affordability of the technologies, and data availability. Care has also been taken to avoid double counting due to similar factors. For example, technical factors like efficiency and lifespan were omitted as separate factors, as they are embedded in other factors like CAPEX, OPEX and LCOE.

Nine candidate factors were finally considered (**Table 9**). All were judged conceptually relevant; however, policy support (direct grants, rebates or tax credits) could not be quantified in a harmonised, country- and system-specific manner. Consequently, policy support has been excluded, giving rise to the **baseline scenario**.

The eight remaining factors (CAPEX, OPEX, LCOE, electricity-to-gas ratio, median income, GDP per capita, employment rate, HICP) are retained without change Together, the selected factors provide a balanced view of different aspects that can influence affordability. The data sources in **Table 9** are also explained under *Step 4: Data Acquisition*.

Table 9. Factors considered for the calculation of the affordability score. It should be noted that policy support has not been included in the baseline scenario.

Factor	Short explanation	Justification for selection	Data source	Units
Capital expenditure (CAPEX)	The initial cost required for purchasing and installing the system.	CAPEX represents the upfront financial barrier for adopting a technology. High CAPEX can deter consumers, making it a critical factor in assessing overall affordability.	GeoBOOST Deliverable 4.1 (Thelin and Malmberg, 2024)	EUR
Operational expenditure (OPEX)	The ongoing costs associated with running and maintaining the system.	OPEX influences the continuing financial burden on consumers. Systems with low OPEX are generally more attractive, as they reduce the total cost of ownership over time.	GeoBOOST Deliverable 4.1 (Thelin and Malmberg, 2024)	EUR/25 years
Levelised cost of energy (LCOE)	This metric spreads all costs over the system's lifetime and divides by the total energy output.	LCOE provides a standardised measure of the long-term cost per unit of energy, reflecting both efficiency and lifespan, which directly influences the true affordability of the system.	GeoBOOST Deliverable 4.1 (Thelin and Malmberg, 2024)	EUR/MWh
Policy support	Government subsidies including grants,	Financial incentives can lower the net upfront cost to consumers, encouraging the	—	EUR

	rebates or tax incentives.	adoption of more expensive, but more efficient technologies.		
Median household income	The median disposable income of households.	Higher income levels often correlate with a greater capacity to afford both the upfront and ongoing costs of heating systems.	Eurostat (online data code: ilc_di04)	EUR per household per year
Gross domestic product (GDP) per capita	A measure of the overall economic performance and health of a country.	GDP is a proxy for the economic environment in which consumers operate. A higher GDP often correlates with greater economic stability and higher household incomes, influencing affordability.	Eurostat (online data code: sdg_10_10)	EUR per capita
Electricity-to-gas price ratio *	The relative cost of electricity compared to natural gas for household costumers.	This affects the operational cost. A higher ratio may make electric systems less competitive compared to gas-based alternatives.	Eurostat (online data codes: nrg_pc_202, nrg_pc_204)	Non-dimensional
Employment rate	The percentage of the working-age population that is employed.	This rate is used to gauge the overall economic strength and the ability of the economy to provide jobs for its working-age population. A high employment rate typically suggests a robust economy with many opportunities, which might relate to higher overall affordability.	Eurostat (online data code: lfsa_ergan)	% of the working-age population (from 15 to 64 years).
Harmonised index of consumer prices	A standardised measure of inflation across countries that tracks changes in consumer goods and services prices.	This measure can influence the long-term affordability as prices for goods and services rise. It enables consistent international comparisons.	Eurostat (online data code: prc_hicp_aind)	Index (reference year = 100)

* Electricity-to-gas price ratio is less meaningful for the Nordic countries because the gas grid penetration there is relatively low. Electricity-to-district heating price ratio is used instead.

Step 3: Defining normalised weights for the factors

Once the relevant factors have been selected, normalised weights are assigned to each. To achieve this, a weight allocation survey was prepared to gauge the relative importance of the factors in determining affordability among geothermal experts involved in the project. In this survey, each expert partner was given a fixed total of 100 points to distribute across all selected factors.

By design, this forced-choice weighting approach prevents all factors from being rated equally or deemed universally important, compelling respondents to make trade-offs between the different dimensions of affordability. It follows that by constraining the total point "budget", the approach reflects the factors considered most critical in a comparative sense, rather than assigning absolute importance to each in isolation. This provides a more meaningful prioritisation, since it gives the relative weight of each factor in the overall affordability assessment.

As mentioned before, care has been taken to avoid double counting when selecting the factor. Yet, double counting could still happen with CAPEX, OPEX and LCOE as separate affordability factors, because CAPEX and OPEX are embedded within LCOE. However, our strategy to mitigate this involves (i) appropriately assigning weights to each factor and (ii) clearly defining how they are interpreted in the context of the present analysis, as follows:

- CAPEX is a direct input into LCOE. If both CAPEX and LCOE are included separately, CAPEX would be considered twice. This can give excessive emphasis to CAPEX. The justification for keeping CAPEX separate from LCOE is that consumer perception often focuses on the upfront financial barrier, which LCOE alone might not fully capture. CAPEX is an immediate, out-of-pocket cost. But LCOE spreads that cost across the system's lifetime, which some consumers might not prioritise. So, while CAPEX is embedded in LCOE, including both reflects two different perspectives: immediate affordability (CAPEX) *vs.* long-term affordability (LCOE). To bypass double counting, CAPEX should receive a smaller weight in relation to LCOE in the weight allocation survey. This way, we acknowledge CAPEX importance as an upfront cost, but its contribution to long-term cost (already reflected in LCOE) is not overemphasised.
- Similarly, OPEX is also a direct input into LCOE. Despite the overlap, OPEX represents a different aspect of consumer affordability than LCOE. The typical consumer is often more concerned about the regular, recurring expenses, rather than the lifetime cost-efficiency of the system. Including OPEX thus reflects a more short-term financial perspective. However, LCOE represents the true long-term vision. So, even though OPEX is embedded in LCOE, it is still necessary to capture it as a separate factor to reflect these more immediate operational concerns. Thus, similar to CAPEX, OPEX should receive a smaller weight than LCOE in the weight allocation survey.

Fig. 1 presents the outcomes of the weight allocation survey, with the mean weight assigned to each factor a corresponding standard deviation. Cost-related factors consistently received higher mean weights, reflecting a shared understanding of their central importance in influencing consumer decisions. Conversely, factors exhibiting wider allocation dispersion (e.g., policy support) indicate variability in the perceived relevance they hold among geothermal experts. Taken together, these weight distributions offer a quantifiable picture of how the partners' geothermal experts prioritise the drivers of affordability relative to one another.

Because policy support had to be omitted, the survey-derived weight vector was rescaled so that the eight active factors still sum to 100%. **Table 10** lists both the original survey weights and the rescaled weights used in the baseline calculation.

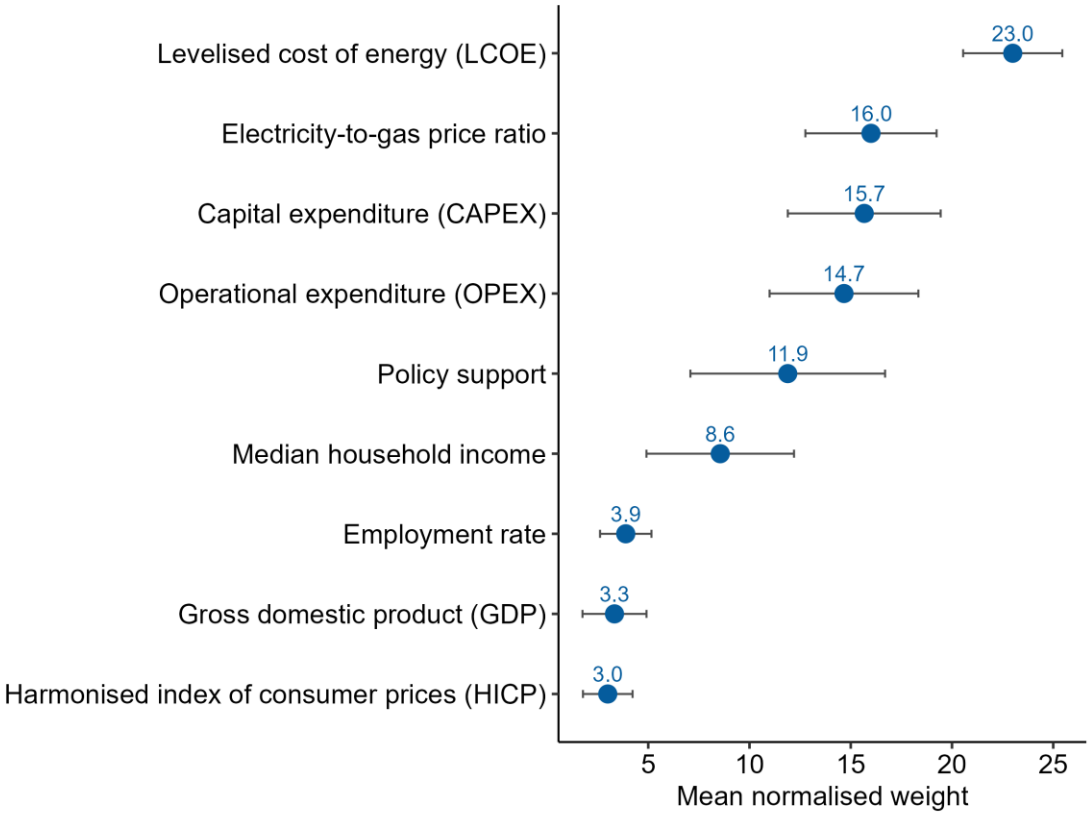

Fig. 1. Mean normalised weights and variability for each factor. This plot displays the average weight assigned to each factor (represented by blue points). Horizontal error bars denote the standard deviation, showing the variability in the weight assignments from the geothermal experts.

Table 10. Survey-derived mean normalised weights and rescaled weights after removing the policy support factor. First column shows the original weights; second column shows the weights renormalised to sum to 100 for the eight retained factors in the baseline calculation.

Factor	Survey weight	Baseline weight
LCOE	23.0	26.1
Electricity-to-gas ratio	16.0	18.1
CAPEX	15.7	17.8
OPEX	14.7	16.7
Median income	8.6	9.8
Employment rate	3.9	4.4
GDP per capita	3.3	3.7
HICP	3.0	3.4
Policy support	11.9	—

Step 4: Data acquisition

Data collection has two tracks: (i) macro-economic and energy-price statistics that are comparable across EU Member States, and (ii) technology-specific cost-and-performance data produced inside GeoBOOST. These two data sources are used to create a dataset for the eight factors retained in the baseline affordability score.

All data taken from Eurostat (i.e., median household income, GDP per capita, electricity-to-gas price ratio, employment rate, harmonised index of consumer prices) are downloaded in nominal euros and timestamped to 2023—the last year for which a complete series exists at the time of writing.

For the remaining technology-specific cost data, we take CAPEX, OPEX, LCOE (all technologies) from the GeoBOOST Deliverable D4.1 life-cycle-cost (LCC) Excel tool (Thelin and Malmberg, 2024). All details behind this tool can be found in the respective project deliverable. Here only the key underlying assumptions are described:

- We use a real discount rate of 3.5% (2% inflation, 5.5% nominal).
- The analysis horizon is 25 years. Straight-line depreciation is used to derive residual values.
- Operating regime: All calculations assume a 55 °C supply temperature, the more conservative of the two options offered in the tool (35 °C and 55 °C) and are therefore more suitable for legacy radiator circuits.
- CAPEX includes acquisition cost and installation cost. Net CAPEX is used (net CAPEX = gross CAPEX – residual). For example, CAPEX for closed-loop systems = drilled-metre price × total borehole depth + plant and installation.
- OPEX combines discounted (i) energy costs (electricity, gas, district heat tariff, pellets); and (ii) service & maintenance plus optional (not considered) major-repair intervals.
- LCOE is calculated as the discounted cost divided by delivered thermal (and, where relevant, cooling) energy.
- System boundary: Only the heat-production installation is costed. Modifications to the building's heat-distribution system (e.g., radiators) are excluded, matching the scope defined in Step 1.
- Component lifetimes:
    - Underground structure: The borehole field for closed-loop GHPs is considered as 100 years. The wells for open-loop GHPs are assumed to last 40 years. Hence there are no replacements in such cases within the 25-year analysis window, but with positive residual values.
    - HP unit (compressor module): For closed-loop and open-loop GPH/GHP, a 20-year lifetime is assumed, while ASHP units are assumed to last 15 years. For boilers, the physical life is assumed to be 15 years. Renewal costs are scheduled at the end of the assumed lifetime and depreciated thereafter.

- All boilers assume a thermal efficiency of 92%.
- Cooling treatment: For HPs, the seasonal cooling energy and passive/active cooling CAPEX are captured. However, district heating and boilers cannot provide cooling. In the LCC tool, the cost of installing (and running) a complementary cooling solution has been added. That is, the cost of a supplementary solution that produces the equivalent amount of cooling as the GHPs has been added to district heating and boilers.
- Each GeoBOOST country has a 'country preset' with residential load profile derived from Typical Meteorological Year data (PVGIS) and heating- and cooling-degree day thresholds (16 °C / 18 °C), plus Eurostat domestic-hot-water statistics. It also includes drilling cost per metre, climate-adjusted HP performance factors (EN 14825 climatic zones), and Earth Energy Designer simulations of borehole depth for three ground thermal conductivities (2–4 W m^{-1} K^{-1}). Here we use a value of 3 W m^{-1} K^{-1} for all countries.

Step 5: Conversion of costs to relative costs

We convert nominal euro-denominated values to standardised costs using Price Level Indices (PLIs). PLIs reflect the relative price level differences between countries compared to the European Union (EU) average. While monetary values are adjusted, non-monetary factors remain unaffected by this conversion. The PLI data is sourced from Eurostat for the GDP analytical category (online data code: prc_ppp_ind). PLI values are derived from the ratio of purchasing power parities (PPPs) to market exchange rates. The formula used for the conversion is straightforward:

$$\text{Adjusted value} = \frac{Nominal\ Value\ in\ Euro}{(Country\ PLI/100)}$$ **Equation 1**

By applying this equation, we create a level playing field. For example, €100 in Country A represents the same purchasing power as its adjusted equivalent in Country B. This adjustment is essential for more meaningful cross-country comparisons, as it corrects for the significant price level differences throughout Europe. The adjusted figures thus reflect the true cost variations beyond what nominal values suggest, enabling fairer comparisons between economies with differing price structures.

Step 6: Normalisation of data values

After adjusting the necessary variables for PLI, the next step involves normalising the data to a common range of 0 to 100. Normalisation is implemented because it certifies that all factors contribute proportionately to the final affordability score, without being skewed by differences in units or scales. We perform a linear transformation of the original data using a simple min-max normalisation. This transformation scales each factor within the specified range, depending on whether higher or lower values indicate greater affordability.

When higher is better (i.e., when a higher value indicates greater affordability):

$$\text{Normalised value} = \frac{x - x_{min}}{x_{max} - x_{min}} \times 100 \qquad \textbf{Equation 2}$$

In this case, the lowest observed value in the dataset is scaled to 0, and the highest to 100.

When lower is better (i.e., when a lower value indicates greater affordability):

$$\text{Normalised value} = \left[1 - \frac{x - x_{min}}{x_{max} - x_{min}}\right] \times 100 \qquad \textbf{Equation 3}$$

Here, the lowest observed value is scaled to 100, and the highest to 0.

In **Eq. 2** and **Eq. 3**, x represents the observed value, while x_{min} and x_{max} denote the minimum and maximum values within the dataset, respectively. This approach places all factors on an equivalent scale for correct comparison, regardless of whether higher or lower values are preferable.

Step 7: Application of the weighting formula

The final step is to calculate the affordability score using a weighted average formula:

$$\text{Affordability Score} = \sum_{i=1}^{n}(x_i' \times w_i') \qquad \textbf{Equation 4}$$

Where:

- x_i' represents the normalised value of the i-th factor (*Step 6*),
- w_i' represents the normalised weight assigned to the i-th factor (*Step 3*),
- i ranges from 1 to n, where n is the total number of factors considered in the calculation (*Step 2*).

Due to the considerations previously described, **Eq. 4** therefore yields a single output between 0 and 100. The outcome reflects the overall affordability based on the selected factors, allowing for direct comparisons between different technologies and countries.

However, we stress that it is important not to over-interpret the results. For example, if Country A has an affordability score of 60 and Country B has a score of 30 for a given system, this does not represent an absolute measure of affordability. Rather, these scores are most useful for making relative comparisons.

Monte Carlo simulation framework

The affordability score is fundamentally a deterministic composite indicator that assumes perfect knowledge of every input and unanimous agreement on factor weights. To quantify the indicator's sensitivity to these sources of uncertainty, we developed a two-dimensional Monte Carlo simulation framework that propagates:

- *Stochastic uncertainty*: Aleatory variations in each affordability factor.
- *Epistemic uncertainty*: Lack of consensus in expert-derived factor weights.

The procedure follows the steps listed below.

Let x_{ijk} be the nominal value of factor k for country i and system j. For each of the eight affordability factors retained in the composite indicator, we specified a symmetric multiplicative tolerance δ_k. That is, uncertainty is modelled as a continuous uniform distribution $\mathcal{U}$

$$\tilde{x}_{ijk}^{(s)} \sim \mathcal{U}\big[(1-\delta_k)\, x_{ijk},\ (1+\delta_k)\, x_{ijk}\big], \qquad \textbf{Equation 5}$$

with independent draws for every simulation $s = 1, \ldots, 10{,}000$. Large-ticket cost items (CAPEX, OPEX and LCOE) were perturbed by $\delta_k = \pm 20\%$; all remaining factors used $\delta_k = \pm 5\%$. Here $k = 1, \ldots, 8$ corresponds to CAPEX, OPEX, LCOE, electricity-to-gas price ratio, median household income, employment rate, GDP per capita, and HICP, respectively.

The expert survey returned a matrix $W = (w_{kr})$ of raw scores (Factor k × Respondent r). For each Monte Carlo iteration, we drew a random weight vector

$$\tilde{\omega}^{(s)} \sim \mathrm{Dirichlet}(\alpha), \qquad \sum_{k=1}^{8} \tilde{\omega}_k^{(s)} = 1, \qquad \textbf{Equation 6}$$

treating weights as fractions summing to unity (multiply by 100 to recover percentages). The Dirichlet parameters α_k are calibrated as follows.

We first calculate each factor's coefficient of variation (CV) from the survey means and standard deviations. We then scale the factors by the inverse CV, so that higher expert disagreement (larger CV) translates into a smaller α_k and hence wider weight dispersion. Subsequently, we apply a single global adjustment so that the total Dirichlet concentration matches the overall uncertainty implied by the survey (i.e., moment-matching the average variance). This CV-scaled, moment-matched Dirichlet keeps the expert-elicited mean weights exactly and approximates their relative spread: factors with more disagreement remain more volatile, while the full set of weights always sums to 1.

On this basis, the simulation workflow runs as follows: For each building-group g and each iteration s:

- **Perturb inputs**: Generate $\tilde{x}_{ijk}^{(s)}$ via **Eq. 5** for every country–system–factor triple.
- **Renormalise factors**: Apply min–max normalisation within group g, preserving the "higher/better" or "lower/better" orientation (**Eqs. 2–3**).
- **Sample weights**: Draw $\tilde{\omega}^{(s)}$ from the Dirichlet distribution (**Eq. 6**).
- **Compute the affordability score:**

$$\widetilde{\mathrm{AFF}}_{ijg}^{(s)} = \sum_{k=1}^{8} \tilde{\omega}_k^{(s)}\ \tilde{z}_{ijkg}^{(s)}, \qquad \textbf{Equation 7}$$

where $\tilde{z}_{ijkg}^{(s)}$ is the normalised value of factor k.

- **Store output**: Append $\widetilde{\text{AFF}}_{ijg}^{(s)}$ to a results array together with (i, j, g, s).

This loop was repeated $N_{\text{sim}} = 10{,}000$ times. The simulation takes a bit over one minute to complete on a desktop computer. For every (i, j, g) combination we then computed:

- mean $\widetilde{\text{AFF}}$ and 2.5–97.5 percentiles, denoted as the 95% uncertainty interval (UI).

Inspection of the running mean and effective sample-size statistics confirmed that 10,000 iterations are numerically sufficient for very stable estimates.

The Monte Carlo mean affordability scores ($\widetilde{\text{AFF}}$) showed a strong correlation with the deterministic scores across building types (Pearson correlation coefficients = 0.95–0.96, *p*-value < 0.0001), which supports the simulation approach validity (**Fig. 2**). Hence we report the results as $\widetilde{\text{AFF}} \pm 95\%\ \text{UI}$, thereby fully accounting for both data and preference uncertainty.

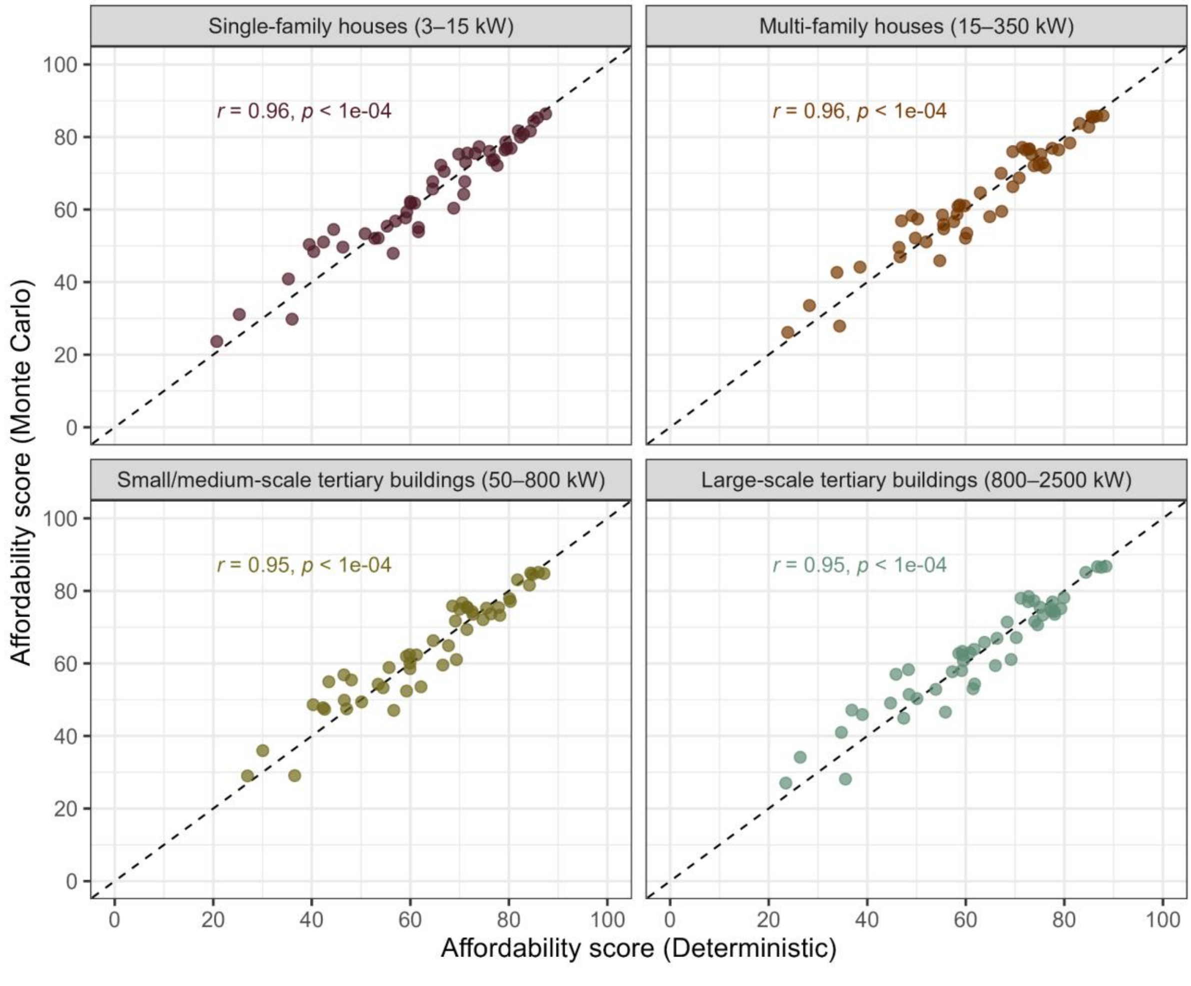

Fig. 2. Deterministic against Monte Carlo affordability scores by building group. Each point is a country–system value, plotting the deterministic score (x-axis) against the mean Monte Carlo score (y-axis). Within each panel, the dashed diagonal is the 1:1 reference line indicating perfect agreement. 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.

EPIC policy scenario

We developed an illustrative scenario to examine how affordability might change under a subsidy scheme linked to intrinsic technical efficiency. The EPIC (**E**fficiency **P**rogram to **I**ncentivise **C**lean Energy) scenario proposes a one-off, efficiency-based capital grant designed specifically to overcome a central barrier to clean heating and cooling adoption: high upfront investment costs.

By tying subsidy rates to technology efficiency, EPIC seeks to capture how targeted reductions in initial capital outlay can shift market dynamics toward efficient renewable solutions, without modifying other critical assumptions, such as consumer behaviour, energy prices or additional supporting policies.

Structure of the EPIC scenario

Compared with the baseline:

- The baseline affordability calculation excluded the policy support factor, and the composite indicator used eight factors (CAPEX, OPEX, LCOE, electricity-to-gas ratio, median income, GDP per capita, employment rate, HICP).
- Under EPIC, the policy support factor is reinstated with its original survey weight (11.9%), and the full nine-factor weight set is used exactly as elicited from experts (**Table 10**). The relative weights of the other eight factors are unchanged.

Policy support is modelled as a tiered capital grant that differentiates between technologies according to their typical efficiency performance, with higher support for options that generally deliver higher seasonal efficiency. In the scenario:

- Flagship tier (60% grant): reserved for the highest-performing HP solutions in the portfolio, represented by GHP (open-loop and closed-loop).
- Advanced tier (40% grant): Assumed for ASHPs.
- Network heat tier (25% grant): Applied to district heating schemes that meet contemporary high-efficiency standards at the system level.
- Low-carbon combustion tier (20%): Assumed for pellet boilers. Keeping the grant below district heating is also justified by air quality externalities and the policy trend favouring electrification and network options.

Fossil fuel boilers are excluded from subsidies. Funds are reserved only for renewable and efficient technologies. Hence, the policy upholds the "energy efficiency first" principle and avoids subsidising equipment with high greenhouse gas intensity.

Grants are simply modelled as upfront discounts, given a fixed percentage of CAPEX. Namely, the grant for system j in country i is $G_{ij} = s_j \times CAPEX_{ij}$, where s_j is the tier-specific rate.

The tier rates (20–60%) are chosen as representative levels that have been used in existing subsidy programs (**Section 2.1**) and are sufficient to address EPIC's purpose. They can be varied in future sensitivity analyses.

How EPIC enters the affordability score

A key modelling choice is that EPIC affects the composite indicator only through the policy support factor. Namely:

- We parameterise EPIC as a CAPEX-proportional euro amount (tier rate × net CAPEX).
- This euro amount is then mapped into the policy support factor in the composite indicator.
- All other cost items (CAPEX, OPEX, LCOE) and macro-economic variables remain fixed at their baseline levels for both the deterministic and Monte Carlo runs. We do not recompute CAPEX, OPEX or LCOE with the subsidy already deducted.

We adopted this representation because it serves two purposes:

1. Isolation of the policy lever: EPIC is explicitly treated as an additional support instrument, separate from underlying technology and macro-economic conditions. Any change in affordability scores between baseline and EPIC can be attributed directly to the presence of the grant.
2. Avoidance of double counting: CAPEX, OPEX and LCOE already capture the financial characteristics of each system. If EPIC discounts CAPEX, and we also let it modify these cost-based factors, the same subsidy effect would be counted multiple times. Restricting EPIC to the policy support factor ensures that its maximum possible influence is bounded by the mean weight assigned to that factor (≈11.9%).

EPIC results are also reported as $\widetilde{\mathrm{AFF}}$. This means that the Monte Carlo weight sampling is done with the Dirichlet over the 9-vector, and uncertainty on the policy support factor is held at $\delta_k = \pm 5\%$. EPIC results are therefore directly comparable with the baseline scores. Differences between the two quantify the isolated effect of an efficiency-linked capital grant on the affordability of each technology across countries and building groups.

2.2.3. Results and discussion

2.2.3.1 Short note on interpreting the results

Before presenting the specific affordability scores, this section outlines how the composite indicator has been constructed and, crucially, how it should be interpreted.

Scope and definition. The composite score serves as a comparative indicator of heating and cooling affordability. It covers seven countries (Austria, Germany, the Netherlands, Ireland, Poland, Spain, and Sweden), seven technology types (closed- and open-loop GHPs, ASHPs, gas boilers, oil boilers, pellet boilers, and district heating), and four building segments (single-family, multi-family, small-to-medium tertiary and large tertiary buildings).

The core definition of "affordability" in this framework combines two distinct categories of data:

1. Direct cost components: CAPEX (including residual values), OPEX, and LCOE.
2. Macroeconomic variables: The electricity-to-gas price ratio, median income, GDP per capita, employment rate, and HICP.

The key modelling assumptions are:

- Baseline scenario *vs.* EPIC scenario: The baseline results exclude policy interventions (grants, tax credits) to provide a neutral reference point. These are reintroduced in the EPIC policy scenario.
- Calculation parameters: Costs are calculated using a 3.5% real discount rate over a 25-year horizon.
- The 55°C standard: All technologies are considered at a 55°C supply temperature. This is a conservative assumption for HPs, as their performance typically improves at lower temperatures.
- Cooling equivalence: To ensure a like-for-like comparison, systems that do not inherently provide cooling (boilers and district heating) are considered with an added cooling module sized to match the GHP's cooling duty. This ensures all options are priced for delivering the same complete service.

Weighting scheme. A primary challenge in affordability analysis is balancing the immediate financial barrier of upfront costs against long-term value. To address this, our weighting scheme retains CAPEX and OPEX as explicit factors to capture short-term pressure, while using LCOE to represent lifetime cost-effectiveness. To circumvent double-counting of cost information embedded in LCOE, expert-elicited weights (rescaled to sum to 100% in the baseline) place LCOE first (26.1%), followed by the electricity-to-gas price ratio (18.1%), CAPEX (17.8%) and OPEX (16.7%). Macroeconomic context carries smaller weights (median income 9.8%, employment 4.4%, GDP per capita 3.7%, HICP 3.4%). In practice, the score prioritises lifetime economics and prevailing energy price structures, while still recognising the importance of upfront outlays in addition to running costs.

Computation and normalisation. Before aggregation, all monetary inputs are adjusted for purchasing power using Eurostat PLIs. We then apply min–max normalisation with consistent directionality, mapping each factor onto a 0–100 scale. It is important to note that this normalisation occurs *within* each specific building group and comparison set. This design choice ensures the scores express the relative position of a technology within that specific context. However, it implies that absolute scores are sensitive to the reference set; adding a new country or technology would rescale the entire panel. Therefore, the rank order within a panel is a more robust metric than comparing absolute score numbers across different panels.

Factors are aggregated using the survey-derived weights via a weighted arithmetic mean, yielding one composite score per technology, country and building group. In total, 196 mean scores are calculated (7 countries × 7 technologies × 4 building groups).

Handling uncertainty. While the composite indicator itself is deterministic, reality is not. To account for this, we implemented a two-dimensional Monte Carlo simulation (10,000 iterations) covering:

- Data uncertainty: Perturbations of input factors.
- Preference uncertainty: Variations in expert weightings.

The resulting Monte Carlo means track the deterministic scores closely ($r > 0.95$), confirming the internal consistency of the approach while providing the 95% UIs that are useful for the interpretation of results.

Policy-sensitive interpretation (EPIC scenario). To quantify the impact of financial incentives, the EPIC scenario serves as a sensitivity analysis. This scenario reinstates policy support at its original survey weight (11.9%) and applies a one-off, efficiency-tiered capital grant. Indicative grant levels are 60% of CAPEX for GHPs, 40% for ASHPs, 25% for district heating and 20% for pellet boilers, with fossil boilers excluded. Grants are implemented as a direct reduction in CAPEX, while all other inputs and processing steps remain unchanged. This scenario quantifies how targeted financial incentives could modify affordability patterns relative to the baseline.

Summary guidelines for interpretation. To grasp the results effectively, readers should consider the following four principles:

- Not a substitute for site assessment: The affordability score is best understood as a decision-support metric for comparing technologies across countries and building types, under harmonised assumptions and nationally averaged conditions. The affordability score is not an absolute measure of cost-effectiveness and is not intended to replace project-specific assessments.
- Relative positioning: Focus on which systems appear more (or less) affordable relative to others within the same building/country group for the 2023 timeframe.
- Ordinal-to-interval: The 0–100 scale indicates order and magnitude, but not ratio. A score of 60 is "better" than 30, but it does not mean it is exactly "twice as affordable".

- Robustness: The 95% UIs are relevant for the interpretation. Some small differences in scores may not be statistically significant, strictly speaking.

Structure of the analysis. The following results section is organised into three main parts:

- First, we present the baseline results with breakdowns by country, building group and technology family, integrating the discussion of uncertainty and robustness alongside each set of findings.
- We then examine the primary drivers of the results and present head-to-head comparisons of GHPs with gas boilers.
- Next, we show the results from the EPIC policy scenario.

2.2.3.2 Baseline results

Headline technology patterns

Fig. 3 shows affordability scores averaged across all four building types for each country, plus an overall cross-country average. The pooled statistics below summarise results across all 28 country–building combinations (namely, 7 countries × 4 building groups; detailed results for each building group are presented separately in **Figs. 4–7**). Hence, these pooled statistics presented below reflect relative technology rankings across building types rather than direct comparisons of raw scores, as each building group has been normalised separately.

The first prominent outcome from the baseline scenario is the emergence of a clear ranking among technologies:

- **GHP (closed loop)** achieves the highest pooled mean affordability score (73.1). It ranks within the top three options in 86% of all country–building combinations and takes first place in 75 % of them.
- **GHP (open loop)** follows closely with a pooled mean of 71.4. It appears in the top three in 82 % of combinations. Whenever closed-loop GHP ranks first, open-loop GHP is very often second; this occurs in 15 of the 21 cases where closed-loop GHP leads.
- **ASHPs** occupy a competitive but slightly lower position, with a pooled mean of 69.2. They still perform strongly, entering the top three in 68% of combinations and achieving the highest affordability score in three cases (11%), all in multi-family residential and small-to-medium tertiary buildings.
- **District heating** (63.0) and **pellet boilers** (62.9) form a mid-tier, typically sitting between the high-performing HP systems and the lower-scoring fossil technologies.
- **Oil boilers** (56.6) and **gas boilers** (50.4) tend to occupy the bottom of the affordability rankings and frequently emerge as the least attractive options within each panel.

Therefore, GHPs lead in most contexts, under a conservative 55 °C supply temperature that reflects legacy radiators rather than best-case design and after charging boilers and district heating for an equivalent cooling solution. This suggests that lifetime economics, combined with prevailing price structures, generally favour electrified heating and cooling in much of

Europe. Where this is not the case (most visibly in Germany), the explanation lies in contextual price relativities, not in an intrinsic disadvantage of HPs. We elaborate on the drivers behind these results subsequently.

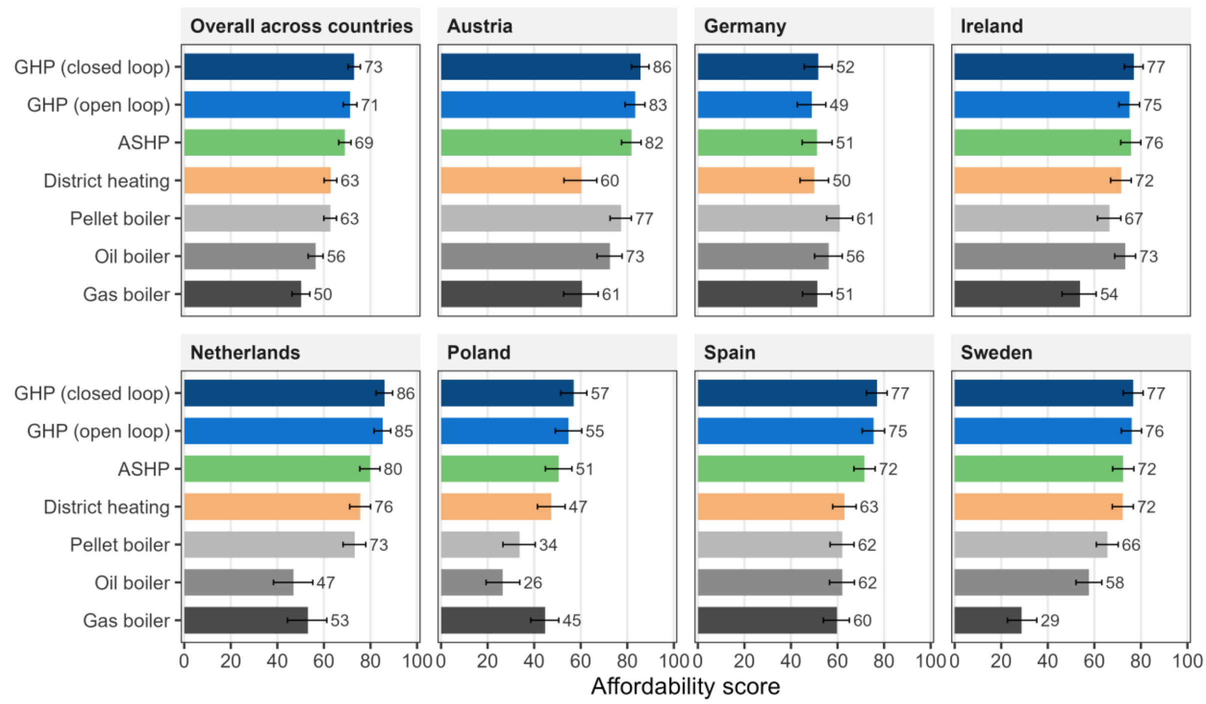

Fig. 3. Affordability scores by technology and country (baseline scenario, heating and cooling, 2023). Horizontal bars show Monte Carlo mean affordability scores for each system on the 0–100 scale from the Monte Carlo simulation ($N_{\text{sim}} = 10{,}000$); error bars indicate 95% uncertainty intervals (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.

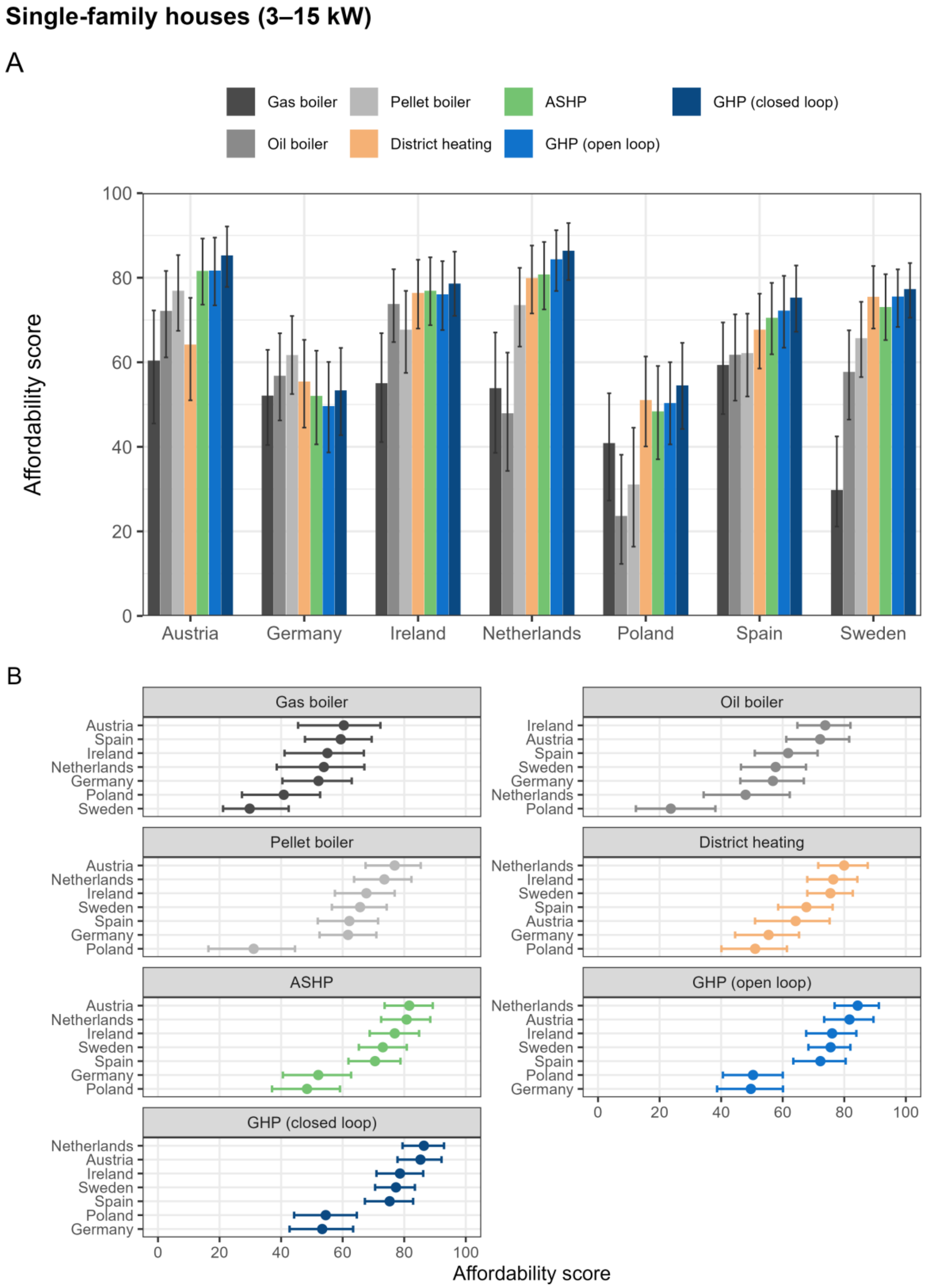

Fig. 4. Affordability scores for single-family houses (baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95 % UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation ($N_{\text{sim}} = 10{,}000$).

Multi-family houses (15–350 kW)

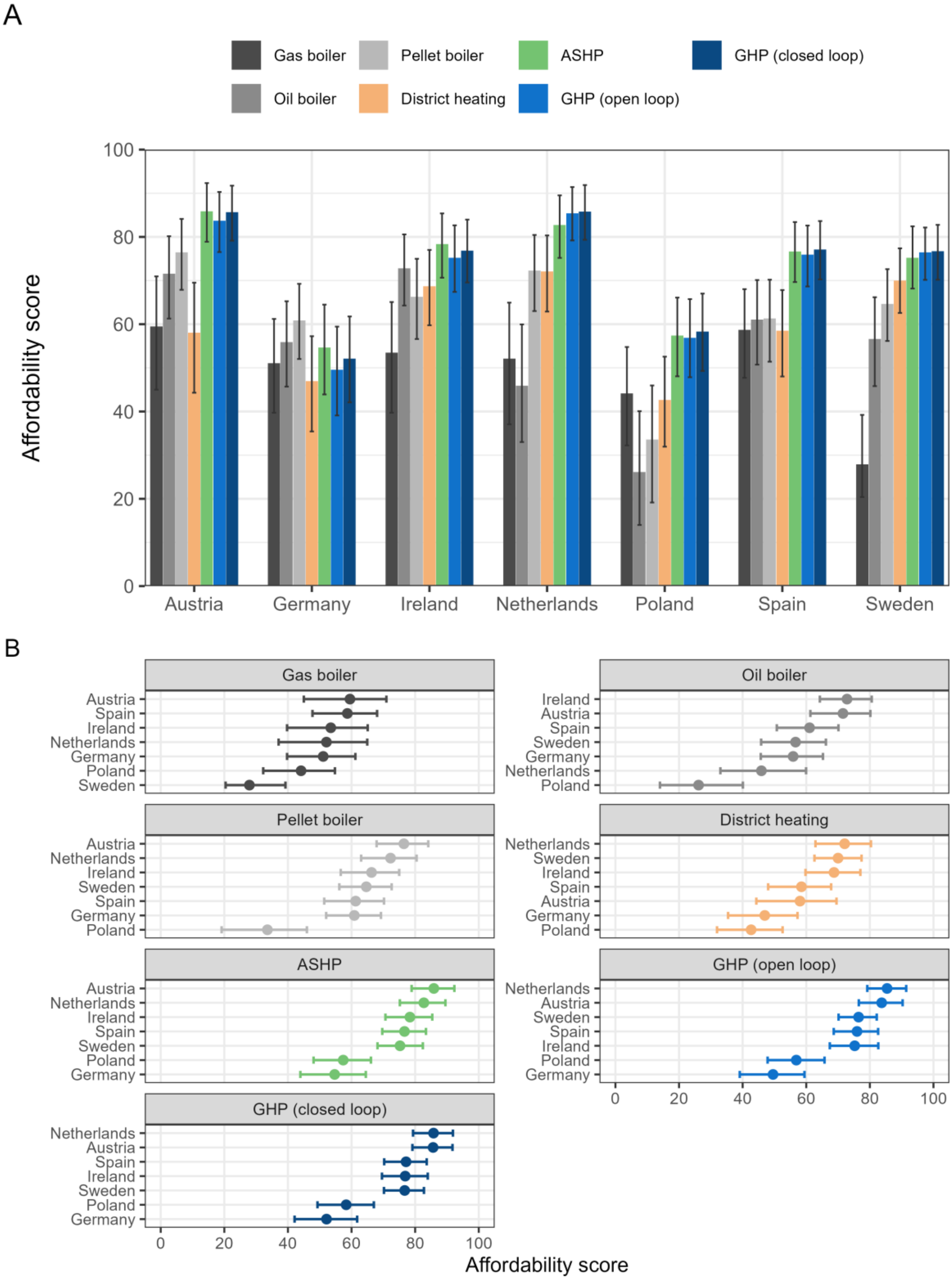

Fig. 5. Affordability scores for multi-family houses (baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation ($N_{\text{sim}} = 10{,}000$).

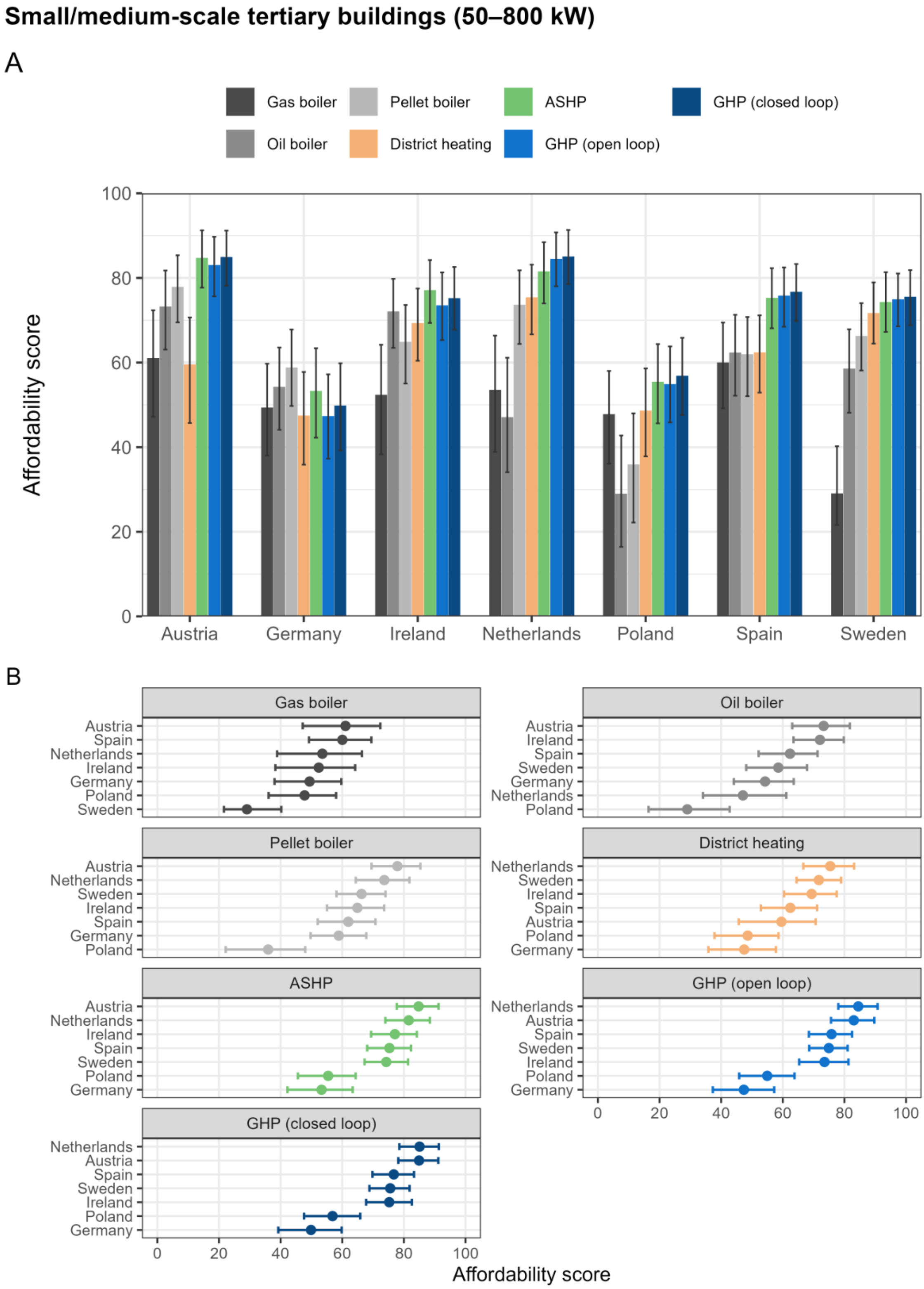

Fig. 6. Affordability scores for small/medium-scale tertiary buildings (baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation ($N_{\text{sim}} = 10{,}000$).

Large-scale tertiary buildings (800–2500 kW)

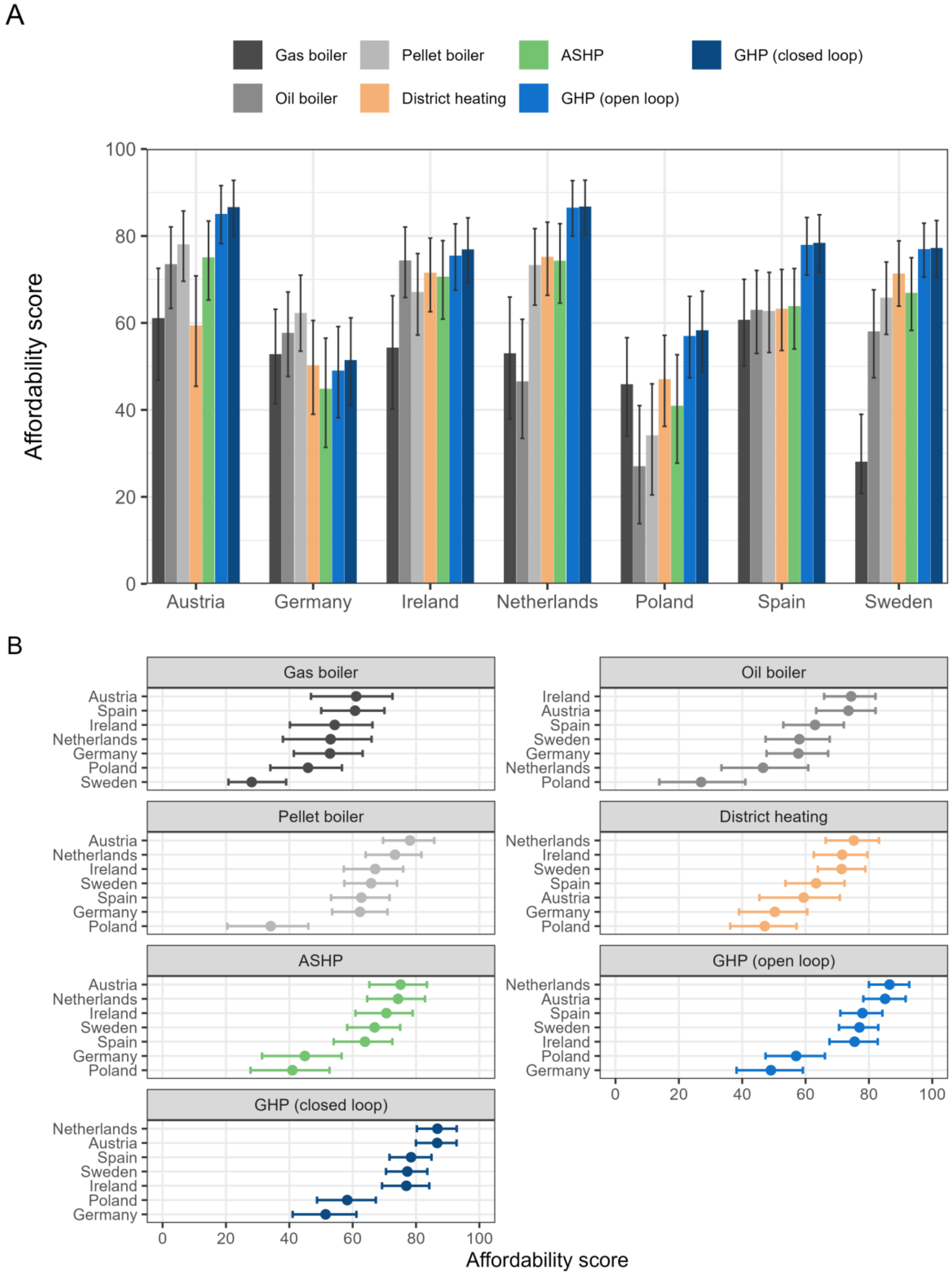

Fig. 7. Affordability scores for large-scale tertiary buildings (baseline scenario, heating and cooling, 2023). (A) Mean scores by country and system. (B) Country-specific mean scores for each system, ranked vertically. In both panels, error bars show the 95% UIs (2.5th–97.5th percentiles) from the Monte Carlo simulation ($N_{\text{sim}} = 10{,}000$).

Patterns by technology family across countries

Fig. 8 summarises affordability by technology family for each country. Four technology families are considered: GHP (closed and open loop combined as *GHP all*), ASHP, district heating, and combustion-based options (gas, oil and pellet as *Combustion all*). The "Overall across countries" row gives the headline picture. On average, GHPs are the most affordable family with a mean score of around 72, followed closely by ASHPs at 70. District heating sits at approximately 64, while combustion systems score lowest at 57. Put differently, when all building types and countries are pooled, electrified options clearly cluster at the top of the affordability scale, district heating occupies an intermediate position, and combustion systems are generally least affordable.

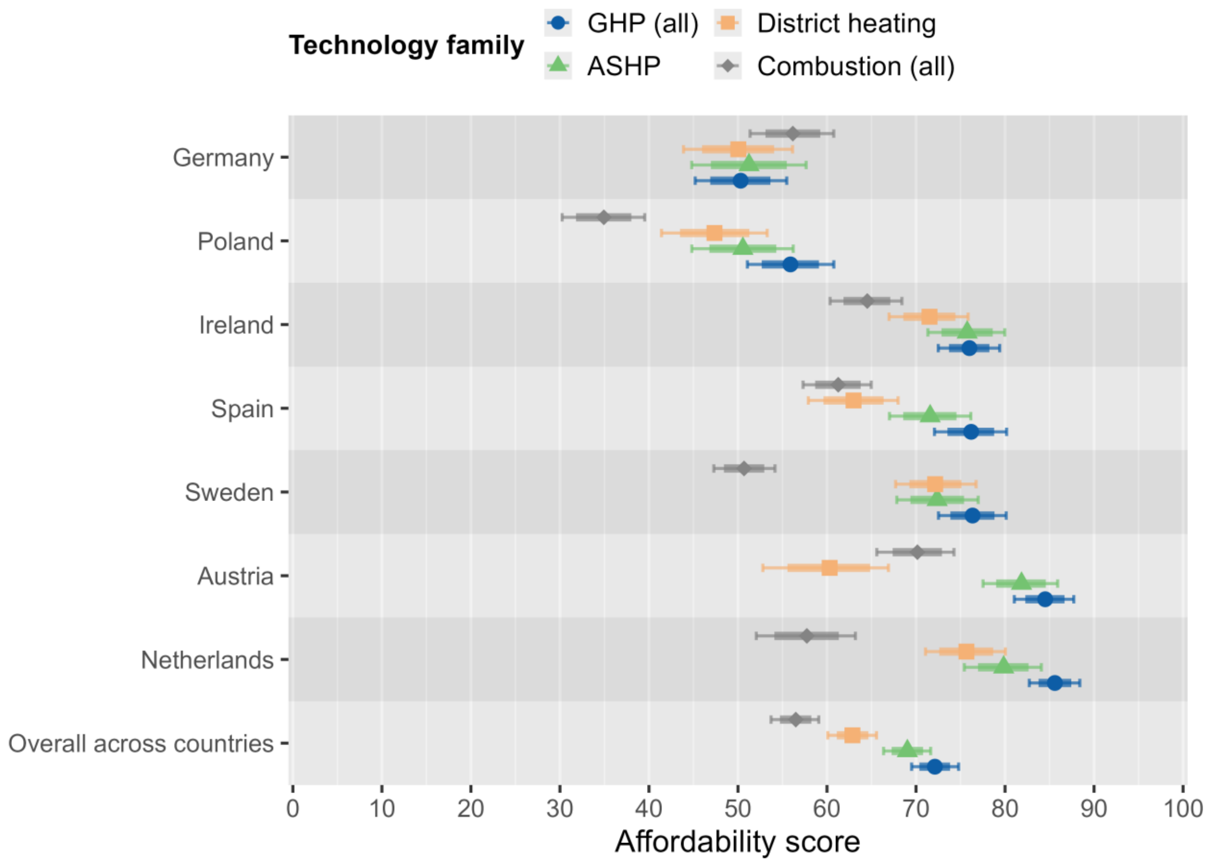

Fig. 8. Affordability scores by technology family and country (baseline scenario, heating and cooling, 2023). Points represent pooled average scores for each technology family aggregated across building groups. Families were defined as GHP all (geothermal heat pumps, combining closed- and open-loop systems), 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.

This pattern holds across most countries. GHPs are either the best-performing family or statistically indistinguishable from the best, in 6 of the 7 European countries (Austria, Ireland, the Netherlands, Poland, Spain and Sweden). ASHPs typically trail by only a few points and occasionally overtake GHPs within the UIs (for example, in Ireland). District heating is competitive where tariffs are favourable, notably in Sweden and, to a lesser extent, Austria and Spain, but rarely exceeds the leading HP family. The main deviation from the general pattern is Germany, where combustion systems marginally outperform the HP families, though overlapping UIs suggest this difference is directional rather than definitive.

As already realised from the previous results, country-to-country variation in the absolute level of scores by technology family is also pronounced. The HP families reach the mid-80s in the Netherlands and Austria, fall to the low-to-mid 70s in Ireland, Spain and Sweden, and drop to the 50s in Germany and Poland. This again confirms that the ranking of technologies is robust. However, the margin by which electrified options lead (or fail to lead) is strongly context dependent. This reflects national price ratios, overall price levels and income conditions that are discussed in the upcoming section on drivers.

Uncertainty is modest at this level of aggregation. Most 80% UIs span only a few points, and while 95% UIs for the leading two families often overlap, the broad ordering (HP families ahead, district heating in the middle, combustion at the bottom) is stable in all but one country.

Fig. 8 therefore suggests that, under baseline assumptions without additional policy support, GHPs are not intrinsically disadvantaged on affordability grounds in most of the analysed markets. Namely, electrified options tend to sit at the top of the affordability range, with district heating in the middle and combustion systems at the bottom. This should not be interpreted as implying that policy support is unnecessary. Rather, it suggests that subsidies can build on a favourable lifetime-cost position to overcome upfront cost barriers, liquidity constraints and other frictions that still prevent end-users from adopting GHPs.

Patterns by building group

Fig. 9 compares baseline affordability scores across the four building groups, averaging results over the 7 countries. The overall ranking is stable across all building types: HPs consistently lead, district heating and pellet boilers occupy the middle tier, and oil and gas boilers trail at the bottom. What changes with scale is how ASHPs position themselves relative to other HP technologies and whether they maintain their advantage over mid-table options.

Across the first three building segments–single-family houses (3–15 kW), multi-family houses (15–350 kW), and small/medium-scale tertiary buildings (50–800 kW)–HPs cluster tightly at the top of the affordability rankings, scoring between 69 and 73 points. Closed-loop GHPs consistently lead or tie for first place, benefiting from low LCOE driven by efficient ground-source performance and, in the single-family case, favourable residual values for boreholes. Open-loop GHPs track closely behind (70–72 points). ASHPs converge with GHPs in the multi-family and small/medium tertiary segments, where they offer the lowest CAPEX of any technology while maintaining the second-best LCOE/OPEX profile after GHPs. This combination allows ASHPs to score around 69–73 across these three building types, making all three HP variants indistinguishable in medium-scale applications from a statistical point of view. In these segments, district heating and pellet boilers consistently occupy the middle tier (60–67 points), sitting roughly 10 points below the leading HPs. Oil and gas boilers remain clearly at the bottom, scoring around 50–56 points. The gap between the best HP option and gas boilers is consistently 20–23 points, with minimal overlap in uncertainty intervals.

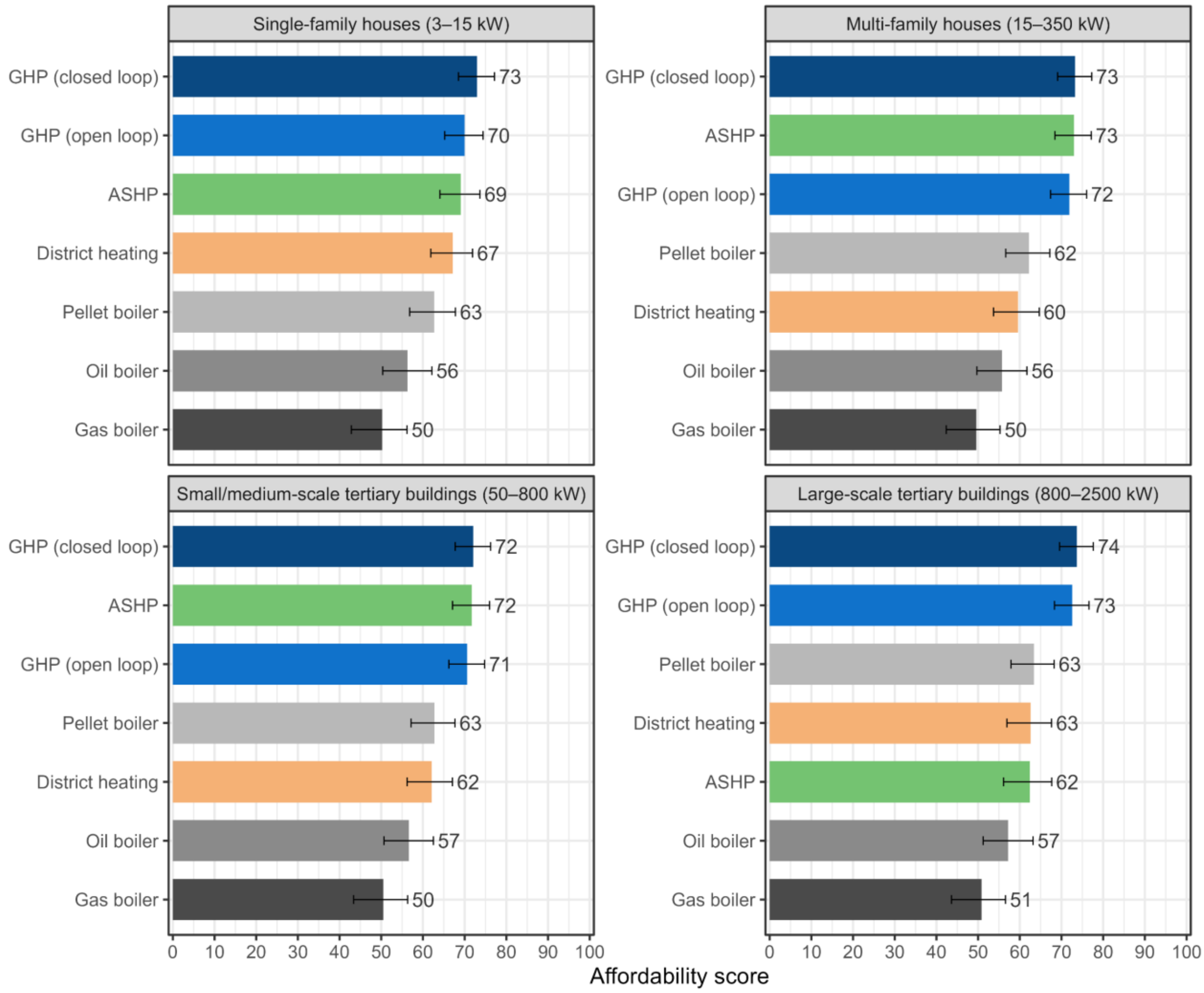

Fig. 9. Affordability scores by building group (baseline scenario, heating and cooling, 2023). Horizontal bars show Monte Carlo mean affordability scores for each system on the 0–100 scale from the Monte Carlo simulation (N_{sim} = 10,000); error bars indicate 95% uncertainty intervals (2.5th–97.5th percentiles).

The pattern shifts in large-scale tertiary buildings (800–2500 kW). Closed-loop GHPs (74) and open-loop GHPs (73) retain their leading positions, but ASHPs drop to approximately 63 points. In fact, ASHPs fall into the upper-middle band alongside pellet boilers and district heating (both ~63). This reflects a change in cost structure at scale. While ASHPs maintain relatively low CAPEX, their LCOE and OPEX rise in large buildings, surpassing both pellet boilers and district heating, and remaining well above GHPs. Because lifetime running costs carry significant weight in the composite index (LCOE alone accounts for 26%), this shift pushes ASHPs below the GHP variants in the large-tertiary segment.

Thus, across all four building groups, the best-performing HP option remains over 20 points ahead of gas boilers, and the uncertainty intervals for the top technologies rarely overlap with those for gas. Thus, once scores are averaged across countries, the same qualitative hierarchy emerges everywhere: HPs at the top, district heating and pellets in the middle, and oil and gas boilers as the least affordable options, with ASHPs shifting from "tied with GHPs" at intermediate scales to "upper-middle" in large tertiary buildings.

Differential affordability: GHP (closed loop) against gas boilers

To further assess the relative affordability of geothermal solutions versus conventional boilers, we focus on the closed-loop GHP and a gas boiler benchmark, still the dominant heating system in many European markets. For each country–building-group combination, 10,000 Monte Carlo affordability scores for closed-loop GHPs were paired with 10,000 scores for gas boilers, yielding a distribution of differences in affordability scores. This paired analysis allows a statistically robust test of whether, and by how much, closed-loop GHPs outperform gas boilers under uncertainty. **Fig. 10** shows the mean difference and its 95% UI for each scenario. Positive values indicate that closed-loop GHPs are more affordable on average.

The overall picture is clear: in 6 of the 7 countries, closed-loop GHPs exhibit a strong and statistically robust affordability advantage in all four building segments. Sweden shows the largest and most precisely estimated gaps, with mean differences close to +50 points and narrow UIs across all segments. The Netherlands also decisively favours closed-loop GHPs, with differences of roughly +30–35 points. Austria, Ireland and Spain follow closely behind, with gaps typically in the +15–25 point range; all segments in these countries have UIs that lie comfortably above zero. Poland is more marginal. Mean differences are positive in every building segment (roughly +9 to +14 points), but three of the four UIs include zero. Only Polish multi-family houses show a clearly positive difference. This suggests that relatively modest shifts in price ratios or investment support could be sufficient to make closed-loop GHPs unambiguously more affordable than gas boilers across the Polish building stock. Germany stands out as the only country without a robust advantage for either technology. Mean differences hover around zero in all segments, and the UIs always span both positive and negative values. In other words, under our current calculation considerations, closed-loop GHPs and gas boilers are roughly on par in terms of affordability. This reflects Germany's particularly high electricity-to-gas price ratio (around 3.4) combined with high drilling costs (about €110 m^{-1}, compared with roughly €31 m^{-1} in Sweden), which together offset the efficiency benefits of geothermal systems.

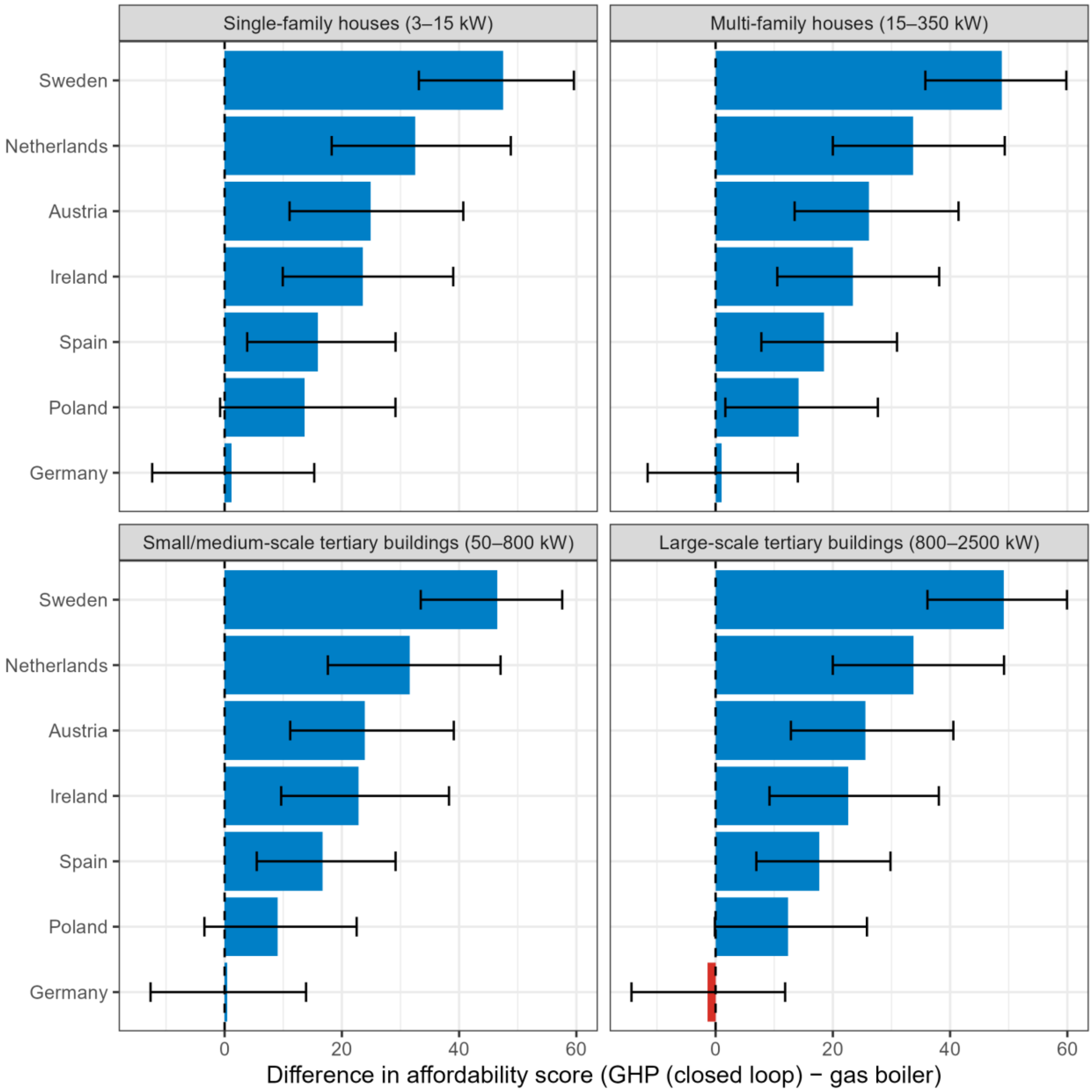

Fig. 10. Difference in affordability score (closed-loop GHP − gas boiler) by country and building segment. Bars show the mean paired difference; positive bars (blue) indicate that GHP (closed loop) is more affordable on average, while negative bars (red) favour gas boilers. Error bars indicate 95% UIs (2.5th–97.5th percentiles) from the paired Monte Carlo differences ($N_{\text{sim}} = 10{,}000$).

A modest scale effect is visible within the countries that already favour closed-loop GHPs: affordability gaps tend to widen slightly with building size, with the largest differences appearing in large tertiary buildings. However, these within-country shifts are small relative to the cross-country contrasts, and the ranking of countries remains unchanged within the UIs. Thus, country-level determinants clearly dominate, with building scale acting as a secondary rather than primary driver of affordability differences.

Overall, closed-loop GHPs display clear affordability advantages over gas boilers in most of the analysed markets. In more borderline cases, such as Poland and Germany, targeted policies that address fuel-price relativities, offer capital support or reduce drilling costs could tip the balance decisively in favour of geothermal options. An identical paired-difference analysis for open-loop GHPs yields very similar country rankings, magnitudes and scale effects, reinforcing these conclusions.

2.2.3.3 Discussion on the baseline scenario results

Primary drivers of affordability patterns

The baseline affordability patterns observed across countries and technologies are primarily explained by four reinforcing aspects from our weighting and calculation methods. **First**, cost factors dominate the scoring. Three cost components—LCOE (26.1%), OPEX (16.7%), and CAPEX (17.8%)—collectively account for nearly 61% of the total weight. Within this cost structure, there is an important distinction: LCOE and OPEX capture lifetime running costs and reward technologies that operate efficiently over many years, while CAPEX represents the upfront investment barrier. HPs perform strongly in the lifetime metrics due to their superior efficiency, which translates into lower operational costs over time. Boilers, conversely, suffer from recurring fuel expenses that accumulate over the system's lifetime. This explains why GHP variants consistently rank at the top across most countries and building types. Namely, they combine reasonable upfront costs with exceptional long-term economics. **Second**, energy price ratios set the playing field. The relationship between electricity and gas prices (or electricity and district heating in Sweden) carries substantial weight at 18.1%, acting as a strong differentiator between countries. When electricity remains reasonably priced relative to gas, HPs maintain their economic advantage. However, this balance varies dramatically across Europe, creating distinct national patterns in technology competitiveness. **Third**, initial costs create real barriers. Given that CAPEX is treated as its own dimension, the composite score captures the immediate budget barrier many adopters face. This is where ASHP have some wins by a small margin, even if their LCOE is slightly worse compared to GHP. In this case, lower purchase cost offsets the modest life-cycle gap once values are normalised. **Fourth**, socioeconomic context provides important nuance. Income and employment together account for 14.2% of the total weight. While insufficient to override cost signals, these socioeconomic factors modulate affordability by contextualising absolute cost burdens within household financial capacity. In other words, they act as amplifiers or buffers, not as the main motor. Inflation (captured by the HICP factor) and GDP per capita exert smaller, marginal effects given the relatively compressed value ranges observed in 2023.

Influence of the energy price structure (electricity-to-gas price ratio)

In the affordability framework, the electricity-to-gas price ratio (or electricity-to district heating in Sweden) serves as a contextual price signal. Recall that the price ratio is constructed directly from retail tariffs. Because it is a dimensionless ratio, no further PLI adjustment is required: dividing both the electricity and gas prices by a common price-level index would leave the ratio unchanged. The ratio is therefore computed directly from national-level tariffs, min–max normalised to a 0–100 scale, and has an 18.1% weight in the composite. For a given country and scenario, this term is identical across technologies, so it does not affect the within-country ranking of systems, which is driven by technology-specific CAPEX, OPEX and LCOE. Instead, it shifts the overall affordability level of all options up or down according to how favourable the retail price environment is for electrification.

Unsurprisingly, the electricity-to-gas price ratio emerges as an influential indicator of HP viability. Perhaps more importantly, empirically the results from our dataset suggest a threshold effect:

- Where the ratio remains well below 2.5, HP efficiency fully manifests in lifecycle metrics, particularly for GHP systems. In these environments, efficiency gains are effectively monetised through reduced operational costs, establishing electric options as dominant.
- Conversely, where the ratio substantially exceeds 2.5, the lifecycle advantage of HPs diminishes or reverses, and combustion technologies improve their relative affordability positions.

Germany is the clearest example of the latter condition, with a ratio of approximately 3.4, where biomass pellet systems lead in all building segments. On the other hand, the Netherlands, with the lowest ratio at 1.7, shows closed-loop GHP leadership across all building categories. This also explains the pooled means patterns: countries with favourable electricity-to-gas ratios tend to have high composite scores for HP technologies, while elevated ratios systematically suppress their rankings. These results underscore the decisive role of national energy tariff policy in shaping economic outcomes and account for substantial cross-country variation in affordability patterns of heating and cooling systems.

Country price levels and purchasing-power adjustment

Applying PLIs to all euro-denominated variables before normalisation removes pure “cost of living” effects and places technologies on a common purchasing-power footing. After this correction, what matters is the shape of each technology’s cost profile (CAPEX-heavy vs. OPEX-heavy), not the absolute price level. Poland offers an instructive example. Its low PLI (≈ 67.6 with EU-27 = 100) scales up CAPEX, OPEX and LCOE when expressed in purchasing-power terms, which depresses affordability scores even though nominal costs appear low. Incomes also rise when converted to purchasing-power parity, but the income factor’s weight (9.8%) is too small to cancel the stronger cost push. The result is a relatively low pooled national score, even though GHPs are consistently the best-performing family within Poland. The composite therefore separates two questions: which technology is best within a country, and how tight the overall affordability constraint is in that country.

Scale and operating regime

Building scale and operating conditions interact with the drivers in two ways. First, LCOE generally improves with scale for most technologies. Closed- and open-loop GHPs, district heating, pellets, gas and oil boilers all show steadily falling median LCOE as the load increases from single-family to large tertiary buildings. This underpins the broadly similar technology hierarchy across building groups: large systems tend to be slightly more affordable in composite terms, but the relative ordering remains stable. Second, ASHPs behave differently at the largest scale. We observe that, in the underlying cost curves of the LCC tool (Thelin and Malmberg, 2024), the LCOE for ASHP follows a U-shape; that is, relatively high in small buildings, lowest in the mid-scale segments, and higher again in large tertiary buildings. At a large scale, ASHPs therefore have higher running costs than GHPs, pellets and district heating, even though their CAPEX remains relatively low. Given the weight placed on LCOE and OPEX, this is enough to pull ASHPs down from the "podium" at mid-scale into the upper-middle band in large tertiary buildings. This reflects conservative assumptions for large-capacity ASHPs serving existing 55 °C systems, rather than any universal scale effect. Indeed, all systems are evaluated under a 55 °C supply temperature, which should reflect legacy radiators typical of retrofits. This choice reduces the performance (and thus the OPEX/LCOE advantage) of HPs compared with a 35 °C case, but it is applied uniformly across technologies. Even so, HPs and especially the GHP solutions, retain dominant affordability positions. This is an important outcome demonstrating robustness under conservative assumptions.

Why closed-loop GHPs score higher than open-loop GHPs

Across all countries and building groups, closed-loop GHPs outscore open-loop GHPs by roughly 2–3 points on the 0–100 affordability scale. Because macro variables (income, GDP per capita, employment, inflation) and the electricity-to-gas (or electricity-to-district heating in Sweden) price ratio are identical within a given country, they cancel out in a direct comparison between the two GHP options. The separation is consequently dictated entirely by CAPEX, OPEX and LCOE, and by how these factors are weighted and normalised. Here are the details:

- CAPEX (net) favours closed-loop. The analysis uses net CAPEX (gross CAPEX minus residual value at year 25). Borehole fields are assumed to last 100 years, so closed-loop systems receive a relatively large residual value within the 25-year horizon. Open-loop wells are assumed to last 40 years, yielding a smaller residual uplift. After PLI correction, the median net CAPEX across all countries and building groups is about €84 thousand for closed-loop versus €99 thousand for open-loop GHP. This is roughly a 15 % advantage for closed-loop. Given CAPEX carries 17.8 % of the weight, this pulls up the closed-loop score.
- LCOE gives closed-loop a small overall edge. On average across all segments, open-loop GHPs show a slightly lower median LCOE (about €84/MWh vs. €85/MWh, a ~1.5 % difference). However, this masks variation by building type. In single-family houses, closed-loop GHPs have notably lower LCOE (about €5/MWh below open-loop), while in the other segments open-loop systems tend to be 1–2 €/MWh cheaper. Once min–max normalisation and the 26.1 % weight on LCOE are applied, the single-family advantage for closed-loop contributes disproportionately to the average.
- OPEX mildly favours open-loop, but with limited influence. Over 25 years, open-loop OPEX is about 3 % lower on median after PLI correction. However, OPEX is slightly less influential than CAPEX and LCOE (weight 16.7 %), and its cross-system spread is narrower, so the normalised gap in OPEX is typically smaller than the gap in CAPEX.

Hence, closed-loop GHPs win decisively on net CAPEX, gain a modest overall edge on LCOE (particularly in single-family houses), and lose only slightly on OPEX. With macro factors not changing between the two options, the composite tilts consistently, but not dramatically, towards closed-loop systems by a couple of points on average. In practical terms, open-loop GHPs are a touch cheaper to run, but once residual values are recognised, they are not cheaper to build. The weighting and normalisation structure of the framework converts that pattern into the small but persistent lead of closed-loop GHPs in the affordability score.

Uncertainty and robustness

To evaluate the robustness of our findings, we utilised a two-dimensional Monte Carlo simulation. By running 10,000 iterations for each country–system–building combination, we propagated uncertainty across both input factors and expert weightings. The following summary outlines the magnitude of this uncertainty and how it should guide the interpretation of the affordability scores.

Across the full results of 196 scores, we observe a standard deviation of approximately 5 points. This translates to a typical 95% UI of about ±10 points around the mean. However, this variance is not uniform across all technologies. HPs demonstrate the highest stability, displaying the narrowest intervals:

- GHPs (closed loop): 13.9 points
- GHPs (open loop): 14.5 points
- ASHPs: 15.6 points

In contrast, combustion-based technologies exhibit significantly wider variance:

- Pellet boilers: 18.0 points
- District heating: 18.7 points
- Oil boilers: 19.8 points
- Gas boilers: 23.2 points

Notably, we observed a strong correlation (Spearman $\rho \approx -0.81$), indicating that technologies with higher mean scores also tend to have narrower UIs. In other words, the most affordable options in the composite index are also the most robust against uncertainty. This represents an important outcome.

When considering rankings within individual country contexts, the 95% UIs of the top two technologies frequently overlap. Consequently, no single technology is statistically isolated from its nearest alternative at the strict 95% UI.

While this prevents claims of statistical significance between the first and second ranks, the qualitative ordering remains highly stable. As seen, HPs consistently appear in the top tier, while gas and oil boilers consistently occupy the lower tier, with pellet boilers and district heating falling in between. In cases where scores differ by only a few points (e.g., ASHPs *vs.* GHPs in the Netherlands), project-specific conditions could plausibly reverse the order.

Furthermore, two specific design features of the affordability framework explain the modest gaps between the leading and secondary technologies:

1. Compensatory aggregation: The use of a weighted arithmetic mean allows a technology to compensate for a weakness in one factor (e.g., higher LCOE) with a strength in another (e.g., lower CAPEX). This naturally compresses the performance gap among front-runners.
2. Min–max normalisation: Because factors are scaled to a 0–100 range based on the observed dataset, the approach emphasises relative positioning rather than hypothetical extremes. When countries are clustered on cost metrics, the absolute spread in scores is reduced.

Given the combination of these methodological choices and the genuine economic proximity of these technologies under 2023 pricing, the leads at the top of the table are often narrow once uncertainty is factored in.

As already mentioned, the 0–100 scores should be interpreted as *ordinal-to-interval*. This means they are more reliable for comparing which options tend to be more or less affordable, but not for claiming that one technology is "twice as affordable" as another, nor for over-interpreting 1–2 point differences.

Ultimately, the Monte Carlo simulation supports a robust conclusion. HPs, particularly the two GHP variants, occupy the upper distribution of affordability with high predictability. Conversely, gas and oil boilers occupy the lower distribution with high variability. While the distinction between specific technologies within these tiers may be close at times, the broader structural hierarchy is clear.

Temporal and volatility context

Our 2023 snapshot captures a unique moment under which energy markets were still reverberating from 2022's price shocks while beginning to stabilise. This temporal context matters differently for different technologies. Combustion-based systems, particularly biomass pellets, remain exposed to fuel price volatility that a single-year analysis cannot fully capture. HPs, by contrast, derive their economics more from efficiency than fuel prices, lending them greater stability under normal tariff conditions. District heating, on the other hand, presents its own complexity, with its affordability remaining more locally determined after all (tariffs, fuel mix, heat density). Our national averages should understate its competitiveness in dense urban pockets and its growing interplay with large electric HPs. These temporal considerations illuminate that while our 2023 analysis provides crucial insights, the economics of heating and cooling remain dynamic, shaped by evolving energy markets, policy interventions, and technological progress.

Limitations and future scope

It is important to acknowledge specific constraints in this study, which also highlight avenues for future research. First, our baseline scenario excludes grants, tax credits, and other financial incentives due to the lack of a consistent, cross-country dataset. While this limitation results in a neutral, pre-subsidy reference point, we recognise that real-world affordability can often be actively shaped by national support schemes. To address this, our EPIC scenario reintroduces policy support via efficiency-tiered CAPEX grants to test sensitivity to these measures.

Second, the current methodology considers data at the national level and does not account for within-country inequality. Even in high-scoring countries, low-income households may still face significant affordability barriers that aggregate scores cannot capture.

Third, while the composite score integrates multiple factors, the results are reported as a single index value. We do not, in this work, decompose individual scores into contributions from individual factors for each case. Exploring these internal mechanics more systematically is a clear avenue for future research.

Finally, all inputs reflect 2023 market conditions, which is a period still influenced by the 2022 price shock and only partial market stabilisation. Re-running this analysis with 2024–2025 pricing could alter rankings, particularly in markets where the ratio between electricity and gas prices has shifted considerably.

Potential implications for policy and practice

Despite the acknowledged limitations, the analysis yields several distinct conclusions that may guide strategic decision-making:

- **The economic case for gas phase-outs**. Gas boilers consistently appear at the bottom of the affordability rankings across nearly every country–building combination, with oil usually ranking second to last. This suggests that phasing out gas boilers does not impose a long-term "affordability penalty". On the contrary, policies banning gas in new builds or setting deadlines for replacement can be justified on economic grounds, as higher-scoring, more affordable alternatives exist in every situation analysed.
- **The criticality of price alignment for HPs.** The three HP options generally form the leading affordability cluster, led by closed-loop GHPs, followed by open-loop GHPs and ASHPs. This advantage holds even under conservative operating conditions (55°C supply temperature) and without policy support, *provided* the price signals are aligned. In markets with moderate electricity-to-gas price ratios, HPs are the most affordable option. However, where electricity carries a high price premium relative to gas (notably Germany in the 2023 data), combustion technologies, in this case, particularly pellet boilers, become more competitive. This underscores that tariff structures and levy designs are as critical as technology costs in determining operational competitiveness.
- **Targeting upfront barriers.** As seen, the aggregate technology ranking across all countries follows a clear hierarchy overall: *Closed-loop GHP* > *Open-loop GHP* > *ASHP* > *Pellets* > *District Heating* > *Oil* > *Gas*. However, the margins between technologies, such as ASHP and closed-loop GHP, are often narrow. This indicates high sensitivity to capital support. As such, targeted CAPEX grants can be decisive. A grant that narrows the investment gap between air-source and ground-source systems can solidify the lead for geothermal, while general grants for HPs can make their dominance over combustion technologies overwhelmingly clear.
- **Robustness of findings**. The directional findings of this work are stable. Even when subjecting the affordability framework to significant stress (including a ±20%

oscillation in cost factor inputs and the full range of expert weight dissent) country-level scores shift by less than 7 points. This relatively low volatility confirms that the identified trends and hierarchies are robust enough to serve as a reliable basis to support policy formulation.

2.2.3.3 EPIC scenario: effect of grants on affordability rankings

Fig. 11 shows how the EPIC grant scheme changes the relative affordability of the seven heating and cooling technologies. For each country and for a pooled "Overall across countries" panel, this figure plots the change in average affordability rank between the baseline and EPIC scenarios, averaging over the four building segments. A rank of 1 denotes the most affordable option in that country and scenario, and 7 the least affordable.

The pooled baseline ranking largely reflects the earlier results from the baseline scenario. Closed-loop GHP already sit at the top of the distribution, with an average rank of about 1.5 across all countries and building types. Open-loop GHPs and ASHPs form the next tier, with mean ranks of roughly 3.0 and 3.2, respectively. District heating, pellet boilers and oil boilers occupy the middle to lower positions (around 4.5–5.2), while gas boilers are clearly last (around 6.0 on average). In other words, even before policy support is added, the ranking is already HP-centred, but ASHPs sit quite close to GHPs in many cases, helped by their lower upfront cost.

Introducing the EPIC capital grants does not overturn this general picture, but it does change the spacing between technologies in a very particular way. At the pooled level, closed-loop GHP improves slightly from a mean rank of about 1.6 to around 1.4. This reflects a ceiling effect for closed-loop systems, which already occupy first place in most panels. Open-loop GHPs move much more strongly, from rank 3.0 to about 2.1, so that the two geothermal variants clearly occupy the first and second positions. ASHPs, by contrast, slip modestly from roughly 3.2 to 3.5 on average, even though they also receive a grant. District heating and pellets shift only slightly, and oil and gas boilers remain firmly at the bottom (with gas worsening from around 6.0 to 6.25). Across the board, the main effect of EPIC is therefore not to rescue any fossil technology, but to pull geothermal options further ahead of ASHPs and the combustion options.

The country panels in **Fig. 11** tell the same story with more texture. In almost every market, closed-loop GHP either retains or strengthens its position as the most affordable option once grants are introduced. Open-loop GHPs are the main "climbers", typically moving from a shared second or third place into a clear second position, sometimes almost tied with closed-loop GHPs. Where ASHPs had a slight edge over GHPs in the baseline, that edge largely disappears under EPIC. In some countries, ASHP and GHP end up effectively tied. In others, the balance tips decisively towards geothermal systems. District heating tends to hold its middle-of-the-pack status, and pellets keep their strong role where they were already competitive, but do not gain new first places from the policy. Gas and oil boilers remain stuck in the bottom two ranks in virtually all panels.

This pattern is exactly what one would expect from a grant that is deliberately structured to relieve the upfront cost barrier that holds GHPs back. In the baseline, many of the narrow ASHP wins are not driven by lifetime economics: GHPs usually offer equal or better lifecycle costs, especially once cooling is included, but their higher CAPEX pushes them out of reach for households and building owners facing tight budgets or borrowing constraints. Faced with a choice between "the cheapest HP to install" and "the HP that is cheaper to own over the long term", it is unsurprising that many consumers gravitate towards the former. The EPIC scheme works precisely on that margin. By offering more generous grants to GHPs than to ASHPs, it compresses the upfront price gap between the two. Once that gap narrows, the composite index effectively allows lifetime economics to speak more loudly, and the GHP variants move into a clearer lead.

Put differently, the ranking shifts in **Fig. 11** are not just a cosmetic reshuffling of technologies. They illustrate how a well-targeted capital grant could change the type of HP that is chosen, not only whether a HP is chosen at all. Without support, the lower ticket price of ASHPs can steer even well-informed consumers towards a solution that is locally optimal for their bank account today but not for their total energy bills over time. Under EPIC-style support, more consumers could seriously consider a geothermal system rather than defaulting to ASHP simply because it is the cheapest electric option at the point of purchase in today's terms. The widening gap between GHP and ASHP ranks under EPIC is therefore best read as the model's translation of a very concrete behavioural effect: when one softens the upfront hit, the technology with better long-run economics and built-in cooling tends to win.

At the same time, the shifts in rank are generally on the order of one step rather than dramatic reversals. That is partly by design. EPIC only touches the CAPEX dimension; all operating costs, energy prices and macroeconomic conditions remain fixed, and we retain the conservative 55 °C regime for all technologies. As stated before, the composite indicator is also compensatory: strong performance on one factor can offset weaker performance on another, which naturally produces relatively small gaps at the top. Given these constraints, the fact that geothermal technologies still manage to pull away from ASHPs and combustion options is a strong signal. It suggests that once upfront barriers are eased, the underlying lifetime economics of GHPs are robust enough to show through clearly, even under cautious assumptions about operating conditions.

The policy takeaway is straightforward. Under 2023 price conditions, an efficiency-tiered capital grant would do three things at once:

- It reinforces the position of HPs as a whole relative to fossil boilers;
- It rebalances choices within the HP options in favour of geothermal systems, which are more capital-intensive but cheaper over their lifetime;
- It leaves fossil boilers stranded at the bottom of the affordability ranking.

For policymakers who worry that consumers might simply "stop" at ASHP because it is the HP to install, the EPIC results suggest that suitably structured grants can open up the geothermal option without distorting the market in favour of any fossil incumbent.

Finally, it should be noted that one practical concern with capital grants is that they can sometimes push prices up. If support is generous and the supply chain is tight, quoted CAPEX can be artificially increased, so that part of the subsidy is absorbed as higher margins rather than fully passed on to consumers. Yet, this risk does not change the main message of our EPIC results, but it does affect how such a scheme should be designed in the real world, namely, with concomitant measures that can limit price inflation.

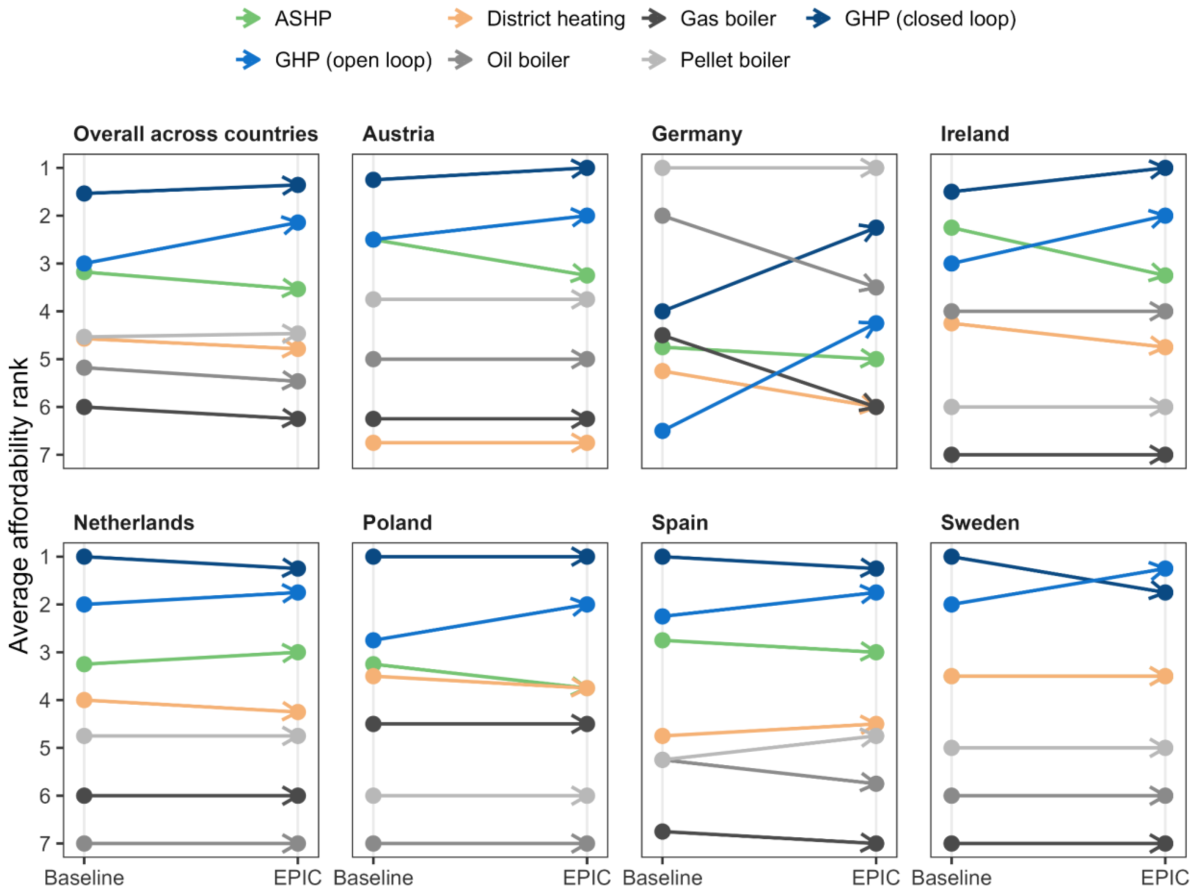

Fig. 11. Change in average affordability rankings under the EPIC grant scheme. Each panel shows, for one country (and for the pooled "Overall across countries" case), the mean affordability rank of each technology in the baseline and EPIC scenarios, averaged across the four building segments. A rank of 1 indicates the most affordable option and 7 the least affordable. Coloured lines (with markers) trace how each technology moves between scenarios. The EPIC scenario only alters upfront costs via technology-differentiated capital grants; all other inputs are held constant. The "Overall across countries" panel summarises the average rank shifts over all seven countries and building groups, highlighting how EPIC tends to pull GHPs further ahead of ASHPs and fossil boilers in relative affordability.

3. Financial measures for scaling up GHPs in EU buildings

3.1. Background

The building sector in Europe consumes a large share of the region's energy and is a major source of greenhouse gas emissions, with heating still primarily reliant on fossil fuels. Decarbonising heating and cooling in buildings is therefore essential for meeting the EU's climate targets. It is well known that GHPs are a key technology in shifting towards a greater share of renewables in the energy mix (Self et al., 2013), since they can significantly reduce carbon emissions by leveraging stable ground temperatures (Bayer et al., 2012; Blum et al., 2010).

Although GHPs have significant potential, deployment remains modest in most European countries outside the Nordics, where adoption is comparatively high. The primary barriers to wider deployment are frequently identified as high initial investment costs and other financial hurdles (Goetzler et al., 2009; Olabi et al., 2023; Strazzera et al., 2024). Rapidly scaling up GHP installations, in single-family homes, multi-family apartment buildings and tertiary (commercial/public) buildings of all sizes, will require innovative financing solutions that reduce these hurdles and foster greater investor and consumer confidence. By overcoming these barriers, GHPs can play a more central role in decarbonising Europe's building stock and helping achieve the EU's long-term climate objectives.

In this part of the deliverable, we explore the role of financial measures to accelerate the mass deployment of GHPs across the EU. Our focus now is on solutions that go beyond traditional subsidy programs, in line with the objectives of this deliverable. We address challenges of high CAPEX *vs.* OPEX imbalance, limited financing access, risk perceptions, inclusivity for lower-income groups and regulatory/market hurdles. Best practices from within and outside the EU are considered to inform a catalogue of policy recommendations targeting EU and national policymakers, investors, as well as end-users.

3.2. Overall structure

We designed the subsequent analysis to follow a logical flow that progresses from problem identification to potential solutions and recommendations, as follows:

- **Financial barriers:** First, we contextualise major financial obstacles to GHP adoption, creating a foundation for understanding what any proposed solutions must address.
- **Innovative financial mechanisms**: We then present specific financial mechanisms that could overcome the identified barriers. Each mechanism is presented with (i) a clear working principle, (ii) identification of which barriers it addresses, and (iii) real-world examples where it has been implemented.
- **Case studies and best practices**: Discussed here is the move from theoretical mechanisms to real-world implementations, showing what has already worked (or not worked) in practice. This provides evidence and lessons learned to inform EU implementation.

- **Feasibility assessment**: Here we bridge the gap between identifying solutions and implementing them by considering how well each mechanism could work in the EU context.
- **Policy recommendations**: Finally, we translate the previous analysis into actionable steps for different stakeholders. By segmenting recommendations and suggestions by stakeholder group, we aim to provide more targeted guidance for application.

3.3. Financial barriers

There are more than a few persistent barriers which have financially constrained the wider adoption of GHPs (Goetzler et al., 2009; Olabi et al., 2023; Strazzera et al., 2024). Below, the primary financial obstacles have been identified and explained:

- **High upfront capital costs:** The total capital cost of GHP systems, encompassing both system components and installation, is considerably higher than that of gas or oil boilers. For example, low-temperature HP systems can have a total upfront cost nearly three times higher than that of a gas boiler, with high-temperature HP systems reaching up to eight times the cost (EHPA, 2024). Drilling boreholes and fitting ground loops add considerable CAPEX, even though long-term operating costs are much lower. Many consumers tend to focus on the steep initial investment and do not fully consider total lifetime savings. This CAPEX–OPEX imbalance makes HPs financially unattractive, even despite favourable total cost of ownership in many cases (Rosenow et al., 2025).
- **Limited access to financing:** Many building owners lack convenient financing mechanisms to cover the upfront cost of GHP installations. Traditional bank loans may have high interest or short tenors for residential retrofits, and not all homeowners qualify. There is a gap in tailored financial products (e.g., green loans, mortgages) that spread costs over the long life of the equipment (IEA, 2022). Incentives for lenders to offer attractive terms have been insufficient; policymakers are only beginning to encourage banks to provide low-interest, long-term loans for HPs (EHPA, 2024). Overall, the lack of “ready cash” or financing options has been a major obstacle, particularly for middle- and low-income households without substantial savings.
- **Investor risk perception and low confidence:** GHP technology is highly proven, but investors and consumers who are unfamiliar may perceive it as risky. Concerns include uncertainty about actual performance, fear of drilling complications or doubts that energy savings will truly materialise as projected. A U.S. Department of Energy study noted that beyond cost, a lack of confidence or trust in the technology and insufficient data for credible lifecycle analysis were important barriers to HP adoption (Hughes, 2008). Similarly, in Europe, first-time adopters often worry whether the system will heat reliably in winter or if maintenance costs will spike. This risk aversion is a problem since it can deter upfront investment. For larger projects, investors may demand high returns to compensate for perceived risks, raising the cost of capital.
- **Split incentives in rental buildings:** In multi-family housing and commercial rentals, the party investing in efficiency upgrades (typically the building owner) is not the one

paying the energy bills (the tenant). This so-called split incentive means landlords have little financial motivation to invest in GHPs since energy savings accrue to tenants. Regulatory frameworks and lease structures often do not allow easy cost-sharing. Without options like green leases or on-bill cost recovery, the split incentive remains a significant barrier in the rented residential and tertiary building sector. Collective decision-making in apartment complexes (condominiums) can also stall investments if even a few owners resist the upfront cost (Castellazzi et al., 2017).

- **Inclusivity concerns:** Without targeted support, the transition to HPs risks excluding lower-income households. Upfront costs and higher electricity prices (relative to subsidised gas) have made clean heating unattainable for many low-income families (Gibb and Sunderland, 2023). Even with government subsidy schemes in 25 of 27 EU countries, only 9 offer higher support levels for low-income households (Braungardt et al., 2022). This means many vulnerable consumers cannot afford GHP upgrades and may be “left behind” in the heating transition. Providing inclusive access to financing and incentives is a major challenge that must be addressed to avoid exacerbating energy poverty.
- **Regulatory and market financial barriers:** In some cases, regulatory frameworks have not caught up to enable innovative financing. For instance, on-bill financing may face obstacles if existing laws do not permit utilities to offer financing services or if there are restrictions on modifying billing structures. Similarly, third-party ownership models might face hurdles due to regulations that do not recognise such arrangements or that impose stringent licensing requirements on third-party providers. Complex permit rules for drilling can also add cost and uncertainty. Additionally, energy pricing structures often penalise HPs, that is, electricity prices bear high taxes/levies while natural gas may be tax-advantaged or capped (EHPA, 2024). This distorted price signal lengthens payback for GHP investments. Market-driven issues like a lack of trained installers or trusted contractors also indirectly increase perceived financial risk (through potential subpar installations or limited competition keeping prices high).

The identified financial barriers show the need for innovative measures that rebalance upfront *vs.* operating costs, spread or reduce the initial investment burden, mitigate risk, and open access to all consumer segments. In the next section, we explore different financial instruments and models with the potential to tackle these challenges.

Another important obstacle, not explicitly listed above but discussed previously in this deliverable, is the inadvertent prevention of innovative business models due to restrictive subsidy schemes in some countries. Namely, current subsidy programs may impose structural constraints that limit or exclude novel service-based approaches, such as heat-as-a-service (HaaS) or leasing models. As highlighted beforehand, these restrictive conditions warrant reconsideration to ensure they do not unintentionally stifle beneficial market innovations. This issue can be directly addressed in the subsidy scheme design.

3.4. Innovative financial mechanisms

We concentrate on presenting six mechanisms (on-bill financing, third-party ownership, performance-based incentives, utility tariff reforms, community financing and risk mitigation) that can help address the previously identified barriers. These mechanisms are based on a combination of financial instruments and business models. Before exploring these mechanisms, it is important to clarify that a business model and a financial instrument are related but distinct concepts:

- A *business model* describes how an organisation creates, delivers, and captures value. It defines the structure of revenue generation, cost management, and overall strategy for sustainability. Examples include third-party ownership and performance-based contracting. Deliverable 5.3 of the GeoBOOST project deals with business models specifically. Here we embrace the core principles of those most relevant to the present analysis.
- A *financial instrument* refers to assets, contracts, or instruments that facilitate financial transactions, investments, or risk management. Examples include loans, bonds, equity investments, and guarantees.

Mechanism 1: On-bill (pay-as-you-save)

Working principle: In on-bill programs, a third party (e.g., utility company, cooperative, financial institution or energy service provider) covers the upfront costs of energy efficiency measures. Customers repay this investment through an additional charge on their energy bill. This charge is structured to be fully or partially offset by the energy savings produced by the measure, making it bill-neutral or cost-reducing. In some cases, the repayment obligation is tied to the meter account, so it automatically transfers to the next occupant. This means that whoever is using energy at that address pays the charge. Utility companies can opt to finance these programs using their own funds (on-bill financing) or partner with a financial institution (on-bill repayment).

Addresses:

– High upfront cost (no immediate payment by customer).
– Split incentive (charges stay with the property, so landlords/tenants can share benefits).
– Credit access (approval can be based on utility bill payment history rather than credit score, aiding inclusivity).

Examples:

– US electric co-ops' tariffed on-bill programs: Financed ground loops with 20–35 year utility loans, repaid on bills and offset by savings (Hughes, 2008).
– UK's Green Deal (2013): It exemplified an on-bill program aimed at overcoming upfront cost and split incentive barriers for home retrofits, including HPs. Repayments for

efficiency upgrades were tied to the property itself, transferring automatically to new occupants to ensure continuity even if ownership or tenancy changed (a design intended to address the landlord-tenant dilemma). However, the program struggled due this and other factors. Its property-linked repayment structure created unintended consequences. Buyers and renters often viewed the obligation as a hidden debt, reducing property marketability. Energy savings were overestimated and rising electricity prices meant repayments frequently exceeded actual bill reductions, violating the program's "Golden Rule" of bill neutrality. Compounding these issues were high interest rates, administrative complexity and consumer distrust in the long-term obligation. Ultimately, the Green Deal's failure revealed the pitfalls of tying debt to property ownership instead of meter usage, besides the importance of precise savings projections and competitive financing terms. It therefore offered valuable lessons for program design (Hough and White, 2014).

- Italy's Superbonus 110%: Although this example is not an on-bill financing scheme, it allowed homeowners to transfer their tax credit to third parties (such as banks or contractors) through a process known as "cessione del credito". This approach effectively eliminated the need for upfront capital by converting the tax credit into immediate cash or a discount on the invoice. Homeowners could then complete their projects without any direct cash outlay, much like on-bill financing does by rolling the cost into the energy bill and offsetting it with savings. Thus, it serves as another relevant example of how financial structures can be designed to overcome high upfront cost barriers. Yet, it should also be noted that the Superbonus 110% is said to have 'blew a hole in state accounts' (Balmer and Fonte, 2024).

Note 1: Importantly, this approach of eliminating or reducing the upfront payment appears to align with a broader market preference: people tend to favour financing options that minimise or eliminate initial out-of-pocket expenses.

Mechanism 2: Third-party ownership and heat-as-a-service (HaaS)

Working principle: A third party (e.g., utility, cooperative, energy service provider) finances and owns the shallow geothermal system. The building owner or occupant pays for delivered heating/cooling rather than for the hardware itself. This can take the form of a subscription, a lease, or a pay-per-heat model often referred to as HaaS. Maintenance and operation are also handled by the provider, minimising the end-user's hassle and risk. The upfront cost to the customer can be minimal or zero, which directly tackles the high capital expenditure barrier.

Addresses:

- High upfront cost (the third party carries the capital expenditure, so the occupant faces low or no initial payment).
- Consumer risk aversion (ongoing service and equipment responsibility lie with the provider, which lowers perceived technology or performance risk for the user).

- Lack of expertise (professional management of the system is included, so the customer does not need in-depth technical knowledge).

Examples:

- Denmark's OK Cooperative: Offers HPs on a subscription or lease model. Homeowners typically pay a setup fee (~€4k) and then a fixed monthly service fee covering installation, maintenance, and even energy use, effectively bundling all costs into one (Clark et al., 2023).
- UK HaaS Trials: Bristol Energy (2020) piloted selling "heat plans" (hours of warmth) instead of kWh, letting customers pay for comfort as a service. This approach showed higher acceptance rates by framing heating as a monthly subscription rather than an equipment purchase (Bristol Energy, 2020).

Note: Some HaaS contracts can include performance guarantees (e.g., the service provider promises a specific level of indoor comfort), but their primary defining feature is third-party ownership plus service-based billing. In contrast, where repayment is tied explicitly to measurable energy savings, that generally falls under performance-based incentives (see Mechanism 3 below).

Mechanism 3: Performance-based incentives (pay-for-results)

Working principle: Under performance-based approaches, financial support or repayment is explicitly tied to measured outcomes (energy savings, renewable heat output or CO_2 reductions). Participants receive payments only if the system performs as expected. These payments can be either ongoing (as in feed-in tariffs or certain performance contracts) or in one/limited tranches (as in white certificate schemes). This structure reduces risk for end-users (because payments help cover operating or financing costs) and reassures investors that the technology will be properly maintained to achieve the projected savings.

Addresses:

- Investor confidence (predictable revenue streams tied to verified performance make projects more financeable).
- Quality assurance (recipients have a built-in motivation to maintain high performance).
- OPEX and energy price gap (performance-based incentives often act to supplement or offset operating costs, shortening payback times).
- By generating a revenue stream, performance-based incentives also improve a project's cash flow and bankability. This helps to repay any loans or recover the initial investment (CAPEX). Moreover, lenders can view the guaranteed payments as reliable income, improving loan terms.
- Performance-based incentives align economic rewards with system performance, which directly benefits GHPs by properly valuing their superior efficiency.

Examples:

- UK Renewable Heat Incentive: Provided ongoing payments to homeowners/businesses for each kWh of renewable heat generated by their HPs. For example, homeowners received quarterly payments over 7 years based on the renewable heat their systems generated. This effectively functioned like a "feed-in tariff" for heat, reducing the payback period for HP installations (Snape et al., 2015).
- Energy performance contracting (EPC) with ESCOs: An Energy Service Company finances and installs (for example) a GHP system. Building owners repay the ESCO from the actual energy savings (or renewable heat output). If the savings fall short, the ESCO bears the cost difference, guaranteeing a certain performance level. This model has been used for example in commercial/public building retrofits in Germany and Switzerland (Jakok et al., 2016).
- White Certificate Schemes (France, Italy, Poland): Market-based instruments designed to promote energy efficiency improvements. Under these schemes, energy suppliers are mandated to achieve specific energy savings targets by implementing efficiency measures among end-users. Participants (e.g., building owners, industrial facilities) who implement approved energy-saving measures receive "white certificates" which can then be sold to obligated parties or on a dedicated exchange. The resulting revenue helps cover operating costs or repay any loans taken to set up the system (Darmais et al., 2024).

Mechanism 4: Utility tariff and tax reforms (enabling savings)

Working principle: Although not a financing mechanism in the narrow sense, adjusting energy pricing is a very important complementary financial measure to improve the economics of HPs. Reforms could include shifting environmental levies off electricity onto fossil fuels and implementing dynamic electricity tariffs. Lowering the running cost via policy increases the attractiveness of financing the capital cost. More utilities should also offer special HP tariffs with discounted rates at certain hours. These measures mean that high-efficiency electric heating is rewarded with lower operational expense, shortening payback periods.

Addresses:

- OPEX imbalance (reduces operating cost hurdle).
- Investor confidence (stable and favourable tariffs for HPs reduce revenue risk).
- Inclusive operation (lowers bills for consumers, important for affordability).

Examples:

- EU policy example: The EHPA urges shifting taxes/levies away from electricity to tackle the cost gap, noting it as "critical to close this gap" and make HPs more financially attractive (EHPA, 2024). Some EU states have moved to reduce electricity VAT or add carbon taxes to heating oil/gas to rebalance fuel costs (EHPA, 2023).

- aWATTar HOURLY tariff: In Austria, aWATTar offers HOURLY, a dynamic pricing tariff where electricity prices are adjusted hourly based on the European Power Exchange (EPEX Spot) market rates. This tariff allows consumers to benefit from lower prices during periods of high renewable energy generation or low demand. The prices are typically published daily for the following day, allowing consumers to plan their energy usage accordingly. To program the HP to take advantage of those hours when electricity prices are lowest, consumers can integrate it with smart home automation systems that support dynamic pricing. For instance, aWATTar provides an Application Programming Interface (API) that allows for the retrieval of hourly price data, which can be used to automate the operation of HPs (aWATTar, 2025).
- Cosy Octopus tariff: This tariff, offered by Octopus Energy in the UK, provides dynamic pricing with multiple off-peak periods of discounted electricity rates (e.g., from 04:00-07:00, 13:00-16:00 and 22:00-00:00). These lower rates encourage users to shift their HP usage to times when electricity is cheaper, directly reducing the operational costs (Octopus Energy, 2025).
- Utility HP tariffs: In Scotland's pilot programs, utilities tested tailored time-of-use tariffs bundled with HP financing to ensure customers pay less for running the HP than they would on a standard tariff (Clark et al., 2023).

Note 1: The reformed Electricity Market Design (EMD) implemented through Directive (EU) 2024/1711 is very likely to increase the availability and attractiveness of dynamic electricity tariffs across the EU. We elaborate on this in **Appendix 2**.

Note 2: Dynamic tariffs are already widespread in Nordic countries, where electric HPs and electric vehicles are very common. However, their availability remains limited in many other parts of Europe, as shown by a recent survey (Burger, 2025).

Note 3: Although gas-fired plants set the marginal cost of electricity in many markets, we argue that the cost balance can still be shifted with strategic reforms. For example, adjusting taxes and levies (e.g., by increasing carbon pricing on fossil fuels and reducing charges on electricity) will make electric heating comparatively more attractive. Besides, market design changes (e.g., decoupling renewable generation from gas-set prices[1]) can lower wholesale electricity costs

[1] Longer-term contracts like Power Purchase Agreements (PPAs) and Contracts for Difference (CfDs) provide generators and buyers with price stability over a set period. This can reduce exposure to short-term market fluctuations.
Under a PPA, a renewable energy supplier and a utility (or corporate buyer) negotiate a fixed or formula-based price for the electricity generated. This arrangement can decouple the buyer's procurement price from spot market prices that are often influenced by gas-fired plants.
In a CfD scheme, the government (or another counterparty) guarantees a "strike price" for clean electricity. If the wholesale market price falls below this strike price, the generator receives a top-up payment; if the market price

over time. A growing share of renewables and storage can also contribute to reducing reliance on gas at peak hours. In combination, these measures can help lower electricity bills and strengthen the economic case for HPs.

***Mechanism 5:* Community and cooperative financing**

Working principle: Communities can band together to invest in HPs, spreading costs and benefits. In a shared ground loop arrangement, a central borehole field or ground loop network may serve multiple houses or an entire apartment block. The community (or a cooperative or utility) can finance this infrastructure collectively, via shared loans or local bonds, and recover costs through a fee or membership dues. This achieves economies of scale and can reduce per-household cost. Such models often involve local governments or cooperatives facilitating the investment.

Addresses:

– Upfront cost (bulk purchasing and shared infrastructure reduce unit cost).
– Access to capital (community pooling and possibly public grants support funding).
– Inclusive access (can include rental units, social housing in the shared system).

Examples:

– Collective ground loops: A ground loop network is built for a new housing development, with costs shared among homeowners. This spreads out the upfront expense of drilling and loop installation, lowering individual household costs. Each homeowner typically pays a connection fee or a monthly charge, similar to how it is paid for shared amenities (e.g., water, sewage). Companies like GeoSource Energy, GeoExchange, or local utilities in states such as Minnesota and neighbourhoods in Ontario have piloted or implemented shared loop systems.
– Energy communities in the EU: Under the "Clean Energy for All Europeans Package", the EU supports the formation of citizen energy communities. These groups can invest in local renewable resources (including renewable heating and cooling) and manage them for the benefit of members. A town, neighbourhood or group of households can create a formal energy community to fund and install GHPs in public buildings, apartment complexes, or individual homes. Community members purchase shares or bonds in the project: the collected capital covers the drilling, HPs and associated

exceeds it, the generator returns the difference. This mechanism helps secure investment in renewables by reducing revenue uncertainty for project developers. Considering favourable conditions (i.e., where renewable costs remain competitive), CfDs can help moderate consumer prices by enabling access to low-cost generation that is not fully exposed to high fossil-fuel price spikes that often set the market's marginal price.

infrastructure. In return, participants receive dividends (if the community sells energy or surplus capacity) or a reduced heating bill due to collective ownership of the system.
- Cooperative utilities: In European countries like Denmark (like OK) and Germany ("Burgerenergie" groups), cooperative or consumer-owned utilities have a history in district heating, wind, and solar power. The same model can be extended to geothermal heating networks. For example, a neighbourhood forms a cooperative that owns the geothermal system. Residents become cooperative members by buying a share, and the coop may also seek loans or government funding. The coop sells the produced heat (or loop access) back to members at cost or a modest profit, and any surplus revenue is either reinvested or paid back to members.

Mechanism 6: Risk mitigation instruments

Working principle: To inspire investors and lenders to support GHP projects, risk-sharing mechanisms can be put in place. Loan guarantees or credit risk guarantees from governments can backstop default risk on HP loans, giving banks confidence to lend at lower rates. Performance insurance or guarantees can cover technology underperformance or drilling risks (e.g., if a borehole yields less heat than expected). By reducing the perceived risk, these instruments lower the cost of capital. For larger-scale investments (e.g., retrofitting many buildings or a micro-network system), public-private risk-sharing funds can be established.

Addresses:

- Investor risk perception (shifts some risk to a guarantor, improving confidence).
- High capital cost (lower interest due to guarantees makes financing cheaper).
- Market development (insurance products build trust in new tech like geothermal).

Examples:

- EU risk sharing: The EU has exploited instruments like the European Fund for Strategic Investments (EFSI) to guarantee loans for innovative energy projects (EHPA, 2024). A similar approach could guarantee portfolios of HP loans or ESCO investments, attracting institutional investors.
- Green mortgage guarantees: Programs could allow HP costs to be added to mortgages with a government guarantee on the loan increment (so banks are covered if efficiency savings do not materialise).
- Drilling insurance pools: In markets like Sweden, insurers offer coverage for borehole failures or groundwater issues, which can be mandated or subsidised to alleviate consumer fear of "something going wrong" underground.

In conclusion, the strategic use and combination of innovative financial mechanisms must align carefully with **market maturity**. Early-stage or emerging markets can benefit from deploying multiple complementary instruments, which collectively address different major barriers such as high perceived risks, lower awareness and upfront investment. These combinations, as for instance integrating upfront grants with performance-based incentives or coupling on-bill financing with public guarantees, can be beneficial for stimulating market growth, reducing perceived risks, and creating a supportive environment. Conversely, mature markets, exemplified by Sweden, can grow well with fewer, more streamlined financial mechanisms, relying primarily on stable, clear policy signals such as carbon taxation and advantageous electricity pricing. However, even in these developed markets, selectively targeted complementary mechanisms can address persistent niche barriers, such as those experienced by lower-income or rental segments. Therefore, policymakers should carefully evaluate market maturity when choosing and designing financial solutions, adjusting complexity and scope to optimise impact and market efficiency.

3.5. Case studies and best practices

Here we detail further successful case studies and best practices of financing instruments from Europe and abroad, which may provide insights for the EU market:

- **The case of Sweden.** While not a financing mechanism per se, the case of Sweden is certainly worth a closer look. Sweden is often cited as a HP success story, including widespread use of GHPs in single-family homes. The country has achieved one of the highest global rates of HP installations, with over 40 HPs per 100 households (numbers for 2021) (Rosenow et al., 2022). About 70% of Swedish detached houses utilise some form of HP technology, meeting approximately 30% of the nation’s total building heat demand. This transition began after the oil crisis of the 1970s, when Sweden initiated a deliberate strategy to reduce fossil fuel dependency. Throughout the 1980s, Sweden invested in research and development, provided subsidies such as grants to early adopters, and created a supportive regulatory environment to foster HP adoption. A cornerstone of this comprehensive policy approach was the introduction of one of the world’s first carbon taxes in 1991, rising steadily from around €21 per ton CO2 initially to over €100 per ton by 2022. This tax significantly elevated the running costs for oil and gas boilers, making fossil-fuel heating progressively less attractive. In parallel, electricity (largely clean in Sweden, mostly from nuclear and hydropower) for heating purposes was taxed at lower rates, enhancing the economic attractiveness of electric HPs. In addition to these government interventions in the initial market rollout phases, more recently tax rebates covered up to 30% of labour costs (capped at about €5,000 per household annually) for HP installations. Local authorities also eased administrative hurdles: for example, drilling permits for GHPs in Stockholm were made faster and user-friendly via an e-permitting platform. Public education campaigns, consumer protection mechanisms, and quality certification programs further increased consumer confidence and acceptance. The resulting market certainty gave manufacturers and installers the assurance necessary to invest in technological development, production capacity and training. Finally, Swedish geology is a gift that inherently favours GHPs. It consists of the Baltic shield with crystalline rocks that are generally stable for drilling up to 200–300 m without technical problems, alongside sedimentary formations in the south, with geothermal gradients ranging from 15–30 °C/km. Groundwater aquifers are primarily found in glaciofluvial esker deposits along river valleys and in some sedimentary rocks in southern Sweden (Gehlin and Andersson, 2016). Therefore, Sweden's widespread adoption of HPs did not happen by chance and was not driven by any single policy measure alone. Rather, it arises from the interplay of multiple strategies, including the predictability of the carbon taxation (i.e., making fossil heating gradually more expensive), government subsidies, regulatory actions, quality-control standards, consumer protection mechanisms and public awareness initiatives.

- **Tariffed on-bill financing by rural electric cooperatives (U.S.):** This model has been implemented by some electric co-ops in the United States, addressing the upfront cost barrier for GHPs. Since 2007, co-ops have accessed low-cost federal financing (35-year loans) to cover the cost of installing ground loops and equipment on customers' properties. The co-op owns the loop infrastructure and recoups the cost via a fixed charge on the customer's electric bill (attached to the meter) (Hughes, 2008). Importantly, the monthly charge is set lower than the estimated savings, so the customer sees immediate net bill reduction. If the occupant moves, the next occupant continues payments while benefiting from the HP. This "pay-as-you-save" structure, backed by a utility, eliminated upfront payments and de-risked the investment for homeowners. The approach has led to higher adoption rates in participating co-op territories and served as a model for inclusive financing (no credit check required, since the debt is tied to the meter and secured by utility disconnection for non-payment). The EU can draw lessons on structuring on-bill programs that are fair (benefits exceed payments) and leveraging public loans or guarantees to enable long-term, low-interest capital for utilities.
- **OK Cooperative HP subscription (Denmark):** As mentioned, the Danish energy cooperative OK offers an innovative HP subscription service for homeowners. In this program, a homeowner pays a one-time fee (DKK 35,000, ~€4,700) and then a fixed monthly subscription, which covers the installation of a GHP, all maintenance and even the operational energy (in effect, a fixed price heating service). Alternatively, customers can opt for a leasing model with a smaller upfront payment (DKK 25,000 or 50,000) and a monthly lease fee for 10 years. At the end of the term, the customer may take ownership or upgrade. This multi-tier offering (subscription, lease or loan via OK's partnering bank) has been quite successful in Denmark, where energy taxes (carbon tax) make HPs attractive to run. The keys to OK's model are the cooperative structure (customer-centric, not solely profit-driven), the inclusion of end-to-end service (removing hassle and technical worry for consumers), and flexibility in payment plans (Clark et al., 2023). It shows that customers value the convenience of outsourcing their heating infrastructure in exchange for predictable fees. EU energy retailers or cooperatives in other countries could replicate this model, especially where trust in utilities/co-ops is strong, and electricity pricing can be managed to ensure the monthly fee is affordable.
- **EPC in multi-family buildings (Germany/Switzerland):** In parts of Europe, ESCOs and municipal utilities have started to implement HP projects via EPCs, particularly for

multi-family housing. For example, a municipal utility in Germany ("*Stadtwerke*") partnered with an ESCO to replace an aging oil boiler in a 30-unit apartment block with a central GHP system. The ESCO financed and installed the system and now sells heat to the tenants under a long-term contract at a rate lower than the previous heating cost. The building owner had no upfront cost and benefits from an upgraded heating system that is expected to increase property value. A study of Swiss multifamily houses found that such energy supply contracting is often offered by public-oriented organisations with access to cheap capital (e.g., city utilities), and while it effectively overcomes owner financing barriers, challenges include high transaction costs and customer acceptance hurdles (Zapata Riveros et al., 2024). The lesson is that standardising contracts and aggregating projects (to reduce overhead per building) can make third-party financing more viable in the residential sector. Policy support (like template contracts, matchmaking platforms, or modest subsidies to kick-start ESCO projects in housing) can help scale this model. It directly tackles split incentives by essentially removing the landlord from the equation. Tenants get cheaper renewable heat, and a third party handles the investment and operations.

- **Property-Assessed Clean Energy (PACE – U.S.), EuroPACE Pilot (Spain):** The PACE financing mechanism, widely used in the U.S., ties the repayment of energy retrofit loans to property tax bills. The debt is attached to the property as a tax assessment, not to the individual owner, and is repaid over long terms (15–20+ years) via slightly higher property taxes. This ensures the costs and benefits stay with the property, resolving split incentives and allowing transfers to new owners automatically. While PACE is not yet readily available in the EU due to legal and financial system differences, the EU-funded *EuroPACE* project tested the concept in Olot, Spain. EuroPACE worked by the city mobilising private capital (through bonds or investors) to provide 100% up-front funding to homeowners for projects like GHPs (CORDIS, 2021). Homeowners then repay through their annual property taxes. The pilot showed strong interest from homeowners when no upfront cost was required. It also highlighted challenges: the need for enabling legislation at national/EU level (for tax-lien seniority and municipal bond issuance), besides ensuring consumer protections. The key takeaway is that legislative action could unlock PACE-like programs across Europe, bringing in substantial private capital for HP deployment, while local governments play a facilitating role. If designed well (with low interest and robust oversight), PACE can make deep renovations like GHPs accessible to a broad range of owners, including those who might move before the investment pays back (since the obligation stays with the property).
- **Inclusive HP programs for low-income households (France & UK):** Some countries have tailored programs to ensure low-income or vulnerable groups can adopt HPs. For example, the incentives under the France's White Certificate Scheme (Certificats d'Économies d'Énergie, CEE) and the "MaPrimeRénov" grant scheme are more generous for vulnerable households – in some cases covering up to 80–100% of a HP installation cost for the lowest income bracket. Additionally, France has offered zero-interest eco-loans (Eco-PTZ) up to €30,000 for energy renovations, which can include

HPs, repayable over 10–15 years and often bundled with bank mortgage offerings. This effectively eliminates interest cost for the borrower, a big help for those with limited income. In the UK, the government's Energy Company Obligation (ECO) required utilities to fund energy efficiency in low-income households; while it mainly covered insulation and efficient boilers, recent iterations allow funding for HPs as part of whole-house retrofits. Note that, under the French CEE scheme, obligated parties also must achieve a specific portion of their energy savings targets through measures benefiting low-income households. For the current period (2022–2025), this sub-target represents 57% of the total obligation compared to the standard requirements. The lesson from these cases is that targeted subsidies or financing (grants, forgivable loans, or interest buy-downs) for low-income groups are essential to safeguard equitable access. A purely market-based approach (i.e., market forces alone) could leave many unable to participate in the HP transition.

Each of these examples provides applicable lessons that can be beneficial in designing EU-wide or national schemes. In addition, less successful attempts (like the UK's first Green Deal previously mentioned) taught the importance of low interest rates, consumer-friendly terms and trust in the program. As a result, our investigation shows that common themes for prospective success include:

i. Minimising or eliminating the upfront cost barrier;
ii. Aligning repayment with savings so that consumers are not out-of-pocket;
iii. Transferring or sharing risk from the end-user to entities better able to manage it (utilities, ESCOs, governments);
iv. Simplifying the process for the customer (one-stop services, automatic bill/tax payments).

3.6. Feasibility of financial mechanisms in the EU context

Implementing these innovative financial mechanisms across EU is of course not that straightforward and will require considering the policy, regulatory and market situations. Next we provide a first-order assessment of their feasibility and what enabling actions are likely needed:

- **On-bill programs:** Many EU countries could implement on-bill programs via their energy utilities or suppliers, but regulatory support is needed. Electricity and gas retail markets in the EU are liberalised, so clear rules must allow utilities or third parties to add loan repayment charges to energy bills. Consumer protection regulators must ensure that disconnection rules and billing transparency are handled fairly (for instance, if a customer does not pay the HP portion of the bill, can they be cut off?). Pilot projects like the RenOnBill initiative in the EU have explored these models (RenOnBill, 2019). For broad rollout, coordination with energy regulators is key to treat energy efficiency upgrades as part of the utility business model. *The feasibility is considered high,* especially in places with regulated monopoly utilities, as they can be directed to pursue such schemes, potentially earning a small return on the investments as they would on other infrastructure. Overall, on-bill financing aligns well with EU goals (e.g., acting as a tool to de-risk upfront costs under the EU's Renovation Wave strategy). But it remains underutilised. With proper design (as shown by U.S. co-ops), it could be a scalable solution for single-family and small multi-family homes, especially if paired with an EU-wide guarantee facility to provide low-interest capital to utilities offering on-bill plans.

- **HaaS:** This business model is emerging in Europe. Its expansion mainly requires a conducive market and possibly slight regulatory tweaks. For instance, in some countries, only licensed energy retailers can sell heat, which could complicate an independent ESCO offering a heat subscription. Clarifying that providing heating/cooling service is permissible (and maybe light-touch regulated) will help. Another important enabler is the standardisation of contracts and measurement of delivered service (e.g., how to verify "comfort" delivered in HaaS). The EU could assist by developing model contracts or certification for HaaS providers, ensuring consumer rights (e.g., what if the service is not as warm as promised?) are protected. This would build trust. From an investment perspective, HaaS turns hardware into an ongoing service revenue, which can attract new investors (like infrastructure funds or even oil and gas companies diversifying into energy services). *Feasibility is deemed high*, as it largely leverages private sector innovation; policy can encourage it by removing any legal barriers and possibly offering additional incentives (like making HaaS for HPs VAT-exempt or lower-VAT since it is a green service). Multi-family and tertiary buildings are especially well-suited, because a professional entity can manage a central system and building owners/occupants just pay for thermal energy, a model in essence not that far away from district heating, but building-specific.
- **Green bonds and aggregation:** The EU has a very active green bond market and strong policy support for sustainable finance (e.g., the EU Green Taxonomy explicitly tags HP investments as sustainable). Thus, issuing green bonds to fund HP programs is quite feasible. National and local governments should evaluate using green bonds to fund zero-interest loan programs or guarantee funds for HPs: the European Commission and EU's Climate Bank (EIB) can encourage this through technical assistance and possibly co-financing. One challenge is guaranteeing a pipeline of projects to justify bond issuance; here aggregation is key. An intermediary (like a national green bank or a consortium of municipalities) might pool thousands of HP projects to be financed from one bond. The EIB could also directly issue bonds and lend proceeds to commercial banks specifically earmarked for HP financing. Given Europe's advanced financial markets, this mechanism is very plausible; it mostly needs clear program design so that bond proceeds indeed reach the intended small projects. Monitoring and reporting (to satisfy investors) is required but manageable. For instance, tracking how many HPs installed per €10 million and the estimated CO_2 saved. In summary, *feasibility is considered high*, especially for large-scale deployments (including in public buildings or social housing where a government-backed entity can implement the projects).

- **White certificates and performance incentives:** Many EU countries already have Energy Efficiency Obligation schemes (white certificate programs), for instance, France, Italy and Poland. Integrating GHPs into these is straightforward if not already done. The main feasibility consideration is the stability of such schemes (to give confidence in long-term incentives) and ensuring the reward level is sufficient to influence decisions. Since these are established mechanisms, scaling them or refocusing them on HPs can be done via policy tweaks. The revised EU Energy Efficiency Directive (EU/2023/1791) encourages outcome-based incentives, so this aligns well. Similarly, any new "Renewable Heat Premium" at EU or national level could be created (learning from the UK RHI experience to make it cost-effective and less bureaucratic). *The feasibility is considered high*, but the impact on its own might be moderate. These incentives help cash flow over time but do not remove the upfront cost, so they work best in combination with other financing (e.g., a household takes a loan and uses the incentive payments to help repay it). For larger projects, guarantees of carbon credit prices or subsidies over 5–10 years can significantly de-risk the investment, so policymakers should warrant long-term visibility of such incentives.
- **Tax and tariff reforms:** Adjusting tax policy is inherently a political decision, but momentum is growing in the EU to remove the disparity between electricity and gas costs. Some countries have started to reduce surcharges on electricity that fund renewables (shifting them to general budgets) and increasing carbon taxes on heating fuels. The European Commission's proposal to revise the Energy Taxation Directive aims to allow lower minimum tax rates for electricity relative to natural gas for heating. This is highly feasible through legislative action and crucial for making HPs economical to run. From a financing perspective, these reforms improve the business case and thus indirectly support all financing models (loans are easier to justify if operational savings are larger). Utility-led special tariffs for HP users (like time-of-use tariffs) are theoretically already allowed in most regulatory regimes, as long as they are cost-reflective; regulators can encourage or approve such tariffs to promote load shifting and reward efficient electrification. *Feasibility is considered medium-high*: it requires coordination and phasing to avoid energy poverty issues (hence why carbon tax increases should be coupled with compensation for low-income households, as the IEA strongly suggests) (IEA, 2022). However, over time, getting the pricing right will greatly accelerate market-driven uptake and reduce the need for heavy subsidies.
- **Community financing:** The EU's legal framework now explicitly recognises renewable energy communities and energy communities, which provides a basis for collective projects (European Commission, 2025). Feasibility depends on local initiative and the ability to organise stakeholders. For new developments, it is quite feasible to design shared ground loops; urban planning and building codes could even encourage or mandate considering communal geothermal systems in new housing areas or campuses. The challenge is more on retrofitting existing neighbourhoods: it requires coordination among homeowners and possibly seed funding to organise cooperatives. The EU and national governments can facilitate by funding pilot community schemes (through grants from programs like the Just Transition Fund) to showcase the model.

Once a template is proven, communities can copy it. These schemes may also need regulatory clarity on whether the community loop operator is considered a utility (and thus subject to regulation) or not; simplifying that (perhaps treating them like self-consumption energy communities) will help. *Feasibility is considered moderate:* of course, not every community will pursue this, but in areas with strong social capital and support from local authorities, it can work well. It particularly suits those situations where drilling one large loop field to serve many homes can be more cost-effective than many individual boreholes.

- **Green mortgages:** European banks are beginning to roll out "green mortgages" or renovation loans with interest rate discounts if used for energy-saving measures. The Energy Efficient Mortgage Initiative (EEMI) led by some EU banks is a positive sign. For feasibility, banks need evidence that HP installations do indeed raise property values or lower default risk (the theory being that lower energy bills free up money to pay mortgages). EU policymakers can help by standardising how energy efficiency is considered in property valuations and by possibly offering a guarantee or subsidy to banks for each green loan made. National governments could extend existing housing loan programs (like KfW's subsidised loans for energy-efficient newly constructed houses in Germany, or France's Eco-PTZ) and specifically earmark portions for HPs with better terms. Given that banks are heavily regulated, having support from central banks (e.g., favourable capital treatment for green loans) would accelerate this. *The feasibility is considered high* if supported by policy (it leverages the large capital of the private banking sector). This instrument should mostly benefit owner-occupied single-family and multi-family homes. One can imagine mass programs where homeowners refinance their mortgages to include GHP installation costs at low rates, a scenario quite plausible within the EU's green finance agenda.
- **PACE (on-tax financing):** PACE requires legal frameworks that are not currently standard in Europe. PACE financing would allow municipalities to help homeowners fund energy upgrades through a special property tax charge. While innovative, this approach faces challenges from mortgage lenders (in addition to potential legal restrictions). The key complication is that PACE liens take priority over mortgage liens, meaning local governments could foreclose on a property to recover unpaid amounts before mortgage lenders can claim repayment. This is why some mortgage lenders oppose PACE financing, primarily due to the increased risk to their loan recovery. However, low default rates provide some reassurance, as energy savings from upgrades like HPs often help offset repayment costs. Countries like Spain and Italy have made initial steps; for example, legislation in some Spain regions was passed to enable on-tax financing for building retrofits (Hay, 2017). EU-level guidance or even a directive might be needed to harmonise how PACE could work across Member States (perhaps as an optional tool that cities can adopt). *The feasibility in the near term is considered moderate.* Pilot projects can continue under specific local legal arrangements, but widespread use will depend on political willingness to adjust financial regulations. If achieved, the benefit is a powerful financing tool with potentially huge scale, tapping institutional investors via green bonds to fund millions of home upgrades with secure

repayment via property taxes. PACE might be most applicable to single-family and smaller multi-family buildings, where other financing (like EPC) is less common.

Therefore, the EU's policy environment is increasingly favourable to innovative financing for the clean energy transition. We argue however that legal and market adjustments are still needed to unlock each mechanism's full potential. A combination of EU-level directives (to allow novel financing models and carry consumer protection) and national implementation (tailoring to local real estate law, utility structure, etc.) will be required.

Critically, all mechanisms should be designed with inclusivity in mind, meaning safeguards or complementary subsidies for low-income participants, and proper outreach to take care of awareness and uptake across all social groups.

3.7. Recommendations

Based on the analysis, we reason that a comprehensive strategy is desirable to support mass adoption of GHPs through financial innovation. The subsequent recommendations target multiple stakeholder levels (EU policymakers, national governments, financial institutions/investors, and end-users).

For EU policymakers and institutions:

- **Establish an EU heat pump financing facility:** Develop a dedicated financial mechanism (namely, an institutional arrangement) that provides low-interest loans, guarantees, or credit lines for HP projects. This mechanism could be structured through entities such as the EIB or a public-private fund. Its purpose would be to support on-bill financing programs and green banks in Member States by reducing the risks for private investors. For example, it could guarantee repayment for utilities participating in on-bill schemes, thereby mitigating their financial risk and encouraging continent-wide adoption. Additionally, the program should prioritise initiatives that benefit low-income households to meet social inclusion goals.
- **Harmonise and enable innovative financing mechanisms:** Through directives or guidance, enable mechanisms like PACE and on-bill financing across the EU. This may involve recommending Member States amend laws to allow property-tied financing (PACE) and to clarify utility rights to offer on-bill programs. Additionally, the EU could develop a *"green heat financing toolkit"* with best practice templates (legal language for on-tax assessments, model on-bill tariff structures, standard HaaS contracts, etc.), reducing the setup efforts for each country.
- **Strengthen the carbon price signal and energy tax reform:** The final goal here should be to progressively correct the CAPEX/OPEX imbalance by making heating with fossil fuels more expensive and HP operation cheaper. At the EU level, push for swift implementation of the Energy Taxation Directive update. Moreover, the VAT Directive (EU 2022/542) allows EU Member States to lower taxes on certain goods and services that are considered necessities, the EU could take an even more active role by encouraging all Member States to fully use the existing VAT provisions, rather than

leaving it entirely to each country's discretion. Similarly, an EU-wide initiative could be established to direct revenues from the upcoming Emissions Trading System (ETS2)—which will cover CO_2 emissions from fuel combustion in buildings and road transport—toward targeted incentives for HPs. A balanced approach might be to prioritise building-related measures (like HP incentives) within the broader ETS2 revenue pool, but without rigidly earmarking by source. Alternatively, governments could use a share of ETS2 revenues proportionate to building-sector emissions in a way that aligns the policy without overcomplicating the system.

- **Support Member State targets and mandates:** As part of the forthcoming EU Heat Pump Action Plan, encourage countries to set more specific deployment targets for GHPs and to develop financing action plans to meet them. This might include requiring national governments to evaluate and report on financing barriers in their National Energy and Climate Plans (NECPs). The EU could also expand technical assistance offerings similar to the ELENA program to specifically help design GHP programs, in order to ensure that applicable countries have at least one robust innovative financing scheme beyond one-off grants.

For national and local governments:

- **Implement and scale diverse incentive programs:** Use a mix of grants, loans, and tax incentives to address different market segments. For single-family homes, expand grant programs for low-income households and zero-interest loan offerings for others. For multi-family and tertiary buildings, provide incentives for ESCO projects (e.g., a subsidy per apartment for those that sign up to an ESCO-driven HP retrofit) and consider tax credits for companies investing in HP systems. Ensure that incentive schemes have higher support rates for vulnerable groups, as only a small portion of current schemes do.
- **Promote utility and ESCO participation:** Encourage national utilities or energy companies to become active implementers of HP financing. This could mean directing gas and electric companies to develop on-bill financing offers (perhaps as a condition in their license or through incentives in regulated returns). Likewise, remove regulatory barriers that prevent utilities from owning customer-sited assets: allow them to rate-base investments in communal ground loops or heat-as-a-service ventures as long as consumer interests are protected. Governments can also seed-fund public ESCOs or public-private partnerships to tackle building blocks or neighbourhoods, providing upfront capital and recovering via heat sales (a model that municipalities in countries like the Netherlands are exploring to phase out gas networks).
- **Address split incentives through regulation:** Update rental laws and building codes to facilitate cost-pass-through and decision-making for energy upgrades. For instance, implement "green lease" frameworks that legally allow landlords to increase rent up to a portion of the achieved energy cost savings after a HP installation (Castellazzi et al., 2017). Similarly, adjust condominium laws so that a majority vote can approve a collective GHP installation, preventing a single owner from vetoing a project that is in

the interest of all. This has been done for instance in Austria under the Condominium Act 2002, version of 09.04.2025 (Article 29). Where social housing is concerned, governments could directly invest in GHP retrofits as part of renovation programs, ensuring social housing providers have access to favourable financing (e.g., via state-backed loans) and technical support.

- **Public awareness and one-stop shops:** Invest greatly in consumer awareness campaigns about the total cost of ownership benefits of GHPs and the availability of new financing options. Often, consumers simply default to like-for-like boiler replacements because they are not aware that financing can make a HP affordable. Set up "one-stop shop" services at the local or regional level that guide homeowners and building managers through the technical and financial process, from initial assessment, passing by finding certified installers, to arranging financing (banks/utilities could have representatives in these hubs). Such facilitation addresses informational and trust barriers, making investors (homeowners) more confident to take on new technologies.

For financial institutions and investors:

- **Develop green home finance products:** Banks and mortgage lenders should actively join the effort by creating or expanding products that target HPs or, even more specifically, GHPs. This includes green mortgages that provide additional borrowing capacity or better rates for homes installing HPs, and unsecured green renovation loans with longer terms (e.g., 15–20 years), given the durable savings from HPs. Investors such as pension funds and insurance companies could partner with banks to securitise and purchase these green loan portfolios, especially if they are backed by EU or national guarantees. This would free up bank capital and allow more lending. By demonstrating low default rates and solid energy savings, these products can become mainstream. Participation in pilot programs (perhaps coordinated by the EEMI) will allow fine-tuning of underwriting criteria that account for energy bill reductions in credit decisions.
- **Issue themed bonds and funds:** Institutional investors and city finance authorities can look to issue green bonds, sustainable ABS (asset-backed securities), or ESG-focused funds (these are investment funds that prioritise Environmental, Social, and Governance criteria when selecting assets) that explicitly include residential and commercial HP projects. Market demand for green investments is high (EEA, 2024), and packaging HP investments as green bonds can attract capital at low yields. Financial intermediaries should ensure robust evaluation frameworks (using EU Taxonomy criteria for sustainable activities) to certify that these bonds indeed fund qualifying HP installations. This transparency will maintain investor confidence. Furthermore, utilities and energy companies could float "heat transition bonds" to finance the conversion of their customer base from fossil to electric heat, a novel approach that aligns utility investor interests with decarbonisation.
- **Embrace risk mitigation and aggregation:** Investors should not shy away from HP projects due to perceived risks but instead make use of risk mitigation tools. For

example, insurers can offer performance insurance, and guarantee facilities can be tapped (where available) to cover credit risk. By aggregating many small projects (via funds or platforms), investors can diversify and reduce risk. Successful examples, such as aggregated rooftop solar financing, can be replicated for HPs. An ESCO or project developer could bundle 1000 home installations and offer investors a share of the resulting payment stream. Standardised contracts and data on performance will help investors get comfortable. Investors could work with industry associations (like EHPA) to understand technology reliability and with governments to possibly co-design guarantee mechanisms that make initial forays attractive.

For end-users (homeowners and building managers):

- **Leverage emerging offers:** Consumers and building owners should stay informed of new financing offers such as utility on-bill programs, leasing options or government loan schemes that can make GHP adoption more affordable. When planning a heating system replacement, proactively seek information on incentives and financing (e.g., through the one-stop shops or official websites) rather than assuming a HP is out of reach. Many new business models (like HaaS) shift the burden of ownership, so end-users can benefit from clean heating without the headache of upfront expenses or maintenance. If the management of a multi-family building is the focus, engaging an ESCO or energy service provider early could be considered; performance-based solutions could allow an upgrade with guaranteed savings and minimal disruption to tenants.
- **Participate in group or community initiatives:** Whenever possible, join or organise collective initiatives, for instance, a group of neighbours all interested in HPs can approach installers or financiers as a block to get bulk discounts and better terms. Consumer cooperatives or local energy communities often have programs for members; joining such groups can provide access to shared expertise and financing capacity. For example, if a community energy group offers to install a shared geothermal loop for the block, residents should weigh the long-term benefits (stable, low heating cost, property value increase) and cooperate to realise projects that would be hard to do individually.
- **Demand quality and guarantees:** End-users should make sure that any financing or service contract comes with performance guarantees. This protects them and also signals to the market that quality matters (weeding out unreliable providers). For instance, a homeowner getting a HP on subscription should check that the contract guarantees a certain level of heating performance and includes service calls. Likewise, if taking on a loan, use certified installers so that warranty claims are valid, and any available insurance (e.g., on drilling) applies. This will build confidence in the technology across the community, indirectly aiding broader adoption as positive experiences are shared between peers.

Overall, historical experience shows that HP market growth typically occurs when there is a combination of supportive policies in place, rather than being driven by just one single policy tool (Rosenow et al., 2022).

Hence, we reason that **different approaches are required**: policy frameworks that enable innovative finance, public funding to support and de-risk private capital and stakeholder engagement to ensure uptake and trust. By considering the above recommendations, the EU and its Member States can make a great deal in lowering the financial hurdles to GHP deployment. This could support the scaling up of geothermal systems across all building types, from individual homes to large tertiary buildings. At the same time, the transition will likely remain more accessible to all Europeans, regardless of income. As various studies and real-world trials show, GHP technology is absolutely ready, and the economics can be made way more compelling with the help of smart financing.

4. Conclusions

This GeoBOOST Deliverable has examined ***(i)*** existing financial frameworks for GHPs in seven EU countries (Austria, Germany, Ireland, Netherlands, Poland, Spain and Sweden), ***(ii)*** developed a new composite indicator (named affordability score) to compare GHPs against alternative technologies, and ***(iii)*** proposed a suite of innovative financial mechanisms alongside policy recommendations to overcome persistent barriers to GHP deployment. The main findings are presented below.

Rethinking subsidy program conditions: Design challenges and opportunities

Renewable heating subsidy programs across GeoBOOST partner countries mostly share a common framework of grants, tax incentives, and bonus structures that signal policy commitment to decarbonisation. However, these programs demonstrate design limitations that restrict their reach and effectiveness. Common issues identified include:

- Liquidity barriers through post-installation reimbursement: The prevalent model requiring applicants to cover full upfront costs before receiving reimbursement (typically 30-100% of eligible costs) creates a fundamental accessibility problem. This approach systematically disadvantages low-income households and small businesses lacking capital reserves or access to affordable credit.
- CAPEX vs. OPEX imbalance: Current subsidies focus almost exclusively on capital expenditure support while ignoring operational expenses. This misalignment fails to address the full cost profile of renewable heating solutions and limits adoption by budget-constrained consumers who prioritise immediate operational savings.
- Program fragmentation and administrative complexity: Separate funding streams for complementary building upgrades increase application complexity, administrative costs and coordination challenges. This fragmentation creates inefficiencies that discourage holistic building renovations.
- Restrictive eligibility criteria for business models: Most subsidy frameworks explicitly require end-users to own systems outright, deliberately excluding innovative arrangements like third-party ownership, leasing models, or heat-as-a-service approaches. This restriction prevents market evolution toward service-based solutions that could dramatically improve accessibility.
- Technology-specific considerations: While some programs differentiate between air-to-water and air-to-air HPs, they often fail to adequately account for the operational efficiency gap between geothermal and air-source HPs. This creates potential market distortions that may steer consumers toward cheaper but less efficient options despite GHPs' superior long-term cost and carbon advantages. Interestingly, the absence of GHP-specific subsidies under market maturity shows how subsidy frameworks must evolve as technologies scale and market conditions change.

These findings suggest that subsidy effectiveness depends critically on intentional design choices that address structural barriers:

1. Redesign payment models: Shift from post-installation reimbursement to upfront or hybrid payment models that reduce initial capital requirements and expand accessibility to all income segments.

- Expand eligibility criteria: Modify program requirements to include innovative ownership structures and business models, particularly service-based approaches that can accelerate market transformation.
- Integrate support programs: Develop comprehensive funding packages that combine heating system upgrades with necessary building envelope and distribution system improvements to simplify application processes and encourage holistic retrofits.
- Technology-appropriate incentives: Design bonus mechanisms that better reflect lifetime efficiency, operating costs and carbon reduction potential of different heating technologies to avoid market distortions and encourage optimal technology selection.

A new affordability score for renewable heating and cooling technologies: Insights and implications

This deliverable has developed and applied a composite affordability score to compare heating and cooling technologies across countries and building types. The score combines technology-specific costs (CAPEX, OPEX, LCOE) with macroeconomic context (price ratios, incomes, GDP per capita, employment, and inflation), with monetary variables corrected for price-level differences between countries. Equivalent cooling provision is also included for technologies that cannot intrinsically deliver cooling, so that all options are compared on a like-for-like service basis. The framework uses expert-derived weights and a Monte Carlo procedure and is implemented for seven technologies, four building groups and seven European countries under 2023 conditions, with and without an illustrative efficiency-based grant scheme. The full implementation of this methodology is openly available at https://doi.org/10.5281/zenodo.17716094 (Brancher, 2025).

The main findings that emerge from this analysis are:

- Electrified solutions form the upper tier of affordability in most contexts. Closed-loop GHPs generally achieve the highest or joint-highest scores, with open-loop GHPs close behind. ASHPs usually complete this top cluster. District heating and pellet boilers sit in an intermediate band, while gas and oil boilers occupy the bottom of the rankings almost everywhere.
- National energy price structures, particularly the electricity-to-gas (or electricity-to-district-heating in Sweden) price ratio, strongly influence these results. Where this ratio is moderate, the efficiency advantages of HPs manifest fully in lifetime metrics, and electrified options dominate the affordability rankings. Where electricity is priced at a large premium relative to gas, combustion technologies narrow or close the gap, and in isolated cases may slightly outscore HPs. The results suggest a practical threshold

behaviour: as ratios drift well above about 2.5, the affordability edge of HPs is progressively eroded.

- In direct head-to-head comparisons with gas boilers, closed-loop GHPs show a clear affordability advantage in most of the analysed markets. In six of seven countries, GHPs are more affordable on average across all building segments, often by a wide margin. Only in one country do gas boilers and GHPs appear roughly on a par, reflecting a combination of high drilling costs and particularly unfavourable electricity-to-gas price ratios. Even there, the results indicate that relatively modest shifts in tariffs or capital costs could decisively tilt affordability in favour of geothermal solutions.
- Building scale alters but does not overturn the main ranking. For single-family, multi-family and small/medium tertiary buildings, all HP options cluster at the top of the scale, with district heating and pellets in the middle and fossil boilers at the bottom. In large tertiary buildings, ASHPs slip into an upper-middle band as their LCOE rises, while GHPs retain a clear lead. This reflects the fact that lifetime running costs may become increasingly influential at scale, and GHPs are best placed to capitalise on this.
- The Monte Carlo simulation shows that these patterns are robust. Typical 95% UIs are on the order of ±10 points, yet the broad technology hierarchy is stable across almost all country–building combinations. Technologies with higher mean scores also tend to exhibit narrower uncertainty ranges. This suggests that the most affordable options in this framework are also the most resilient to plausible variation in inputs and preferences.
- The EPIC scenario demonstrates how an efficiency-tiered capital grant can reshape affordability rankings without altering underlying energy prices or operating assumptions. Reinstating the policy support factor and applying differentiated grant rates by technology does not fundamentally reorder the technology families, but it does change spacing in a meaningful way. Closed-loop GHPs strengthen their lead; open-loop GHPs move clearly ahead of ASHPs; district heating and pellets shift only modestly; gas and oil boilers remain firmly the least affordable. In practical terms, the main effect of EPIC is threefold: it reinforces the advantage of HPs over fossil boilers, strengthens the position of geothermal technologies relative to ASHPs, and leaves combustion systems stranded in the least affordable tier. This pattern illustrates an important behavioural insight. In the baseline scenario (no policy support), some of the small advantages of ASHPs over GHPs are more driven by upfront cost rather than lifetime economics. By preferentially reducing GHP CAPEX, the EPIC-style grant reduces this liquidity barrier and allows lifetime cost-effectiveness (reflected in LCOE and OPEX) to play a larger role in decision space. Under such conditions, geothermal options emerge as the preferred HP technology in a wider set of circumstances.

Taken together, the findings have some potential implications for policy and practice:

- Gas boilers (and typically oil boilers too) are persistently located at the bottom of the affordability ranking. Phasing out these systems in new buildings or at replacement does not appear to impose a long-term affordability "penalty" under the assumptions applied here. Instead, it encourages a shift towards solutions that are both cleaner and, over their lifetime, more affordable.
- Tariff structures are as important as technology costs. The electricity-to-gas price ratio acts as a structural determinant of HP viability. Without suitable price alignment, even highly efficient technologies can be rendered less attractive in composite terms. Tariff reforms, levy reallocation and carbon pricing therefore become core instruments for improving HP affordability.
- The modelling done in the EPIC scenario suggests that well-designed capital grants may influence which technologies are chosen, not just whether a low-carbon option is adopted at all. Support that is linked to intrinsic efficiency and that favours GHPs relative to cheaper but less efficient alternatives can unlock geothermal deployment without improving the standing of fossil options.
- Once like-for-like service provision (including cooling), GHPs emerge as highly competitive in most of the examined markets. Where they do not clearly lead, the explanation lies in context-specific barriers (e.g., energy price relativities) rather than in any fundamental economic weakness of the technology.

For practitioners, the composite score therefore functions as a strategic diagnostic tool. It highlights where geothermal systems can be promoted with confidence on affordability grounds, where the tariff environment needs reform, and where capital support could be most effective in shifting choices within the HP family.

To sum up, within the constraints of its assumptions and 2023 data context, this analysis arrives at a clear overarching message: electrified heating and cooling solutions, and in particular GHPs, are not only central to decarbonisation efforts but also emerge as some of the most affordable options when assessed over their lifetime. Where they do not clearly lead, the reasons are identifiable and, in principle, amenable to policy intervention through, for example, tariff reform and targeted financial support.

Affordability, properly defined and measured, need not be a barrier by itself to the decarbonisation of heating and cooling. With coherent price signals and well-structured support for efficient technologies, the economic and environmental objectives of the transition can be aligned rather than traded off.

Innovative financial mechanisms for scalability

To bridge the gap between calculated affordability and real-world adoption, this deliverable proposes six financial mechanisms focusing on those that go beyond traditional subsidy programs:

i. On-bill financing to eliminate upfront costs through utility-managed repayment.
ii. Third-party ownership models (e.g., heat-as-a-service) to transfer risk and operational burden from end-users.
iii. Performance-based incentives (e.g., white certificates, feed-in tariffs) to align revenue with system efficiency.
iv. Tariff and tax reforms to correct distorted price signals favouring fossil fuels.
v. Community financing to leverage economies of scale in shared infrastructure.
vi. Risk mitigation instruments (e.g., guarantees, insurance) to lower capital costs.

These mechanisms are not mutually exclusive; their combined application could address multiple barriers simultaneously. For instance, Sweden’s success (driven by carbon taxation, stable policies, and mature markets) illustrates how systemic alignment of pricing, regulation and consumer trust can achieve widespread GHP adoption. Moreover, specific policy recommendations for different stakeholders have been made.

The EU’s climate ambitions demand rapid decarbonisation of heating and cooling systems, and GHPs offer a proven, efficient pathway. This deliverable reaffirms that a main barrier to GHP scalability is not truly technological but financial. With more strategic action, European countries can place GHPs as a central technology for heating and cooling in the building sector.

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Appendix 1. Questionnaire

Your information			
First name		Last name	
First name		Last name	
Organisation			
Country			
City			
Email			
Date			

Goal

The goal of this questionnaire is to assess the financial framework for geothermal heat pumps (GHPs) in the project partner countries.

Instructions

This questionnaire can be used for reporting on up to three subsidies. The main sections of the questionnaire are called *'Subsidy 1'*, *'Subsidy 2'*, and *'Subsidy 3'*.

If you need to provide information on more than three subsidies, please copy a 'Subsidy' section and paste it at the end of the document as many times as needed. Then, rename each new section accordingly (e.g., 'Subsidy 4', 'Subsidy 5', and so on).

Definitions

The term *'subsidy'* refers to any direct financial assistance in terms of transactions or transfer that helps reduce the cost of GHP projects for recipients. Usually but not always, a subsidy involves a one-time funding aid.

The following is how the subsidy types are categorised:

a) ***Non-repayable funds:*** Including grants (funds provided with no repayment required), tax credits (amounts that can be subtracted from the total tax owed) or rebates/waivers (reimbursements, discounts or charge exemptions on the use of energy-efficient equipment).
b) ***Debt:*** Including loans, bonds, mortgages and their greens derivatives such as green loans, green leasing and PACE (Property Assessed Clean Energy).
c) ***Equity:*** Including private equity, venture capital, angel investing, public offering and crowdfunding. Note that equity financing is typically related to larger projects or companies rather than individual installations. For residential GHP projects, this type of financing might not be commonly used or not used at all.
d) ***Other:*** Any other type of subsidy that do not fit exactly into the previous categories. Examples are hybrid instruments (subsidies that combine features of debt and equity), performance-based incentives, donations, guarantees.

As a reference, in this link, more information on some subsidy types considered more innovative can be found.

- **Please provide information on all national-level subsidies in your country. Additionally, if there are multiple regional subsidies (e.g., in Federal States), you may focus on the ones you are most familiar with or consider the most relevant.**

Our contacts

If you require assistance or have any queries regarding the questionnaire, please contact us.

Subsidy 1

General Subsidy Information

1. **Subsidy program name**
    - What is the name of the subsidy program?
2. **Subsidy citation**
    - Please specify preferably the official reference for this subsidy (e.g., a link where the subsidy is officially explained or established).
3. **Type of subsidy**
    - Please categorise the type of this subsidy (explanations of categories see above in the intro text). Select one of the following categories and specify the sub-type of the subsidy after the colon (:).

    a) *Non-repayable funds:*
    b) *Debt:*
    c) *Equity:*
    d) *Other*:
4. **Source of funding**
    - Who funds this subsidy (e.g., government, private sector, international organisation)?
5. **Geographic level**
    - At which geographic level does this subsidy run (federal, regional, local)?
6. **Co-funding**
    - Does this subsidy work together with other subsidies (e.g., a subsidy from a Federal State is complemented by a national subsidy) (Yes/No)?
7. **Construction type**
    - Please specify the type of building construction (new construction, renovation, both) applicable to this subsidy?

Detailed Financial Information

8. **Financial support specifics**
    - Does this subsidy cover only GHPs or other renewable technologies as well? If yes, please specify which ones.
    - Does the subsidy amount vary depending on the technology type of the heat pump (Yes/No)? If yes, please specify the technologies.
    - Does the subsidy amount vary depending on the size of the installation (e.g., planned installed capacity in kW) (Yes/No)? If yes, please specify the differences.

- Does the subsidy amount vary depending on the income level (Yes/No)? If yes, please specify how.
- Does the subsidy amount vary by any other factor not listed above (Yes/No)? If yes, please specify.
- What is the funding amount or percentage of costs covered by this subsidy? If there are different subsidy amounts depending on factors listed above, please specify all of them.

9. **Duration and funding availability**

- What is the lifetime (start and end dates) of this subsidy program?
- What is the total amount of funding available for this subsidy program?

10. **Timeframe**

- What is the typical timeframe for receiving this subsidy after the application has been approved?
  - (a) Up-front or less than 1 month
  - (b) 1-3 months
  - (c) 3-6 months
  - (d) More than 6 months or only after successful installation of the GHP

11. **Eligibility criteria and technical requirements**

- Who is eligible to apply for this subsidy (e.g., private companies, public organisations, individuals)?
- Does the GHP need to fulfil any technical requirements or performance conditions such as global warming potential (GWP), minimum seasonal performance factors (SPF) or regular monitoring during the operational phase?
- Are there any other specific technical requirements, geographic restrictions (e.g., absence of a district heating network at the planned location) or eligibility criteria for applicants (e.g. exchange of an oil/gas fired system) that must be met to qualify for this subsidy?

Stakeholder Perception

12. **Effectiveness rating**

- In your opinion, how effective has this subsidy been in promoting the adoption of GHPs? Please rate your answer on a scale of 1 to 5. Justify the answer if you feel necessary.

Appendix 2. Potential impact of the EMD on dynamic tariffs

While not explicitly mandated, dynamic electricity tariffs are encouraged under the reformed Electricity Market Design (EMD) framework (Directive (EU) 2024/1711) as a means to optimise renewable energy usage and enhance consumer choice. Consequently, the use of dynamic electricity tariffs is likely to expand as a result.

Why the EMD affects dynamic tariffs

1. Consumer empowerment and choice: A key goal of the EMD reform is to provide consumers with more choices, including the option to benefit from lower-cost electricity during off-peak times. In practical terms, this means encouraging or requiring electricity suppliers to offer time-of-use or real-time pricing options, both forms of dynamic tariffs.
2. Demand-side flexibility: With a growing share of intermittent renewables (wind and solar), EU policymakers see demand-side flexibility as crucial to stabilising the grid. Dynamic tariffs are one of the simplest ways to incentivise end-users to shift their consumption to periods of excess renewable generation or lower wholesale prices.
3. Legal and regulatory signals: Although the reformed EMD proposals still must be adopted and transposed into national laws, the text of the Directive (EU) 2024/1711 include consistent language about:
    - Mandating more transparent cost signals for consumers, so they can adapt their usage in real-time.
    - Requiring large electricity retailers (usually above certain thresholds) to at least offer one dynamic-pricing contract.
    - Streamlining the roll out of smart metering infrastructure, which is essential for dynamic pricing.
4. Long-term price stability *vs.* short-term price signals: One of the core principles under the reformed EMD is balancing long-term stable pricing mechanisms (like CfDs) with the short-term market that reflects real-time demand and supply conditions. While CfDs reduce volatility for generators and can help lower overall consumer risk, the day-ahead and intraday markets still matter for operational decisions, and dynamic tariffs tie retail consumers directly to these short-term price signals. The EMD aims to preserve and even enhance this aspect to ensure flexibility.

Implications for heat pumps and utility tariff reforms

1. Reduced operating costs: If dynamic tariffs encourage consumers to use electricity when it is cheaper, the running cost of HPs can be significantly lower. This boosts the financial attractiveness in particular of GHPs. In fact, since GHPs typically have higher efficiency and more consistent performance than other types of HPs, they should stand to benefit proportionally more from cheaper electricity.

2. Higher investment confidence: For many potential GHP customers, variable energy bills introduce uncertainty. If dynamic tariffs are coupled with clear, stable rules under the EMD, it helps reduce the "revenue risk" of lower-than-expected savings. There is more clarity about when electricity will be cheaper (e.g., overnight or during times of high wind/solar production).
3. Alignment with policy goals: By rewarding off-peak usage, dynamic tariffs complement other policy measures (like shifting levies away from electricity or implementing carbon pricing on fossil fuels), further shortening payback periods for GHP installations.

Potential caveats

1. Implementation varies by Member State: The EMD creates the framework, but ultimately Member States decide how aggressively they push utilities to offer dynamic tariffs or how they shift taxes and levies. Expectedly, some countries will move faster; others may be slower or more conservative.
2. Customer engagement: Dynamic tariffs only bring real savings if end-users can (and do) shift their consumption. That is, consumers need to be aware how to schedule operation at cheaper hours. This seems not hard in theory, but in practice not all consumers are well informed about or proficient in the use of modern technology.
3. Need for smart infrastructure: Dynamic pricing relies on smart meters, data management and sometimes automation (e.g., connected thermostats). The reformed EMD signals more support for these things, but the actual roll out will still depend on national and local utility strategies.

Concluding remarks

The reformed EMD is very likely to foster the availability and attractiveness of dynamic tariffs across the EU. For GHPs, this means that regulatory changes and utility tariff reforms under the EMD can improve the economics of high-efficiency heating and cooling. By reducing off-peak electricity costs and adding revenue stability for both utilities and consumers, dynamic tariffs can help address key barriers around operating costs.