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Opportunities and costs for shared ground loops

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ABSTRACT

Shared ground loops (SGLs) combine shared ground heat exchangers with distributed heat pumps across multiple properties and may offer a route to decarbonise heating where individual heat pumps or heat networks are not feasible. SGLs can be installed in homes and buildings with limited outside space for a heat pump or insufficient demand density to support a heat network. To make the most of potential opportunities, greater awareness of factors shaping UK deployment is needed. Through a mixed-methods approach combining rapid evidence assessment, case studies and policy mapping, this study finds SGLs mostly limited to deployment by social landlords and in new build settings, with wider use impacted by high capital costs, policy gaps around mid-scale solutions, market concentration around a single supplier, and the need for business models applicable to mixed-tenure settings. SGLs are particularly suitable for dwellings in higher density areas outside of government-designated Heat Network Zones, where it is expected that large heat networks will deliver the lowest-cost route to decarbonising heat. We suggest policy and practice recommendations intended to create conditions for wider deployment. At a national policymaker level, SGL suitability for mid-scale, medium-density settings and support for a flexible energy system should be more clearly recognised, especially in areas outside Heat Network Zones. At the individual company level, deployment would be supported through development of utility-style business models and installation approaches by infrastructure developers which can offer SGLs to households of a range of tenure types.

1. Introduction

The shift to decarbonised heating remains one of the most challenging aspects of the net zero transition [1,2]. Provision of heat accounts for 37 % UK's greenhouse gas emissions [3,4]. With 25.5m UK homes still using gas or oil boilers, the UK lags behind many European neighbours in switching to low and zero carbon (LZC) heating systems and at current installation rates this would take many hundreds of years [1,5–7]. It is vital that deployment of available solutions for decarbonising heating is scaled-up without delay. Alongside the challenges of heat decarbonisation, the UK has recently committed to a clean power system by 2030 largely from renewable energy sources [8]. This presents huge opportunities to decarbonise heat through electrification but also challenges which may threaten this goal through inefficient or inflexible approaches [9,10].

The UK Heat and Buildings Strategy launched in 2021 remains the primary policy instrument strategy to decarbonise homes, commercial, industrial and public sector buildings [11]. A range of LZC heating technology options offer routes to heat decarbonisation. These include heat pumps, heat networks and shared ground loops (SGLs), which are the subject of the study. Others include direct electric resistive heating, individual boilers combusting hydrogen or biomass, as well as hybrid options [12]. Each technology option features potential advantages and drawbacks. For example, there is significant and mounting evidence to support the case against hydrogen as a replacement for natural gas boilers on economic and environmental grounds [12–14]. Direct electric resistive heating such as wall-mounted panel heaters are seen as low-cost and straightforward to install [15]. However, inherent

Abbreviations: ASHP, Air source heat pump; BUS, Boiler Upgrade Scheme; CoP, Coefficient of performance; 5GDHC, fifth generation district heating and cooling; GHE, Ground heat exchanger; GSHP, Ground source heat pump; HNZ, Heat Network Zones; LAEP, Local Area Energy Plan; LZC, Low and zero carbon; REA, Rapid evidence assessment; SGL, Shared ground loop; SHDF, Social Housing Decarbonisation Fund; SPF, Seasonal performance factor.

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maximum limits to efficiency means widescale deployment would require significantly greater electricity generation capacity, and lower flexibility reduces the ability to use electricity when it is generated, leading to higher overall costs [10,16,17]. Biomass boilers are recognised as LZC technologies, but only supported for deployment in rural areas due to air quality impacts [18]. Rather than seeking to compare and contrast all available or emerging technologies, the study focuses on available options which align with current UK policy to decarbonise homes and suitable for deployment in urban areas [19].

Heat networks are expected to play a far more significant role than at present, to supply around 18 % of UK heat by 2050, up from around 3 % today [19–21]. Heat networks are likely to be deployed primarily in higher density urban settings where individual heat pumps are less viable [19]. Importantly, of the current c12,000 heat networks currently deployed in the UK, 90 % continue to rely on natural gas combustion for heat generation [22] and must be decarbonised. In addition, 80 % of systems fall under the single-building definition of 'communal' rather than 'district' systems. To support the growth and development of low carbon heat networks, the UK Government is due to implement Heat Network Zoning (HNZ) across England [23]. HNZ will designate areas where heat networks represent the lowest cost solution to decarbonise heat [24]. To identify those areas, HNZ uses a range of geospatial, energy and socioeconomic data and an optimisation algorithm to compare the heat network option to an individual-building air source heat pump (ASHP) counterfactual [25]. If implemented successfully, HNZ should support heat decarbonisation through: (1) supporting growth and development of new heat networks through clustering of future customers, (2) a requirement for those new heat networks to be low carbon, (3) powers to require connection of low carbon heat sources to heat networks, and (4) powers to require connection of certain building types to a heat network once established, including new buildings, larger existing non-domestic buildings and existing homes served by communal heat networks [25,26]. Through this approach, HNZ should support decarbonisation of existing communal networks within zones, which will be required to connect to the low carbon zonal heat networks. If successfully implemented, HNZ should support heat network deployment and cost-effective heat decarbonisation within zones. However its impact will be limited to zoned areas [27], highlighting the need for alternative solutions outside of zones.

The UK government sees heat pumps as the primary 'no-regrets' technology for decarbonising heat across the country, with a target for 600,000 per year to be deployed by 2028, primarily in new-build homes and lower density areas [28]. Heat pumps can be considered net zero compatible when connected to local renewable electricity generation or to an electricity grid with a reducing carbon intensity [29,30]. The UK has seen major reductions in carbon intensity of the electricity grid from 2012 onwards [31,32]. This is primarily due to drastic reductions in the use of fossil fuels for grid electricity generation, correlated with significant increases in wind and solar generation, and marked by the closure of the country's last working coal power plant in 2024 [31,33]. The UK's commitment to a largely decarbonised electricity system by 2030 is seen as the most ambitious of any major industrialised economy [34]. Much of this low carbon power will come from renewable sources which come with intermittency challenges [35]. With the UK having incurred an estimated £1.5 billion in costs from electricity congestion leading to underutilisation of renewable energy [36] this trend is likely to increase with higher renewables penetration. Electrified heat systems such as heat pumps or heat networks which include heat pumps can help to mitigate intermittency through utilising excess electricity generation and reducing curtailment [30]. Potential impacts of different heat technologies on the wider energy system are recognised by policymakers, civil servants and energy system managers, with a growing focus on the need for system planning at national [37,38], regional [39–41], and local [42–44] levels.

A key advantage of heat pumps is the high level of efficiency made possible by accessing environmental energy sources from the air, ground, or water. Some sources such as waste heat from industry or data centres hold significant potential to support efficient heat pump systems but tend to be viable only in shared systems rather than single properties. By utilising these sources, heat pumps can typically provide heating and hot water at around a third to a quarter of the energy needs and associated carbon emissions of equivalent direct electric or fossil fuel heating [45]. Importantly, unlike conventional fossil-fuel based systems such as gas boilers, once fitted, heat pump systems won't need to be retrofitted to enable a home or building to reach net zero carbon [19]. ASHPs are the type of heat pump most commonly deployed in the UK (as well as globally), making up around 90 % of recent installations [30,46]. However, their applicability has been limited by the need for outside space as well as planning regulations requiring fan units to be placed at least 1m from the property boundary[1] [45,48]. Ground source heat pumps (GSHPs) combine heat pumps with a ground heat exchanger (GHE), typically a borehole, to access heat in the ground, alongside electricity to provide space heating, hot water and cooling in some cases. Whilst they are more expensive to install, GSHPs can potentially offer efficiency and running cost benefits over equivalent installations of ASHPs through access to more stable temperatures across the year and ability to store energy to reduce seasonal demand peaks [29,30]. Because of this, they can offer peak demand reductions and associated system savings compared to ASHPs [49]. GSHPs also require outside space for the GHE element either in a borehole or horizontal configuration. The need for outside space can limit deployment of single-building ASHPs and GSHPs, though in the case of GSHPs this can potentially be overcome through a shared ground loop system (SGL) design. Because 45 % of UK homes are arranged in terraced streets or housing blocks [50–52], this leaves many with little or no outside space to accommodate the fan unit of an ASHP or GHE of a GSHP.

SGLs comprise heat pumps distributed across multiple properties, connected via a low/or ambient temperature network to a shared ground array [28,53–55]. Each user has autonomy over their heat pump, providing heating and hot water as required. In addition to their suitability for settings where individual heat pumps or centralised heat networks are impractical, SGL systems can offer several distinct advantages compared to other options. SGLs can potentially offer the higher efficiencies of GSHPs to homes and buildings where they are not otherwise viable [49,56,57]. In-situ monitoring of an installed SGL system showed an operational seasonal efficiency, or SPF, of 3.5 and demonstrated superior carbon saving and operating cost performance than typical ASHP systems in the UK [56]. Unlike conventional GSHPs, SGLs distribute the cost and complexity of ground infrastructure across multiple dwellings, improving economic feasibility—particularly in retrofit scenarios [54,57]. Ground heat exchanger designs can be further optimised by accounting for increased diversity across multiple properties. In comparison to ASHPs, SGLs can reduce peak electricity demand through access to stable subsurface temperatures, thereby supporting grid load management and enhancing system flexibility [49]. Centralised maintenance of the shared ground array also offers operational efficiencies and potential service model innovations, such as utility-style delivery [54,57].

These opportunities highlight the potential of SGLs to contribute to a more resilient and cost-effective heat transition. However, they have yet to achieve widespread deployment. Evidence suggests there are 2500 systems deployed in the UK, primarily in social housing and new build developments [58]. Fig. 1 illustrates a simplified representation of two SGL systems serving a row of terraced homes and a residential housing

[1] The UK Government has committed to remove the 1m rule in 2025 reforms of the planning system [47].

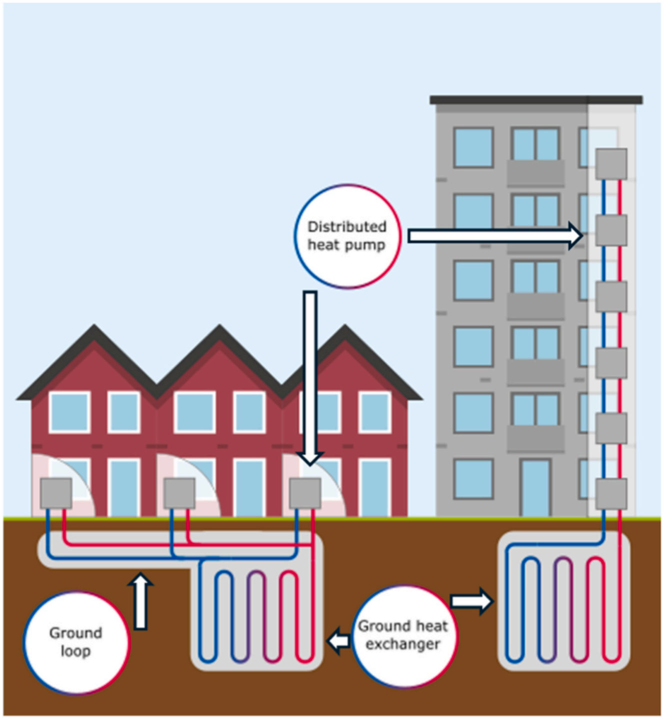

Fig. 1. Infographic of two SGL systems serving a row of terraced homes and a residential housing block, with labelled components.

Fig. 2. Image of SGL groundworks installation to residential housing block in Leeds, UK, 2022. D Barns.

block. Fig. 2 shows borehole drilling works at an SGL installation in 2022.

A wide range of terms are used to describe shared ground loop technology, and this is unlikely to help technology awareness or understanding. As well as shared ground loops [19,57,59,60], the technology is variously known as shared ground heat exchange [28,53], shared-loop ground source heat pump systems [54], street-by-street heat networks [61], networked GSHPs [49,62], communal ground loops [63] and ambient loop district heating [64]. Fifth generation district heating and cooling (5GDHC) is more commonly used in Europe to describe district scale systems which employ distributed heat pumps and a low temperature network to provide heating and cooling [58, 65–67]. Whilst most UK SGL systems are smaller, typically extending over the scale of a single multi-dwelling residential building or street, the term 5GDHC is also used by the SGL sector in the UK [60]. The term ambient loops is generally used in the UK to denote larger local heat networks systems that may include SGL elements and bi-directional heat flows [55,59]. The shared heat network or loop in an SGL system is generally used for heat extraction and so operates at sub-ambient temperatures like other large scale GSHP systems. When extended to include mixtures of building types and heat sources the term ambient loop would appear more accurate given the temperature could float around ambient levels. Table 1 provides a set of definitions which are used

Table 1
Definitions and key terms used in the study.

Term	Definition
Heat pump	Device which uses energy taken from the environment (air, ground or water), along with electricity, to provide heating and hot water.
Air source heat pump (ASHP)	A heat pump which uses energy from the air to provide heating and hot water.
Ground source heat pump (GSHP)	A heat pump which uses energy from the ground to provide heating and hot water.
Coefficient of performance (CoP)	An instantaneous measure of heat pump efficiency expressed as the ratio of useful energy output to electricity input, with greater CoP resulting in lower energy consumption and operating costs.
Seasonal performance factor (SPF)	A ratio of useful heat energy output to system electrical energy inputs over a season. Provides a measure of heat pump efficiency expressed over a year to account for the integral effect of variations in operating conditions.
Heat network	System comprising a central heat source connected to a range of users including homes, commercial buildings, hospitals etc. Many configurations of heat sources are possible, but typically include centralised combined heat and power infrastructure.
Fifth generation district heating and cooling (5GDHC)	A low temperature network suppling heating to multiple properties using low temperature distributed heat pumps, centralised infrastructure and a range of energy sources at a district scale. Some configurations allow cooling and bi-directional heat flow. System operation and temperature ranges are actively controlled.
Ambient loop	Low temperature heat network with distributed heat pumps and some centrally managed infrastructure. Buildings may extract or reject heat to the network. Temperatures are close to environmental conditions but not actively controlled.
Ground heat exchanger (GHE)	Pipes, typically in a borehole, which transfer heat to and from the ground.
Shared ground array (SGA)	An array of ground heat exchangers connected to multiple users.
Shared ground loop (SGL)	System that comprises distributed heat pumps with no centralised plant, a shared ground array and a low temperature heat network that serves more than one end user.

throughout this study.

To address limited understanding of SGL deployment in the UK, this study sets out to explore the technical, economic, and policy factors shaping their uptake. Specifically, it aims to fill gaps in the literature by (1) synthesising existing evidence on deployment drivers and barriers, (2) mapping real-world SGL installations to identify best-fit contexts for deployment, (3) assessing the recognition of SGLs within UK policy frameworks, and (4) comparing installed costs of SGLs with other LZC heating technologies. Study objectives are explored through the following research questions.

1. What can the current literature reveal about factors shaping deployment of shared ground loops?
2. What type of shared ground loop systems are currently being deployed in the UK and in what context? What does this suggest may be ideal settings for shared ground loop deployment?
3. How are shared ground loops identified and supported in national policy and what effect is this having?
4. How do current installed costs of shared ground loop systems compare to other low and net zero heating technologies, and what does this mean for deployment prospects?

The article proceeds as follows: the next section details the methods to address the research questions including a Rapid Evidence Assessment review, case study mapping and analysis, a participatory stakeholder and policy mapping process, and comparison of installed costs for SGLs compared to other LZC alternatives. Section three presents the results of the study finding current deployment is primarily limited to single-tenure settings in the social housing sector. Results also show SGLs subject to a policy gap around mid-scale solutions, a market currently concentrated around a single supplier and requiring the evolution of technical designs, standards, and industry practices. In section four, the paper further discusses implications of the findings on the potential for SGL deployment in the UK, including a comparison with a recent study [54] carried out over a similar timeframe. Section five concludes the paper with a summary of key findings.

2. Methods

To address the research questions, the study involved a mixed-methods approach including a Rapid Evidence Assessment for factors shaping SGL deployment, primary data gathering on UK SGL installations, and a policy mapping exercise. Outputs from these elements were compiled for use in a subsequent participatory workshop to explore stakeholder perspectives. An evidence-gathering exercise yielded real-world installed cost data. Fig. 3 summarises the multi-method qualitative research approach.

2.1. Rapid evidence assessment (REA)

To explore the current state of the literature around factors shaping SGL deployment, the first stage of the study involved an evidence review between December 2021 and January 2022 following a Rapid Evidence Assessment methodology [68]. This approach was chosen for its ability to generate insights within limited timeframes whilst applying a structured approach with rigorous academic principles [69,70]. Academic and grey literature sources were searched using various naming combinations including “shared ground loops”, “distributed heat pumps”, and “5GDHC” etc. As noted in Section 1, whilst the 5GDHC typically applies to larger-scale systems more common in Europe, the approach features similarities and the research team considered cross-relevance during data gathering. Additional search terms were used such as “business models,” “governance,” “local policy,” “socio-technical” etc. A table of search terms used in the Rapid Evidence Assessment included in supplementary materials and full list of sources has been made publicly available [71]. Insights were grouped according to themes based on prior research applying sociotechnical frameworks with additional themes directed to answer the research questions [72,73].

2.2. Case study mapping

To explore current deployment characteristics of shared ground loop (SGL) systems, the study identified 37 UK case studies through a structured search and snowball sampling approach conducted between December 2021 and February 2022. Searches were carried out using combinations of relevant keywords (e.g., “shared ground loop,” “shared ground heat exchange,” “networked GSHP,” “ambient loop”) across targeted platforms including government websites (e.g., GOV. UK, Ofgem), industry portals (e.g., Kensa, Ambient Earth), and news outlets. Snowball sampling was initiated from a list of known SGL project developers and GSHP technology providers included in UK Government data [74], as well as professional networks, including local authorities, housing associations, and infrastructure contractors with a track record in SGL deployment. As noted in Section 4.5, access to data was a key study limitation. Requirements on public bodies to make information available was helpful to the study team in gathering case study data but does introduce potential biases. Each case was examined to ensure it met the definition of an SGL set out in Table 1 and that the system that comprises distributed heat pumps without the use of centralised heating plant, a shared ground array and a low temperature heat network

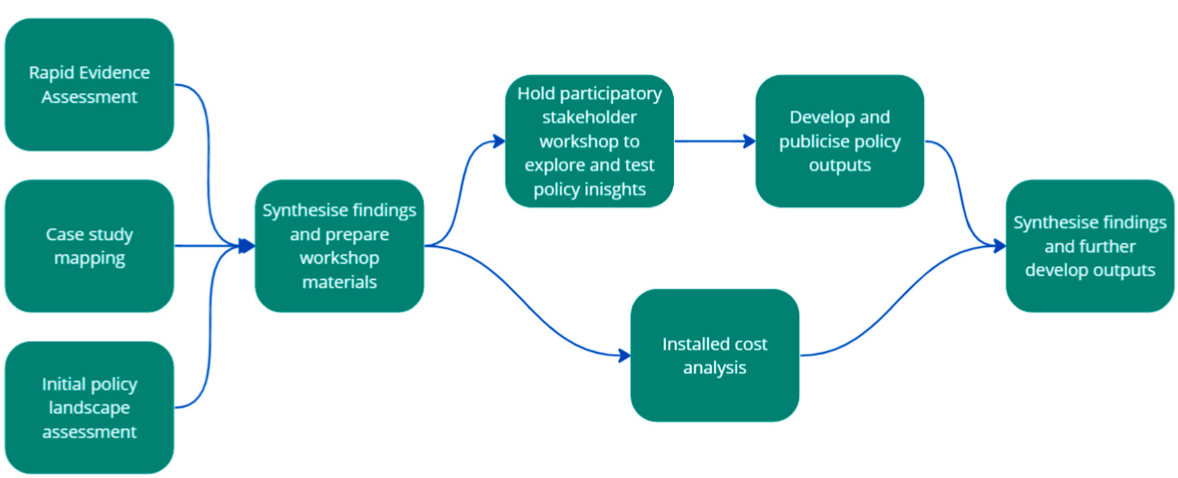

Fig. 3. Diagrammatic illustration of the multi-method approach used in this work.

serving more than one end user. It was not possible to verify data beyond what was made publicly available, and this is also acknowledged as a study limitation. However, as the data type in this section of the study was deemed non-sensitive with little commercial incentive to publish false information, it was deemed eligible for use in the mapping exercise.

Once a case study was identified to be eligible according to the definition of an SGL, each scheme was analysed to classify each scheme according to whether it was applied in a retrofit or new build setting, the type and number of properties involved, the previous heating type, and details of the scheme initiator/landlord, installer, and heat pump type. Posters were created from a selection of the case studies for use for use in the participatory workshop. To avoid overloading participants with information, six case studies were selected to present participants with a spectrum of SGL applications and settings. Stakeholder workshop materials have been made publicly available [71].

To explore deployment patterns in greater detail, Leeds was selected as a case study city. This choice was based on its status as a typical medium-to-large UK urban area with a mix of housing types and densities, making it representative of many UK cities. Additionally, the research team had established collaborative relationships with Leeds City Council and other local stakeholders, which enabled access to detailed geospatial data on SGL installations and heat network infrastructure. The 30 Leeds SGL cases were identified through direct engagement with the local authority and cross-referenced with publicly available planning and procurement documents. All selected cases met the study's definition of an SGL and were verified to include distributed heat pumps, a shared ground array, and a low-temperature heat network serving multiple dwellings.

2.3. Policy landscape assessment

To assess the UK national policy environment relevant to SGL deployment, a structured mapping exercise was conducted in January 2022. Policy documents were identified through targeted searches of official government portals and databases, including GOV. UK, the Department for Energy Security and Net Zero (DESNZ, formerly BEIS), and relevant parliamentary publications. Search terms included combinations of "shared ground loop," "heat pump policy," "low carbon heating," "heat networks," "Heat Network Zoning," "Boiler Upgrade Scheme," and "Social Housing Decarbonisation Fund." The scope was limited to policies active or proposed between 2018 and 2022, with a focus on strategic frameworks, funding mechanisms, and regulatory instruments affecting residential heat decarbonisation.

Policies were screened for relevance to SGLs and classified according to their primary aim (strategic vs. funding), technology applicability, and eligibility criteria. See Table 2 in supplementary materials for summary of policy mapping attributes and data types. Funding policies were further analysed based on administering agency, total and project-specific funding envelopes, applicant eligibility, and expenditure timelines. The mapping was supported by expert input from external collaborators, consultants with direct experience of working with UK government departments on heat policy, who reviewed and validated the policy selection. This ensured that despite time and resource limitations, relevant policies were identified. Outputs were synthesised into summary materials for use in the stakeholder workshop described in Section 2.4.

2.4. Participatory stakeholder workshop

To build on the evidence review and mapping exercises, a participatory stakeholder workshop was held in February 2022 to gather insights from practitioners, policymakers, and industry experts. Participants were selected using purposive sampling to ensure representation across key stakeholder groups involved in SGL deployment. Initial invitations were extended to individuals with prior involvement in related research projects, followed by targeted outreach to organisations active in heat decarbonisation, including local authorities, infrastructure developers, housing providers, regulatory bodies, and national government departments. Snowball sampling was used to identify additional participants, with referrals vetted to maintain sectoral and geographical diversity.

Selection criteria included professional role (e.g., policymaker, technical expert, housing officer), organisational type (public, private, third sector), and geographical coverage. Efforts were made to balance representation across industry, policy, and local implementation perspectives. Of the 32 participants, 22 organisations were represented, including national government, local authorities from different regions, social housing providers, and heat infrastructure firms. Whilst the sample was broadly representative, private developers and consumer advocacy groups were underrepresented, and this is acknowledged as a limitation. Ethical approval was obtained from the University of Leeds, and all participants provided informed consent.

With support from the research team, participants took part in a series of collaborative exercises and breakout sessions. These were themed as (1) technical & design, (2) national policy and regulation, (3) business models, (4) local implementation, and (5) users. Participants were encouraged to share, discuss, and debate insights and experiences relevant to the various themes. The outputs were recorded for subsequent thematic analysis by the research team to draw out relevant insights. Digitised outputs from the stakeholder workshop have been made publicly available [71].

2.5. Installed cost comparison

To explore indicative capital cost (capex) differences between SGLs, individual heat pumps, and heat networks, a desk-based analysis was conducted using publicly available data from 72 UK projects, of which 36 provided sufficient cost detail for inclusion. Projects were selected purposively to ensure equal representation across the three technology types, enabling comparative analysis of installed costs. Whilst this approach does not ensure statistical representativeness, it was appropriate for the qualitative and exploratory nature of the study. Limitations in data availability and comparability are explicitly acknowledged here and further discussed in Section 4.5. Table 2 provides a summary of project cases included in the analysis.

2.5.1. Data sources and validation

Capex data was extracted from a range of publicly accessible sources, including local authority officer reports, minutes of council meetings, published annual accounts, developer websites, and case study documentation. Where possible, multiple sources were cross-referenced to validate figures. Projects were only included if they provided clear and consistent definitions of installed cost - typically encompassing capital expenditure for heating system installation, including ground loop infrastructure (for SGLs), heat pump units, and associated pipework. However, definitions varied slightly across sources, and this variability is acknowledged as a limitation. Lifecycle and operational costs were not considered in this study due to inconsistent availability and reporting standards.

Table 2
Summary of cases included in economic costing research.

	Heat network	Shared ground loop	Individual heat pump
Number of cases analysed	33	26	18
Installed cost data available	12	12	12
No. of homes included	9451	2822	1085
Homes per project (average)	788	235	90

2.5.2. Standardisation and normalisation

To improve comparability, cost data were normalised on a per-dwelling basis. Projects were categorised by retrofit or new build status, and contextual factors such as project scale, housing type, and inclusion of ancillary works (e.g., sprinkler systems, solar PV) were documented. Costs were not adjusted for inflation due to the relatively narrow time window of data collection (2020–2022), but year of installation was recorded to support interpretation. Regional cost variations were not explicitly modelled, though geographical spread was noted.

2.5.3. Analytical approach

Descriptive statistics were calculated using parametric methods, including mean, range, and standard deviation. These were used to highlight indicative cost patterns rather than to support inferential claims. The use of actual numbers meant that no formal sensitivity analysis was necessary, but the influence of project characteristics on cost variability was qualitatively assessed and summarised in Table 6. Given the exploratory nature of the study and the limitations of the dataset, findings are intended to inform future research and policy development rather than to provide definitive cost benchmarks.

3. Results

The results presented in this section address each of the four research questions. Section 3.1 presents the results of the Rapid Evidence Assessment (REA) evidence review on factors shaping current SGL deployment. Section 3.2 presents analysis of installed SGL case studies to establish characteristics of UK deployment including a focused analysis on the city of Leeds in Section 3.2.1. Section 3.3 details the outputs from the UK policy mapping exercise including the results of the stakeholder workshop. Section 3.4 details the results from the investigation into how installed costs of SGLs compare to other LZC heat technologies in the UK.

3.1. Rapid evidence assessment (REA)

To explore the literature on factors shaping SGL deployment, a first stage exercise to map sources by country of primary focus highlighted a hotspot of research activity focusing on the UK (see Table 3).[2]

A hotspot of research activity focused on Denmark was identified but screened out during the REA process. Denmark features a strong history of district heating research and practical implementation [75–78]. However, the studies tended to describe *ultra-low temperature district heating*, featuring some similarities to SGLs such as ground heat exchanger arrays and decentralised heat pumps, but other aspects of traditional district heating such as unidirectionality of heat flow and centralised infrastructure and higher-than-ambient temperatures requiring insulated pipework. It is argued that the decentralised character of 5GDHC marks a fundamental break with all earlier generations including ultra-low temperature district heating [66]. 5GDHC systems often employ sophisticated control strategies to manage multiple heat sources and limit changes in loop temperature in contrast to SGL systems that allow the loop temperature to adjust passively. Overall, there is a clear focus of research in the UK and Europe.

Once sources were screened in or out, results of the rapid evidence assessment identified insights over various themes. These were classified according to whether they apply to SGLs (C), to any heat pump system (B), to any type of electrified heat system (A) The classifications are reflected in the Venn diagram in Fig. 4 highlighting that most results were specific to SGLs.

Table 4 summarises highlights gathered from the REA classified over seven themes: national policy, local policy, technical and design issues, business models, user considerations, as well as the opportunities offered, and challenges faced. These are cross-refenced to Fig. 4 to reflect which aspect of the technology they are most relevant to.

Table 4 shows most insights from the rapid evidence assessment were specifically relevant to SGLs, but that SGLs face shared challenges with other heat pump and other electrified heat systems. Overall, SGLs are subject to a range of factors impacting deployment. Some of these are specific to SGLs, such as the need for improved design standards. Some apply to all heat pump systems, for example the need to minimise impact from refrigerants used in the pumps. Others were more of a generalised feature of the UK energy landscape which impact all electrified system, primarily the ‘spark gap’ electricity-to-gas price difference.

The insights were developed into materials used to prompt discussion and analysis within the participatory stakeholder workshop and the implications of the findings are explored together in Section 4.

Table 3
Sources included in Rapid Evidence Assessment, mapped by country focus.

Country/region focus	Number of sources	% of sources (n = 83)
UK	20	24 %
Not country specific	20	24 %
Europe-wide	11	13 %
Switzerland	5	6 %
Germany	4	5 %
The Netherlands	3	4 %
Spain	3	4 %
Sweden	3	4 %
Austria	2	2 %
Canada	2	2 %
Denmark	2	2 %
Finland	2	2 %
Italy	2	2 %
Belgium	1	1 %
China	1	1 %
France	1	1 %
Nordic countries	1	1 %

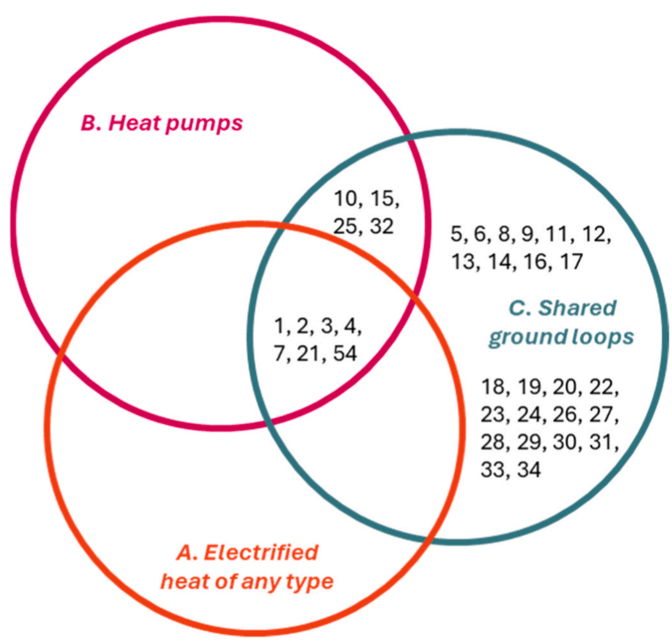

Fig. 4. Venn diagram showing how insights from the Rapid Evidence Assessment apply primarily to SGLs, to any heat pump system, any type of electrified heat solution, or all.

[2] Multi-country ‘Europe-wide’ and ‘Nordic countries’ as locations where sources spanned these areas.

Table 4
Highlighted insights from Rapid Evidence Assessment. Applicability to A (electrified heating of any type), B (heat pumps) and C (shared ground loops) correlates with Fig. 4.

Rapid Evidence Assessment insights by theme	A	B	C
National policy			
1. Out-of-date carbon factors in UK building regulations have favoured gas boilers over electrified options including SGLs[17,53,79,80]	x	x	x
2. Electricity to gas price differential ('spark gap') impedes the economic case for SGLs over combustion-based alternatives[17,53,57,64,81–84].	x	x	x
3. Ending new connections to the gas grid widely recognised as supporting electrified alternatives, especially in the context of the spark gap and absence of market reform[53,79,80,85].	x	x	x
4. Long-term policy consistency is key to unlocking solutions like SGLs[86].	x	x	x
5. National regulation and permitting for use of the subsurface would support greater deployment of SGL and other geothermal systems[87].			x
Local policy			
6. A coordinated neighbourhood-based approach would likely help unlock SGL deployment[58,88]			x
7. Through design and implementation of local planning policy, local authorities can create conditions for SGL deployment through restriction of fossil heating and recognition of SGLs as an appropriate net zero compliant approach in new homes[53,57].	x	x	x
Technical and design			
8. Systems should be carefully designed to minimise oversizing and associated efficiency loss[80,89,90]			x
9. A range of network design configurations are possible and these impact efficiency and associated running costs[91,92].			x
10. It is important to consider the global warming potential (GWP) of heat pump working fluid[93,94].		x	x
11. Lack of industry design standards and knowledge held by a few companies is holding back deployment[58,95].			x
12. Standardisation of systems, technologies and practices is key to driving down installation costs[58,95].			x
13. Provision of cooling and reinjection of waste heat from cooling supports long-term sustainability and efficiency[96].			x
Business models			
14. The primary business case challenge for SGLs remains high capital costs, but these can be overcome with innovative business models[58,97].			x
15. Supporting grid flexibility and benefitting from flexible tariffs supports business cases[92,98,99].		x	x
16. A utility (heat as a service) approach similar to gas or broadband network infrastructure could unlock widespread SGL deployment[57].			x
17. Conditions for SGL deployment are more favourable in settings where a building owner retains a long-term interest, known as 'patient capital' (e.g. a social landlord) compared with short-term 'fit-and-forget' approaches common to residential development[53,89,97,100].			x
18. The ability to provide cooling as well as heating can support viable business cases[58,64,88,96,101–103].			x
19. Thermal activation of building foundations and other buried structures can reduce capital cost of drilling[92,104].			x
20. Real-world examples demonstrate that SGLs can deliver cost and carbon savings compared to individual approaches[58,67,82,101,105,106].			x
User considerations			
21. Especially in retrofit settings, early consideration of and engagement with users is key[58,64,80,92,107–109].	x	x	x
22. It is important to consider placement of distributed heat pump to meet user needs[89].			x
Opportunities			
23. SGLs can offer residents in multi-dwelling units (MDUs) access to the higher efficiencies and lower running costs of ground source heat pumps which would otherwise be unavailable[110].			x
24. SGLs can connect multiple dwellings sources of heat which would otherwise be uneconomical, such as buried infrastructure[92,111].			x
25. Systems can work flexibly with grid balancing services and help facilitate renewables integration[67].		x	x
26. Low operating temperatures avoid thermal losses which can be seen in higher temperature traditional district heating[58,112].			x

Table 4 (*continued*)

Rapid Evidence Assessment insights by theme	A	B	C
27. SGLs can be set up to accept heat extracted from the building in warmer months to support long-term energy availability and performance, and reduce peak winter demand[65,92].			x
Barriers			
28. High up-front costs combined with long payback times acts as a barrier to SGL deployment, especially when compared to more established technologies[92,97,113,114].			x
29. Related to current niche status, a characteristic of the market is concentration, with technology knowhow held by a few companies[58].			x
30. The UK SGL sector lacks widely adopted design standards or technical guidelines specific to shared ground loop configurations contributing to variability in system design, sizing, and performance monitoring practices, which may affect operational efficiency and user experience. Related to Finding 28, while some internal standards exist, these are not publicly available or independently validated. The development of formalised design protocols covering aspects such as loop sizing, diversity factors, and integration with building systems, which would support more consistent performance outcomes and facilitate broader market adoption[58,115].			x
31. System designers are not yet taking advantage of diversification of heating demand arising from multiple users when conducting system sizing. Taking full account of this effect (reduced risk-aversity) could lead to further reductions in SGL infrastructure costs[116].			x
32. In-dwelling heat pumps generate some noise, and placement requires careful consideration[89,117]			x
33. Designers should use natural refrigerants with low GWP where possible[93,94].		x	x
34. Whilst SGLs can offer advantage to externally space-constrained dwellings, they typically require internal space for thermal storage which can be challenging in some dwellings[89].			x

Table 5
Results of case study analysis by a range of characteristics.

Characteristic	Category	Number of Projects	% of total (n = 36)
Location	South West	8	22 %
	West Midlands	8	22 %
	Greater London	4	11 %
	East of England	4	11 %
	South Wales	4	11 %
	North West	3	8 %
	East Midlands	3	8 %
	Yorkshire & Humber	2	6 %
Location type	Rural/low density	23	64 %
	Peri-urban/medium density	11	31 %
	Urban/high density	2	6 %
Building type	Houses	15	42 %
	Flats/apartment buildings	12	33 %
	Both	8	22 %
	Commercial	1	3 %
Previous heating type	Direct electric	20	56 %
	New Build	5	14 %
	Oil	4	11 %
	Not Specified	4	11 %
	Other	2	6 %
	Gas	1	3 %
Project owner/ sponsor type	Social housing provider	24	67 %
	Private	7	19 %
	Local authority	4	11 %
	Other	1	3 %
Heat pump type	Kensa	26	72 %
	Mastertherm	4	11 %
	Vaillant	2	6 %
	NIBE	1	3 %
	Dimplex	1	3 %
	ICAX	1	3 %
	Heliotherm	1	3 %

Table 6
Descriptive statistics for installed SGL systems.

Configuration characteristic	Statistical measure	Result
Number of heat pumps per project (data available for 34 cases)	Minimum	2
	Maximum	770
	Average	84
	<20 heat pumps	13 cases
	20-100 heat pumps	12 cases
	100+ heat pumps	9 cases
Number of ground heat exchangers (GHEs) (data available for 21 cases)	Minimum	4
	Maximum	100
	Average	25
	<10 GHEs	9 cases
	10-40 GHEs	9 cases
	40+ GHEs	3 cases
Depth of ground heat exchangers (GHEs) (data available for 19 cases)	Minimum	60m
	Maximum	227m
	Average	140m
	<100m	3 cases
	100–199m	12 cases
	≥200m	4 cases

3.2. Current UK shared ground loop deployment

Installed SGL projects were analysed according to location and rural or urban setting, dwelling type, previous heating type, the type of project owner, and the make/manufacturer of the heat pump element of the SGL system. Table 5 summarises the project attributes across six characteristics.

Installed cases in the UK showed a broad spread across England and South Wales, with most projects developed in the West Midlands. Analysis by location type found most projects deployed in settings of low and medium density, with only two identified in more densely built-up urban areas. This suggests that SGLs may offer a route to heat decarbonisation in areas that are unlikely to be suitable for heat networks which tend only to be viable in more dense urban settings with large anchor loads. Around half the projects were installed in apartment blocks or other types of communal building, with the other half to serve houses or low-rise developments including terraced homes. This suggests SGL are strongly suited to homes such as flats and terraced houses without outside space for an individual heat pump.

Analysis of previous heating type found that SGLs were most often deployed to retrofit homes previously using direct electric heating, typically night storage heaters. As this will necessarily require a higher level of intervention to install heat emitters and hot water tanks, it is likely to have an impact on system costs as explored further in Section 3.4. This may be explained by the analysis of project owner/sponsor type showing most schemes were carried out by social housing providers and local authorities. SGL installation in these cases was undertaken to help social housing tenants suffering from high running costs as can be expected from direct electric heating systems that exist in many locations where gas central heating is not possible [17]. This is backed up by documentary analysis which found evidence of non-financial justifications such as "*Residents had made numerous complaints about the high running cost of these [electric] systems and the low level of control they had over their operation*" [118].

Data on heat pump type shows over 70 % of installations used Kensa heat pumps, indicating SGL market concentration around a single company. This finding aligns with UK Government data on the UK market for GSHP installations (not limited to SGLs) to be highly concentrated between Kensa and NIBE, at 57–65 % market share [74]. This is contrasted to ASHPs where three product suppliers, Mitsubishi, Daikin, and Samsung, accounted for around two-thirds of annual sales in 2019. Whilst theoretically the ground loop and heat pump element of installed schemes can be considered separately, in practice the ground loop is designed to align to a specific heat pump capacity and operation. Where evidence on ground loop installers was available, twelve were carried out by Kensa's contracting arm.

To characterise the scale and configuration of installed SGL systems and provide a basis for comparison with conventional heat networks, we analysed project-level data on the number of connected heat pumps (i.e. SGL end-users), as well as number and depth of ground heat exchangers (GHEs). For each parameter, Table 6 shows descriptive statistics including minimum, maximum, average and frequency distributions to illustrate how many systems fall within defined ranges (e.g., <20 heat pumps per system; 10–40 GHEs per system, borehole depths ≥200m).

Table 7 shows descriptive statistics for the current UK deployment of conventional heat networks from UK government data [22].

Whilst the summative nature of the national dataset limits direct comparison with the project-level SGL data, it illustrates that SGL systems, particularly those with 100+ connected heat pumps, can approach or exceed the scale of many communal and district heat networks. This suggests that SGLs may offer a viable mid-scale alternative in settings where conventional heat networks are not feasible due to density, infrastructure, or cost constraints.

3.2.1. Shared ground loop deployment in a UK city

To further explore the hypothesis that SGLs are likely to be most suitable in areas outside of denser urban centres which may be more appropriate for heat networks, we conducted a detailed analysis for the case city of Leeds in the north of England. Fig. 5 shows the distribution of 30 installed SGL systems across Leeds, the current route of the Leeds PIPES heat network, and indicative Heat Network Zones, based on UK Government data published in September 2024 [27].

Fig. 5 illustrates the current extent of the Leeds PIPES heat network in the dense urban centre within the proposed central Heat Network Zone, with SGLs deployed further out from the city centre including towards the urban-rural boundary. Both the SGL and heat network installations have been implemented by the city's local authority, Leeds City Council (LCC). Since 2018, LCC has been constructing and expanding Leeds PIPES. The network currently serves around 2000 homes as well as non-domestic customers, and the council's own buildings in the Civic Quarter of the city. Since 2020, LCC has retrofitted SGL installations into 30 existing housing blocks which had previously featured electric night storage heating [119–126]. LCC has also been working with the UK Government to support development of the Heat Network Zoning methodology [127]. The extent of the Heat Network Zones suggests that heat networks will be limited to the higher density centre of the city. Whilst SGL deployment in Leeds shows some overlap with the central Zone, they are on the very edge to the east and west and are therefore likely to be the last areas that could be connected to a future heat network. The current route map of the Leeds PIPES network in the middle of the central zone highlights the scale of the task ahead for heat network developers seeking to meet zonal scale demand, in this case Leeds City Council and their delivery partner, Vital Energi [128]. Overall, the lack of overlap between SGLs, heat networks and Heat Network Zones further suggests that SGLs may be best deployed in areas further out from the centre which are less likely to be served by a heat network.

Table 7
Descriptive statistics for UK heat networks.

	Total heat networks	Total number of customers	Average customers per network
Communal	9242	250,667	27
District	2605	257,047	99
Total	11,847	507,714	43

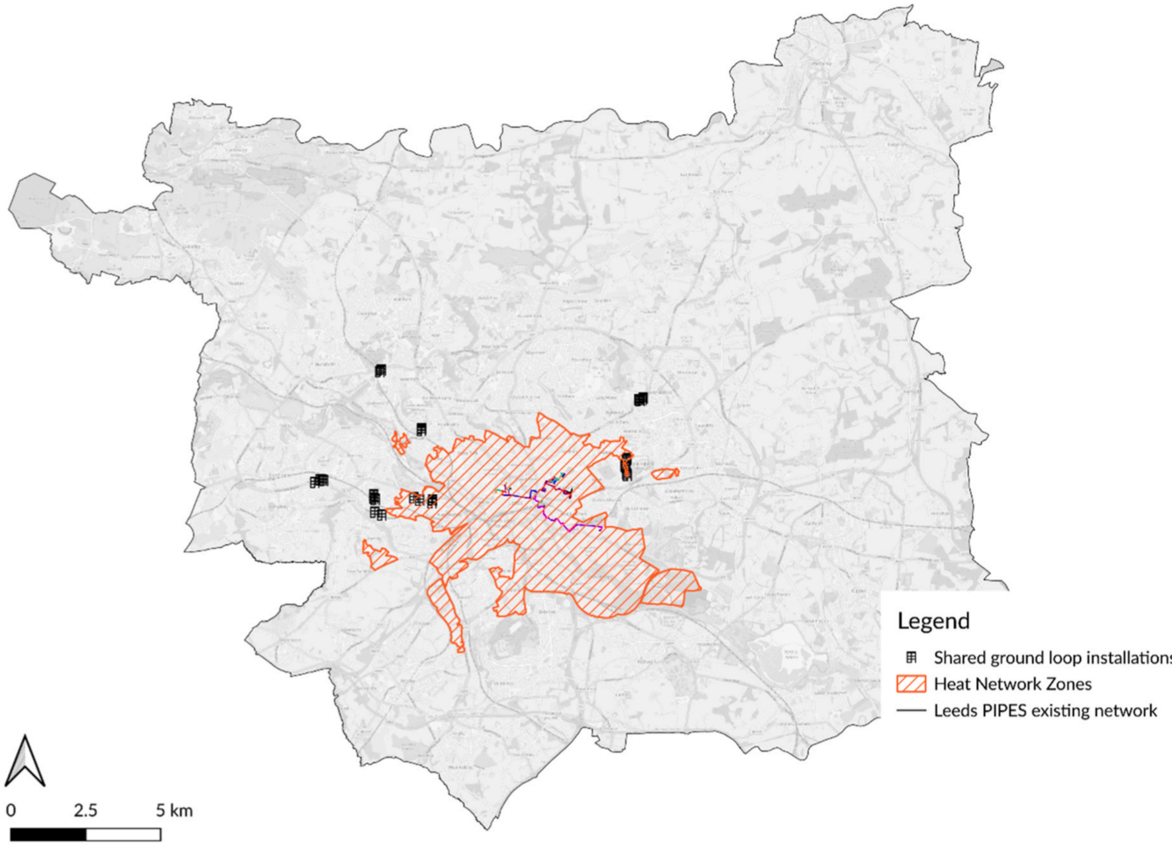

Fig. 5. Map of Leeds, UK showing SGL locations, the current route of the Leeds PIPES heat network (indicated in purple), and indicative Heat Network Zones.

3.3. UK policy landscape mapping

Through the policy mapping and stakeholder workshop, the study explored perspectives on how national policy is shaping deployment of SGLs. There is a clear recognition of the role and importance for individual heat pump systems for single homes and heat networks for higher density settings. This is set out in the UK Government's overarching Heat & Buildings Strategy [19]. However, whilst SGLs are implicitly recognised by virtue of their heat pump and heat network characteristics, they have so far received more limited recognition of the role they may be able to play in residential decarbonisation. Table 8 summarises the outcomes from the policy mapping exercise exploring the relevant UK government policies, indicating the level of support for SGLs in each case.

Results in Table 8 illustrate the current policy gap, with mixed levels of support and recognition of SGLs. For example, SGLs were eligible for support under the Social Housing Decarbonisation Fund. This is an £800m fund between 2022 and 2025 to support energy efficiency and heating upgrades. The scheme is limited to social housing only, however, aside from some flexibility to include a "small number of properties in a block or terrace" [144] being non-social homes, which necessarily limits applicability in mixed settings. The Boiler Upgrade Scheme represents the UK government's most prominent funding stream to support LZC heating deployment. Based on individual householder applications via installers, whilst it would theoretically support the heat pump element of SGLs, it would not cover the shared infrastructure element, and the application process does not lend itself to shared or collaborative approaches necessary for SGLs. No SGL schemes were identified which had successfully used Boiler Upgrade Scheme funding.

Heat Network Zoning (HNZ) proposals were thought to be a key consideration for future SGL deployment. In contrast to prior policy support for heat networks based around competitive grant funding for individual schemes, HNZ is intended to take a geospatial and data-driven strategic approach to identify areas across where "heat networks are expected to offer the lowest-cost solution for decarbonising heat" [23]. The overarching goal of HNZ is to support the business case for new and expanded heat networks through the clustering of future customers. To do this, the policies will include powers to require certain types of buildings and low-carbon heat sources to connect to a network. Requirements to connect to heat networks will likely apply to new buildings, larger existing non-domestic buildings, and existing homes which already have communal heating rather than individual boilers (these are referred to in heat network zoning proposals as 'mandatable' buildings) [25,26]. At the time of the study, the methodology for designating heat network zones was yet to be finalised. Engagement with policymakers clarified that the intent of HNZ plans is to support the development of large-scale centralised heat networks [145]. As larger conventional heat networks are limited to much higher operating temperatures, there are restrictions on integrating systems. For these reasons, SGLs are unlikely to become part of future zonal heat networks.

As is evident from the REA, SGLs are an emerging technology with relatively little publicly available information on the factors affecting their deployment. Restricting evaluation of these factors to published literature would, therefore, limit the comprehensiveness of the review and may not fully reflect the current state of knowledge. Specifically, the industry encompasses a broad range of stakeholders, extending beyond the SGL supply chain to include landowners, policymakers and regulatory bodies. Many of these stakeholders are likely to have insight into SGL deployment, however, do not routinely publish their experiences. To address this, research activities were carried out to capture unpublished knowledge. A cross-section of industry and policymaker perspectives were captured during a series of interactive guided activities held at a hybrid online/in-person workshop event. During these activities, participants were presented with case studies of SGLs collected

Table 8
Recognition of SGLs in UK government policy.

Policy	Territory	Description	Recognition/eligibility of SGLs	How this impacts SGL deployment
Heat & Buildings Strategy [19]	England only	Overarching policies and initiatives intended to reduce carbon emissions from buildings.	Implicit: commitment to scale up heat pumps & heat networks but no specific recognition of role of SGLs	Indication of low technology awareness, contributes to SGLs being excluded from decision-making at all levels.
Heat Network Zoning [24,129,130]	England only	Plans to designate heat network zones where heat networks are likely to be most cost-effective way of decarbonising heat.	Partial: SGLs only eligible when they can be connected to larger district heat networks, not applicable to most UK SGLs.	SGLs will not come forwards in HNZ areas. Lack of equivalent mechanism for optimal technology deployment outside of zoned areas means SGLs don't benefit from strategic recognition of local and wider system benefits over initial costs.
Building Regulations/ Future Homes Standard [131–135]	UK-wide	Fabric efficiency standards and notional heating systems for new build developments, carbon factors by fuel source.	Implicit: current (Part L 2021) regulations permit gas boilers. 2025 onwards, the FHS allows only low carbon heating, SGLs not specifically recognised.	As SGLs will not be identified as optimal solution in certain settings, likely to mean deployment of other technologies with lower initial costs, even when SGLs may be optimal solution.
Social Housing Decarbonisation Fund [136]	England only	Capital grant fund for reducing carbon emissions & fuel poverty in social housing	Explicit: SGLs eligible, following fabric measures	Funding enabler. Inclusion of SGLs has supported deployment.
Public Sector Decarbonisation Scheme [137]	England only (UK-wide for reserved)	Capital grant fund for replacement of fossil fuel heating at end-of-life, funding marginal over-cost.	Partial: SGLs theoretically eligible, but scheme does not support measures in residential settings	Funding barrier. As an optimal solution for multi-end-user contexts, SGLs especially suited to ineligible residential deployment.
Green Heat Network Fund [59]	England only	Capital grant fund to support development of new LZC heat networks and retrofitting of existing systems.	Excluded: SGLs eligible only when forming part of aggregated larger district heat networks. Min 2 GWh/yr (c130 homes) rules out most SGLs.	Funding barrier. SGLs not eligible meaning potential upfront cost hurdle.
Boiler Upgrade Scheme [138,139]	England & Wales	Capital grant fund to support households and businesses to install LZC heating including ASHPs, GSHPs and biomass in rural off-grid settings.	Partial: heat pump costs for dwellings already connected to SGLs eligible, but not ground loop or borehole installation costs. Coordination required	Funding barrier. BUS operates in an individualistic approach. The inherent shared/infrastructure elements of SGLs are key to their deployment, which is not supported.
Sustainable Warmth Fund [140–142]	England only	Combination of two capital grant schemes directed at households likely to be in fuel poverty, via local authorities.	Partial: SGLs eligible but short timeframes and fuel poverty requirements make SGL approach challenging.	Funding barrier.
Heat Pump Ready Programme [143]	England, Wales, Scotland	Small capital grant scheme aimed at improving commercialisation of heat pumps e.g., though business models, customer experience	Eligible: SGLs under Stream 1 but intended to fund demonstration scale SGLs rather than mass deployment.	Funding enabler, although with likely little impact as the scheme didn't support mass deployment.

during the mapping exercise and invited to comment on the strengths, weaknesses, and challenges. This case study evaluation was then expanded to consider the broader factors affecting SGL at local, regional, and national scales, with focus on the opportunities and barriers affecting their deployment.

Stakeholder engagement on the findings of the Rapid Evidence Assessment agreed that SGL deployment has been impacted alongside other electrified options as a result of central government policy. Key concerns were noted regarding the 'spark gap', where higher cost-per-unit electricity compared to gas was holding back running cost benefits of heat pump-based systems, and that electricity carbon intensity factors in building regulations had until recently had the effect of making electrified options appear to be less appealing to developers in meeting carbon reduction requirements.

Overall, the review of national policy indicates a policy gap for SGLs with an absence of direct support for mid-scale solutions that fall between the ends of the spectrum of individual heat pump systems and heat networks. This is a clear missed opportunity given the range of benefits that these systems could provide in properties that are likely to be left without heat decarbonisation.

3.4. Installed cost comparison

The study compared installed costs of SGLs with heat networks and individual heat pumps, those three being the primary alternative LZC technologies that the UK government recognises will play a key role in the heat transition. Across the sample, SGLs currently represent the higher cost LZC option, followed by heat networks, with the lowest cost option represented by individual ASHPs. However, this situation is complicated by many factors, primarily whether the heating system was

Table 9
Summary of cost findings including average installed cost, standard deviation and range.

	Heat networks	Shared ground loops	Individual heat pumps
Average cost (£, per dwelling)	14,200	16,300	12,900
Mean±standard deviation (£, per dwelling)	9000–19,500	14,700–17,900	9400–19,800
Range (£, per dwelling)	5800–40,600	10,700–20,500	5400–22,300
Average cost for new build (£, per dwelling)	10,639	N/A	6318
Average cost for retrofit (£, per dwelling)	21,600	16,300	16,400

installed in new homes or retrofitted to existing properties. Table 9 shows that when considering retrofit projects only, SGLs represented the lowest cost approach.

The figures in Table 9 illustrate significant cost implications inherent in retrofitting heating upgrades in comparison to installing technologies in new homes. Study data identified that retrofit works often included replacing electric systems with hydronic central heating (i.e. installing radiators and associated pipework). In addition, in some cases building owners took the opportunity to include additional non-heating work in the retrofit work such as installing sprinklers for fire suppression or fitting roof-mounted solar PVs. It was not possible to isolate costs for the heating upgrade elements only in these cases. This led to the large ranges, most evident in regards to heat networks with £34,800 per dwelling cost difference between lowest and highest cost installations.

Table 10
Summary of project characteristics potentially impacting on installed cost.

	Heat network	Shared ground loops	Individual heat pumps
1. Net zero compliant	10/12	12/12	12/12
2. Retrofit project	7/12	12/12	8/12
3. Hydronic central heating installation	6/12	9/12	7/12
4. Installation elements included: generation plant (0), primary (1), secondary (2), tertiary (3) pipework	0, 1 (most), 2, 3 (some)	0, 1, 2, 3 (all)	0, 3 (all)
5. Other works (most frequent identified)	Connection to non-domestic	Sprinkler installation	Batteries, solar PV

Table 10 summarises characteristics from the thirty-six cases which are likely to have had a complicating effect on project and per-dwelling costs.

4. Implications for shared ground loop deployment

Despite limited UK deployment, findings suggest that SGLs may be particularly suitable for use in residential settings in urban areas not served by an existing heat network and outside of new heat network zones. However, the study highlights several indicators that SGLs remain a niche approach in the UK with deployment limited to certain settings and scenarios. Whilst other studies found hotspots of activity in the new build residential sector [15,54], SGL installations included in the study were mostly limited to social housing providers and local authorities for the benefit of their social tenants. This suggests the importance of 'patient capital' where decision-makers have a long-term interest in the property and its inhabitants. Importantly, as with new build developments, the role of a single decision-maker was found to be key to deployment. The lack of schemes serving retrofit private and mixed settings was clear, emphasising the need for business models or other approaches to tackle these harder-to-reach sectors.

4.1. Optimal deployment approach

A limiting factor shaping deployment of individual heat pumps is the physical space required for the outside fan unit (in the case of ASHPs) or the GHE (in the case of GSHPs). Many homes do not have the garden, yard or other space necessary. This feature is especially prominent with terraced homes, many of which have no street-facing outside space at all [146,147]. Deployment of individual ASHPs has been limited to date by government planning policy that required the outside unit to be at least 1m from the property boundary and not installed on a pitched roof [48]. Many terraced homes in the UK primarily have limited outside space that would not allow compliance with these rules. The UK Government indicated in late 2024 that this requirement would be relaxed [47] opening up more homes to ASHP eligibility. However, physical space limitations remain for many homes.

Whilst SGLs share some characteristics with more traditional heat networks, their low temperature operation and distributed heat pumps means they are likely better suited to areas with lower heat demand density, out of the reach of a current heat network or future Heat Network Zone. Heat Network Zoning is likely to mean larger, connected heat networks become the preferred solution for deployment within Zones. Whilst SGLs will be eligible when they can be connected to larger heat networks, in practice zoning proposals mean heat networks are likely to grow outwards from city centres with their large non-domestic heat demands [28]. Taking these considerations together, Fig. 6 illustrates study findings for how shared ground loops might best be deployed in lower density urban, suburban and peri-urban settings along with individual heat pumps and heat networks.

4.2. Policy environment

The review of the UK policy environment and its impact on SGL deployment found that UK heat decarbonisation polices recognise the role of individual heat pumps in more rural settings and heat networks for higher density urban situations. However, policies somewhat overlook mid-scale settings in between rural and high-density urban areas, where SGLs are most appropriate, shown graphically in Fig. 7. There was a clear difference in policy support for different technologies. A more strategic approach to supporting heat network deployment was illustrated by incoming Heat Network Zoning policies, which will incorporate a range of geospatial, technical and energy related data to designate areas most suitable for heat networks to be the preferred (and importantly, lowest cost) solution for decarbonising heat, and feature powers to require connection of both heat consumers and suppliers. The policy review found that support for heat pumps continues to be based on a more individualised and market-led approach, with grants to household and businesses to encourage uptake. SGLs with their shared infrastructure are an inherently collective solution, suggesting a collective approach to policy support may be more appropriate.

Analysis of local policy and implementation suggests that local authorities are well-placed to support SGL deployment and can do this without national policy intervention. There was evidence of direct

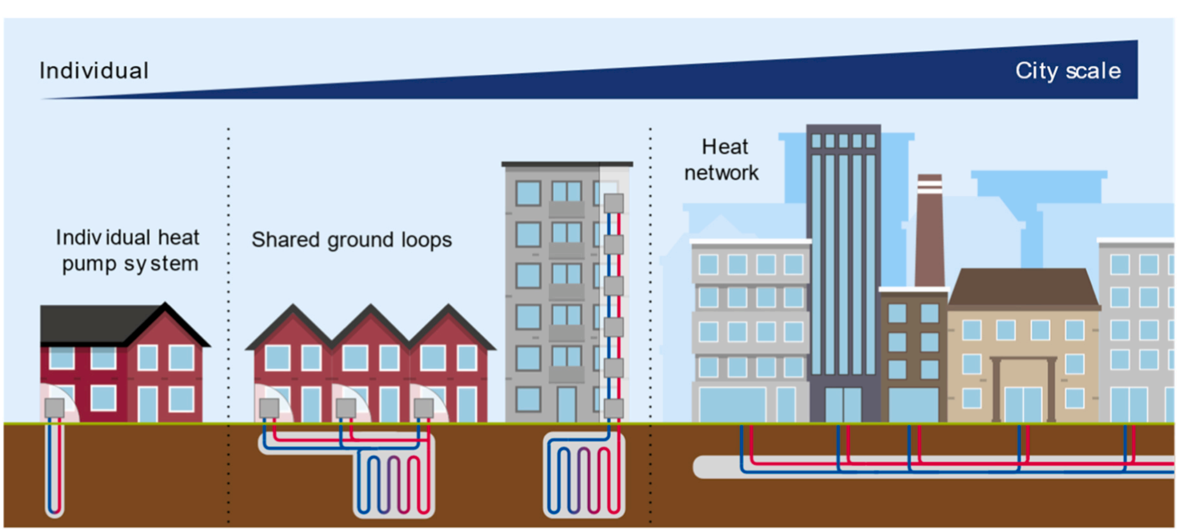

Fig. 6. Illustration of how shared ground loops align with mid-scale deployment between individual heat pumps and heat networks in dense urban centres.

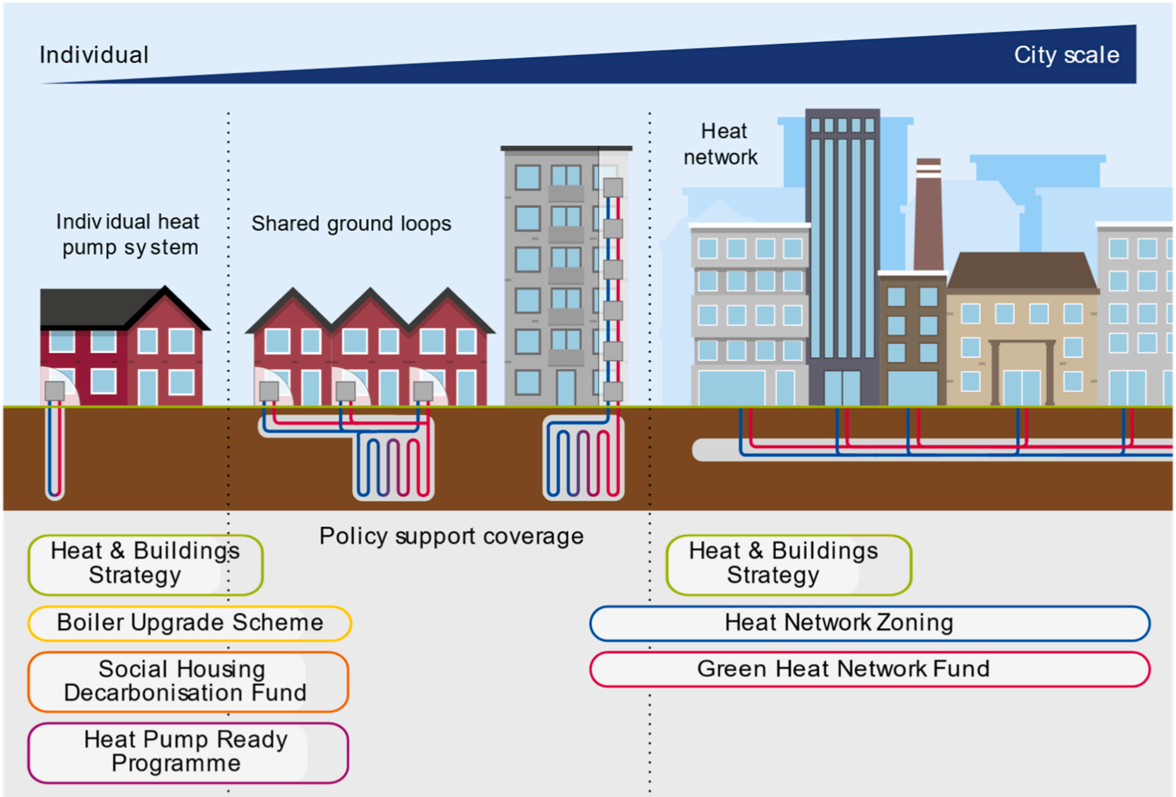

Fig. 7. Policy landscape for low carbon heat technologies over a range of scales [19,23,59,139,143,144].

investment in SGLs and heat networks by local authority and other social landlords motivated to tackle fuel poverty issues associated with direct electric heating. Further deployment on this basis is however limited by constrained public sector finances. Due to their role in setting local spatial planning policy, there are opportunities for local authorities to recognise SGLs as a suitable option for areas not served by heat networks and outside of heat network zones, in Local Plans or supplementary guidance. The impactful approach was highlighted by Barns et al. [15], and could be especially important tool for local authorities given well-known pressures as it could can support greater SGL deployment without capital investment.

4.3. Utility business models

One potential benefit of the SGL approach identified in the study is the ability to mirror a utility business model in a similar way to, for example, a broadband or gas network. This was found to potentially enable 11m additional UK homes to be suitable for a GSHP [57] and is highlighted in this study findings as well by Brown et al. [54]. In this approach, a utility operator would install the shared infrastructure (i.e. the shared ground array and connecting pipework, for example, under the pavement or alleyway behind a row of terraced homes). It could then be advertised to households as ready for them to switch to as-and-when they choose. Given that currently most gas boiler installations are made as ‘distress purchases’, prior to or following breakdown [148], this approach could fit more naturally with household buying patterns.

Since data collection ended, a small number of utility-style SGL models have emerged in the UK. The primary UK SGL supplier, Kensa, is investigating a utility approach [149] and has deployed a scheme in one village - Stithians in Cornwall [150,151]. The village scheme was delivered with support of EU European Regional Development Fund rather than a fully private finance initiative. A community-led utility approach to retrofit and SGL deployment is being explored in Rossendale in the north-west of England, with the support of national government Innovate UK funding [152,153]. A commercial UK operator, Rendesco, has recently partnered with utility owner Last Mile Infrastructure to form a joint venture with the aim of providing a funded utility offering to new build homes for both SGLs and ground source heat networks [154]. At the time of writing there are no fully commercial utility approaches targeted at the retrofit sector in the UK.

Whilst utility approaches in theory offer significant potential to increase SGL deployment, the lack of offerings highlights challenges to scaling up. Securing private investment for utility-style business models is especially pertinent in the retrofit sector where many different types of ownership (e.g. owner-occupier, private rented, social rented) would need to be connected to the same system. This is reflected in our study with mixed-tenure deployment in retrofit settings found to be particularly difficult. Despite this, privately financed utility models are well established in electricity, gas, water and broadband sectors, where financial backers such as pension funds are comfortable with high upfront investment and long-term payback, suggesting viability is possible under certain conditions.

4.4. The need for a coordinated approach

For utility style models (explored in Section 4.3) to be successful, investor confidence in long-term returns is critical. This is especially the case if third-party finance, for example from pension funds, is sought to fund the infrastructure installation. Long-term returns for investors in SGL infrastructure will depend on access to customers and stable customer base into the future. This is especially challenging in the mixed-tenure settings of a terraced street, for example.

The UK Government understands the need for creating and maintaining a stable customer base for the deployment of heat networks. The policy instrument chosen to support this, Heat Network Zoning, is due to come into force across England. This collective approach aligns well with the shared technology of heat networks. However, this leaves questions regarding what happens to those areas outside of a Zone. This is an issue of energy justice if it means those households and businesses miss out on access to low-cost heat. Study findings indicate current UK government policy offers no dedicated support for unzoned areas beyond the individualised grants for heat pump installation. As was found, deployment of individual ASHPs and GSHPs is likely to be highly limited by other factors.

Recent work by UK innovation charity Nesta on a policy blueprint for coordinated (or street-by-street) switching may present a possible route to tackle these unzoned areas [155]. The approach is intended to increase awareness, build consumer confidence in proposed solution for the area, and reduce household effort required to undertake a switch. This could be thought of as 'zoning the unzoned'. Brown et al. identified Local Area Energy Plans (LAEPs) as a potential route to plan effective deployment of SGLs alongside other technologies for their ability to provide greater investor confidence [54]. However, there are questions as the to the impact of LAEPs beyond planning exercises and into delivery [43]. If enacted effectively, the developers of the coordinated switching approach intend that it would take LAEPs forward to delivery. Fundamentally, this type of coordinated approach will be dependent on sufficient resource in place to deliver it, and depleted local authority finances [15,156] are likely to be clear barrier without additional funding. Based on these findings, we propose a model for how strategic energy planning at a local level could help move forward with locally-agreed solutions including SGLs. Fig. 8 illustrates how a range of data and intelligence such as building and customer types, local grid constraints, expected Heat Network Zones, and so on, would feed into a local modelling and engagement exercise, with the optimal solutions moving forward on an area basis.

4.5. Economic factors

The study established that on a simple per-home basis, SGLs are currently higher cost than other LZC options of individual heat pumps or heat networks. However, in retrofit settings they may represent the lowest cost option. There was considerable variation and complexity in the data that the sample could not disentangle. Higher average costs indicate SGLs' continued niche status and associated market immaturity. Importantly the results showed all technologies represented a significantly higher average cost than a typical gas boiler installation (around £3000 with fitting in 2024 [157]), noting that this cost is for a boiler only rather than complete hydronic upgrade. It remains an important comparison given that upgrade is not required in most homes replacing one gas boiler with another. Despite current higher average cost, there is likely to be greater potential for the cost reductions with less mature SGLs and GSHPs compared to ASHPs [57]. Future cost reductions will be dependent on supply chain development.

Whilst the study considered directly incurred costs in isolation, it is important to note whole-system implications and costs associated with the different heat technologies. With fossil fuel systems such as gas boilers, the primary drawback is the locked-in carbon emissions over the lifetime of the appliance. With electrified heating systems, there are important considerations are how these may support or threaten other parts of the energy system and transition to low carbon electricity [17]. For example, electric resistance heating (electric panel wall heaters) are being installed in many new build homes [15]. This is understandable as they are low cost and easy to install. However, they are comparatively less efficient than heat pumps leading to significantly higher peak demand and running costs for consumers [3]. They do not enable energy storage to facilitate time-shifting of heat demand, and feature high 'ramp rates' (i.e. can increase electricity usage very quickly). For deployment of electric resistance heating on the scale of a housing development or even a town or city, these factors are unlikely to be critical, but when scaled up to a country's power system, this presents potentially destabilising effects. Heat pumps which include energy storage either short-term above ground storage (such as with ASHPs) or a combination of short-term above ground and longer-term subsurface storage (in the case of some SGLs and heat networks) can facilitate grid balancing and integration of intermittent renewables by storing energy and cutting demand when called for e.g. at times of lower wind generation. As an example of how these costs are reflected in national energy systems, in pursuit of its commitment to clean power by 2030, the UK government expects generation and network reinforcement costs of £40bn per year between 2025 and 2030 [158]. However, it has been shown that locating 5 GW of flexible demand behind network bottlenecks could save consumers £5 billion by 2050 and avoid the need for some network reinforcements [159].

Alongside upfront costs, the price of heat that SGL operators would be able to provide to users is a key consideration. The key fuel input to SGL systems (alongside all electrified systems including ASHPs, direct electric heating, heat networks using heat pumps) is electricity. The distributed nature of the heat pumps in SGL systems gives households greater control over their energy bills due to the ability to switch to find the best deal [114]. This may be supported by a recent study found that 57 specialist electricity tariffs now available to support household adoption of heat pumps and electric vehicles in the UK [160]. However, a fundamental market failure in the skewed electricity-to-gas price differential that is especially prominent in the UK [161]. With UK electricity prices currently 3–4x that of natural gas on a per-unit basis, means any heat pump system must operate at very high levels of 300 %–400 % efficiency in order to compete on price. This is also the reasons that direct electric systems which operate at up to 100 % efficiency currently provide a poor user experience and is illustrated in this work where many SGL installations were chosen to replace direct electric heating rather than gas-based systems.

4.6. Final comments

Overall, the study found that SGLs can offer opportunities to

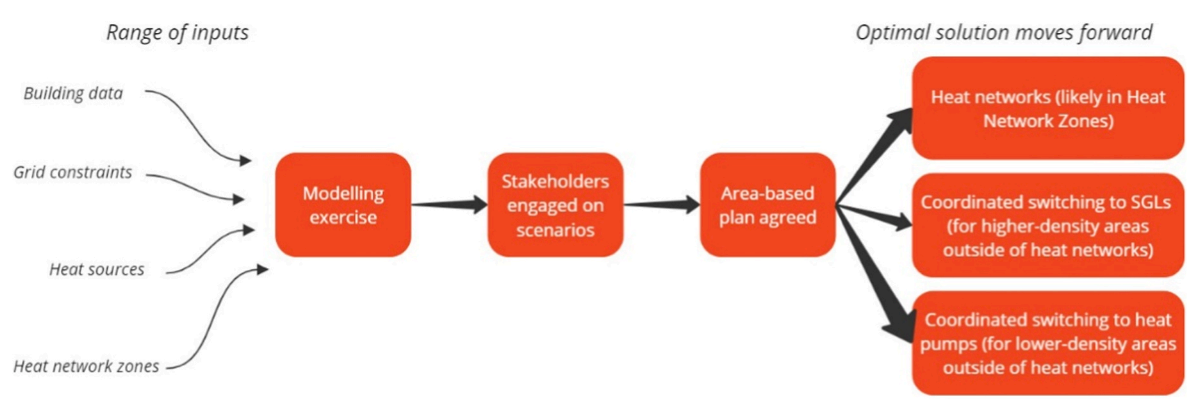

Fig. 8. Proposed model for local heat planning to identify where SGLs, heat pumps or heat networks may present the optimal solution.

decarbonise heating for homes which would otherwise be unavailable, primarily due to limited outside space or the density to support a traditional heat network. Therefore, SGLs have the potential to play an important role in transitioning to net zero residential heating if the challenges can be addressed. Currently the UK SGL market is highly concentrated around a single UK-based supplier [74]. This market concentration is indicative of continued niche status and technology knowhow held by a select few and represents a significant challenge to wider deployment. The introduction of greater competition in such a highly concentrated market is key to technology innovation, cost reduction and the ensuring a positive user experience.

4.7. Limitations

This study was designed as a qualitative, exploratory investigation into the deployment SGLs in the UK. As such, it did not aim to produce statistically generalisable findings, but rather to identify indicative trends, barriers, and opportunities based on available evidence. Several limitations are acknowledged.

First, the availability and consistency of data, particularly on installed costs, was a key constraint. Cost data were drawn from publicly available sources including local authority reports, meeting minutes, annual accounts, and developer websites. Under the Local Government Act 1972, local authorities are required by law to publish meeting agendas, minutes and connected reports and this proved a valuable source of data on SGL and other LZC heat projects [162]. Unsuccessful attempts were made to source financial data direct from private developers and other social landlords. This introduced a potential skewing of data towards public sector and social landlord schemes. Whilst efforts were made to cross-validate figures and ensure consistency in definitions of "installed cost," variations in reporting standards across sources could not be fully controlled. Lifecycle and operational costs were not included due to inconsistent availability. Costs were normalised on a per-dwelling basis and categorised by retrofit or new build status but were not adjusted for inflation or regional variation.

Second, the sampling approach for cost comparison was purposive rather than random, with equal representation across three technology types (SGLs, individual heat pumps, and heat networks). Whilst this enabled comparative analysis, it may not reflect the actual distribution of technologies in the UK market. Projects varied in scale, location, and context, and while these factors were documented and qualitatively assessed, no formal sensitivity analysis was conducted. Descriptive statistics (mean, range, standard deviation) were calculated using parametric methods to highlight indicative patterns, not to support inferential claims.

Third, the stakeholder workshop was designed to capture a cross-section of perspectives from industry, policy, and local implementation. Whilst efforts were made to ensure balance across sectors and geographies, some groups such as private developers and consumer advocacy organisations were underrepresented. This may have limited the diversity of viewpoints captured.

Finally, the focus on Leeds as a case study city was based on its representativeness as a medium-to-large UK urban area and the availability of detailed geospatial data through established relationships with local stakeholders. Whilst this enabled deeper analysis, findings from Leeds may not be directly transferable to other cities with different governance structures, housing stock, or energy infrastructure. Time and resource restrictions limited the depth of analysis in some areas. For example, the spatial analysis of SGL deployment in a UK city system would have ideally incorporated key socio-economic or infrastructural data such as population density, income levels, and building age. Such analysis would help to deepen understanding of socio-technical factors driving SGL deployment patterns.

Taken together, these limitations reflect the challenges of researching an emerging and under-documented technology. Nonetheless, the study contributes valuable insights to the growing evidence base on SGL deployment and highlights areas for future research and policy development.

4.8. Further research

Given the emphasis identified in the study of the potential for utility-style business models to support greater SGL deployment, there is a need for social research into public perceptions of shifting to this combination and whether the utility-style model would facilitate greater adoption. The political and media disclosure has tended to portray UK households as deeply committed to individual gas boilers [163,164], as well as negative headlines around heat networks which offer poor performance or high costs to users [165,166]. To support the investment case for utility investors, there is value in a greater understanding of public attitudes into SGLs through a utility approach including how prevailing narratives may impact household decision-making.

Building on the work of Nesta and others, this study proposes a local coordinated switching approach to cluster future users and support the investment case for SGL developers. With little evidence to suggest widespread policymaker support, additional research with innovative local operators and stakeholders could explore how this could be achieved at a local level with minimal reliance on state intervention.

Current research activity on SGLs is highly UK-focused, as evidenced by the rapid evidence assessment findings. However, many countries including The Netherlands, Italy and the US are similarly gas-dependent for heating and must also rapidly scale up net zero compatible heating [1,167]. There are signs of increased awareness of SGLs internationally, such as a scheme at Framingham in Massachusetts, USA which has garnered recent attention [168]. To support the required rapid heat transition, research is needed into the conditions shaping local deployment of SGLs across these countries and beyond.

Building on study limitation noted in Section 4.5, further spatial analysis of system deployment would help to reveal the socio-technical factors driving SGL deployment patterns, such as potential correlations between low-income communities and SGL deployment density.

5. Conclusion

Most UK homes continue to rely on natural gas to supply their heating and hot water and this is incompatible with reaching net zero carbon by 2050. Shared ground loops (SGLs) with their combination of distributed heat pumps, low temperature heat network and shared ground array have potential to support decarbonisation of UK homes. Deployment is currently concentrated in settings like terraced houses and tower blocks that often lack the outdoor space required for individual heat pumps. They are also especially suitable outside of areas where heat networks will be the preferred solutions, as designated by forthcoming Heat Network Zoning.

However, deployment is held back by a range of factors.

- Current deployment in the UK is primarily limited to settings where a single decision-maker such as a social landlord takes the decision to invest in SGLs, often to tackle social as well as economic and carbon reduction needs. The challenge of mixed-tenure settings where there is no single decision-maker remains a major hurdle, to which a utility business model approach may hold the key to unlock more widespread deployment.
- Heat decarbonisation policy in the UK has to date focused on individual heat pumps and heat networks, with a lack of dedicated strategic and funding support for SGL deployment. At a local level, local authorities have the power to support SGL deployment through the planning system which can encourage developers to choose SGLs technology in new homes, and this would deliver an overall benefit to SGL market and technology development.
- SGLs are currently deployed at higher cost than either individual heat pumps or heat networks on a per-home basis. However,

considering only retrofit settings, SGLs demonstrated a lower cost. A wide range of complicating factors make a simple comparison very difficult, and the analysis did not factor in wider system efficiency and flexibility savings. High costs emphasise the need for overall market development, supplier diversification and increased levels of competition to support cost reductions.

Three policy areas could support deployment of SGLs and hence flexibility in the transition to a fully electrified heat system. At a national policy level there are opportunities to recognise SGLs and their suitability for mid-scale, medium-density settings, especially in areas outside future Heat Network Zones. The policy lever here need not be based around dedicated funding but could, for example, be enacted through clear recognition of the system-wide benefits of SGLs in flexibility markets. This would provide an additional revenue stream to developers and support development of utility business models. At a local level, local authorities can support SGL deployment by recognising them in local planning policy. This includes the need to take a strategic and collective approach to what works for the local area, for communities, and for the wider energy system. A street-by-street approach to coordinated switching may help unlock feasibility of no-cost offerings to households. Finally, there are key developer-level innovations in the need for development and iteration of utility-style business models and installation approaches which can offer SGLs to households of all tenure types especially in retrofit settings. Taken together with likely learning curve rates, wider technology adoption and additional providers in the market, SGLs could become cost comparable with other LZC technologies.

Credit author statement

David G. Barns: Conceptualization (equal), data curation (lead), formal analysis (lead), funding acquisition (supporting), investigation (lead), methodology (equal), writing– original draft (lead), writing – review and editing (lead); project administration (lead), visualization (equal). Catherine S. E. Bale: Conceptualization (equal), funding acquisition (lead), formal analysis (supporting), methodology (equal), writing– original draft (supporting), writing – review and editing (supporting); Joshua L. Turner: Data curation (supporting), formal analysis (supporting), investigation (supporting), writing– original draft (supporting), writing – review and editing (supporting); Fleur Loveridge: Conceptualization (supporting), formal analysis (supporting), writing– original draft (supporting), writing – review and editing (supporting). Simon Rees: Conceptualization (supporting), formal analysis (supporting), writing– original draft (supporting), writing – review and editing (supporting). Martin Fletcher: Formal analysis (supporting), investigation (supporting), writing– original draft (supporting), writing – review and editing (supporting).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2025.116490.

Data availability

Data shared via supplementary materials and DOI

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