

Technological Innovations and Climate Change: Geothermal Technologies

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Organisation: British Geological Survey

Introduction

Summary of organisation / expertise

The British Geological Survey (BGS) is a world leading applied geoscience research centre, which provides objective and authoritative geoscientific data, information, and knowledge to inform UK Government and other stakeholders on the opportunities and challenges of the subsurface environment.

BGS has been undertaking research on the UK geothermal potential since the 1970s, including the delivery of multimillion-pound UK Geothermal Energy Programme (1977–1984) (Downing & Gray, 1986) and the UK Hot Dry Rock R&D programme (1977-1991) (MacDonald et al., 1992). The programmes were funded by the UK government and European Commission. These assessments and recent BGS research (Busby, 2010, 2014; Busby & Terrington, 2017; Pharaoh et al. 2021) on geothermal targets present the most comprehensive collection of data and knowledge on deep geothermal resources in the UK, including new estimates of reserves that had not been assessed during these earlier studies.

BGS has also received £31 million of funding to build field infrastructure and research facilities for geothermal energy – the UK Geoenergy Observatories (<https://www.ukgeos.ac.uk/>). Each observatory delivers a different body of knowledge relating to different geothermal systems including ground source heat pump systems and thermal energy storage (UKGEOS Cheshire), mine water geothermal (UKGEOS Glasgow) and integrated urban geothermal systems (Cardiff).

We work closely with stakeholders from government, industry and regulation in the UK and internationally to identify and advise on policy and regulation necessary to progress geothermal energy developments in the UK (1922 BEIS Backbench Committee, 2022). Our outputs include science briefing papers and reports (Abesser et al., 2018; Abesser et al., 2020), as well as a POST brief on Geothermal Energy which a member of staff developed during her academic fellowship at the Parliamentary Office for Science & Technology (POST) (Abesser & Walker, 2022).

References:

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In Part 1 of this document provides summary responses to questions 1,2,3,4,5,7,8. Part 2 provides more detailed responses to these questions with references to give further context.

In our responses, we draw on the terminology and definitions in the POST brief 46 (Abesser & Walker, 2022). Key terms include:

- Deep geothermal in the UK is focussed in: 1) deep sedimentary basins (warm water in aquifers, to about 80°C), (2) in heat-producing granites which have higher geothermal gradients (hot water in fractures [to c. 190°C at 5 km deep]), elevated geothermal gradients give higher temperatures nearer the surface and hence drilling is easier and less expensive).
- Mine water geothermal are (typically) shallow geothermal systems (some mines are deeper than 500m) that use the energy (10–25°C) stored in flooded mines for heating and cooling applications or for thermal energy storage.
- Shallow geothermal refers to the low-temperature heat resource (10–25°C) that is stored in the shallow subsurface (tens of metres to around 500 m beneath the surface) and typically exploited through ground source heat pump (GSHP) systems
- Underground thermal energy storage (UTES): system in which hot water is pumped into underground boreholes, aquifers or caverns for the temporary storage of thermal energy
- Unconventional technologies exploit settings where there is heat (hot rock), but no water that could be used to extract the heat.

Part 1: Summary responses

We see the main role for geothermal technologies in the UK in supporting the decarbonisation of heating and cooling in buildings and in agriculture/ industry sectors as well as for some power production.

The geothermal resources to support this role are distributed across the UK. They include deep sedimentary aquifers, radiothermal granites as well as mine water systems and heat stored in the shallow subsurface.

In terms of technologies, we see an important role for conventional geothermal doublets, e.g. to exploit deep geothermal resources in sedimentary basins, in addition to enhanced geothermal systems (EGS) as well as for ground source heat pumps (GSHP) to exploit low grade heat in the ground and shallow aquifers, including mine geothermal systems. (Note: In our responses, we consider all the above-mentioned technologies, drawing out technology-specific aspects where necessary and relevant to the question.)

We also see an important role for other technologies, specifically for Underground Thermal Energy Storage (UTES) systems which use the ground/ aquifers/ mine water systems for storing and recovering excess heat/cold from other sources, including renewables (like solar thermal) or industry.

Furthermore, we anticipate that some unconventional technologies will mature in the next decade or so, providing access to resources that currently cannot be exploited cost effectively. In conjunction with improvements in drilling technologies and cost, we anticipate that more of the deep, hot subsurface will become accessible for exploitation and as a result deep geothermal opportunities are likely to grow to include all parts of the UK.

Question 1: What role can geothermal technologies take in the transition to net zero in the UK?

The main role of geothermal technologies in the transition to net zero in the UK are:

- 1) decarbonisation of heating/cooling of buildings (especially in new builds, off grid areas, via heat networks) as well as for use in agricultural processes.
- 2) some power production where geothermal gradients are high enough, initially feeding power to the national grid at locations distal from major power sources. In addition to power, these systems can also provide heat for purposes outlined above.

In countries with similar geology and geothermal potential to the UK, geothermal technologies are contributing to significant CO₂ savings. In Germany, for example, geothermal technologies saved 3.5 million tonnes of CO₂ equivalent in 2021. The geothermal industry also provided €14.9 billion since 2000 and created 24,500 jobs (Abesser & Walker 2022). In the Netherlands, the use of geothermal energy saved 176 million cubic meters of natural gas in 2019, which is equivalent to a CO₂ reduction of 333,000 tons (ThinkGeoenergy, 2021a).

Question 2: What barriers (technological, regulatory, or otherwise) are there to deploying operational geothermal technologies in the UK?

Through its research and extensive stakeholder engagement, BGS has identified several common themes in relation to barriers to deployment of geothermal technologies in the UK:

- 1) Shortage of demonstration projects that prove the resource and determine the economic case in different UK geological settings.
- 2) Absence of geothermal technologies in UK energy policy and renewable targets.
- 3) Insufficient incentives and financial support mechanisms/ risk sharing schemes for geothermal projects.
- 4) Lack of tools, open access data and data sharing obligations that enable the industry to identify best locations for geothermal installations.
- 5) Absence of recognition of geothermal energy as a natural resource in UK legal and regulatory framework.
- 6) Lack of awareness and data relating to geothermal project cost and risk profiles.
- 7) For deep systems, lower-cost drilling technology, plus also technology optimised for drilling hard crystalline rocks.

8) Low numbers of district heat networks.

Other themes that are not currently holding back development but need consideration as the industry develops, include:

9) Approaches to social engagement and acceptance.

10) Improved understanding of cumulative environmental impacts and requirements for monitoring.

11) Updating of the regulatory framework to better accommodate geothermal operations.

Question 3: What is the scale of the potential market for geothermal energy sources and which geographic or other geological types are most suitable for exploitation of this natural resource?

Geothermal resources are distributed across all of the UK. District heating networks and agriculture use could provide a UK-wide potential market for geothermal heat. Shallow geothermal systems/ heat networks can be developed in most geological settings, but specifically where shallow, highly productive aquifers are present. Potential for mine geothermal exists in areas of coal fields while opportunities for geothermal district heating (without GSHP) exist in a number of deep sedimentary basins.

Potential for power generation is currently limited to radiothermal granites but drilling innovation and reduction in drilling costs as well as the development of unconventional technologies has potential to unlock geothermal resources that currently cannot be exploited cost effectively. This will make deep geothermal for heat and power assessable in many parts of the country.

Question 4: Are current government support schemes sufficient to grow geothermal energy deployment in the U.K.?

As highlighted in response to question 2 (see also point 3 in extended answer to Q2), government support schemes are likely to be insufficient to grow geothermal energy deployment in the UK. While support is available for small GSHPs and heat networks, there is currently no government support for geothermal heat projects > 45kW, and geothermal is unlikely to be able to win subsidy for geothermal electricity generation under Contracts for Difference (CfD) because of direct competition with more advanced technologies like Offshore Wind and ACT.

In addition, there are no risk sharing mechanism available for geothermal energy projects. Geothermal risk mitigation schemes are used in France, Netherlands, Switzerland and Poland to attract private capital by de-risking geothermal drilling and construction. Such schemes are considered the key mechanisms for addressing pre-development risks in geothermal during early market development stage (Dumas, 2019; Boissavy, 2022) and could provide valuable support for the geothermal industry in the UK.

Question 5: What environmental concerns are associated with geothermal technologies, and are they appropriately accounted for in regulations?

Development and exploration of geothermal energy systems can have minor environmental impacts on subsurface temperatures and groundwater quality. They may also be associated with the emission of some greenhouse gases, indirectly through using non-renewable electricity for the operation of heat pumps or directly through releasing gases contained in deep geothermal fluids. Geothermal schemes, if not executed optimally, can also carry some

drilling and operational risks, including induced seismicity although these would typically be of very low magnitude.

Activities are controlled under existing regulations developed for petroleum exploration, water resource use and protection, and planning. As a result, responsibilities and interests for geothermal regulation are split between different authorities including local planning authorities, environmental regulators, Coal Authority and Health and Safety Executive (for deep drilling). While individual regulatory frameworks are well-established, environmental impacts are not accounted for holistically by a single regulatory framework, and there is no standard requirements for ongoing monitoring of operational systems and feeding back data to regulators, hence cumulative impact of systems are unknown. In addition, there is no system for licensing, ownership and management of geothermal resource (abstraction/ injection of heat) itself.

While regulators and industry regard existing regulations as sufficient at the current low levels of system deployment, a review of regulations will be needed as numbers increase. Cumulative environmental impacts of shallow geothermal system deployment need to be investigated and understood in more detail, especially in dense urban settings and mine water environments, and regulation updated accordingly to (1) protect the environment from pollution and (2) enable better management of the resource. Experience with regulation of deep geothermal systems is limited in the UK. Stakeholder feedback suggests future reviews should consider (3) a licencing regime for larger projects and (4) ensure that regulation is proportional to the anticipated risks and applied consistently across the energy sector.

Question 7: How does the density of mine water systems affect their efficiency? Could widespread uptake of geothermal systems in dense population centres lead to a reduction in their ability to provide heat?

Widespread use of GSHP systems in densely populated areas can lead to risk of thermal interference (see also response to Question 5). A heightened risk of “thermal interferences” has been identified in central London where many GSHP schemes are within 250–500 m of each other, where interactions of adjacent GSHPs are increasingly of concern as more systems are being installed (Environment Agency, 2018; Fry, 2009). Recently there have been reports of suspected interference (Herbert et al. 2013; unpublished PhD thesis 2022), but these could not be proven because locations of GSHPs and/or their thermal loads to the subsurface are not recorded.

Interference risks can be mitigated by managing the deployment (locations, thermal loads, operational strategies) of such systems. At minimum, this requires recording locations of GSHP systems (above a certain size), including their thermal loads, management and monitoring of the system and their operations and reporting back to the regulator.

There is potential for multiple mine water schemes in densely populated coalfield areas. Depending on the size/flow rates/temperature drop of each scheme, the depth utilised, the spacing, the local

geology and hydrogeology there is a possibility of heat depletion and interactions between schemes that could reduce efficiency if not managed, and cause challenges for scheme operators.

Conversely, there is a huge opportunity for integrated heating/cooling/thermal storage using the mine systems (as well as the urban subsurface) for example to store heat in summer months and use heat in winter months. Using the mines as a heat source and store within a heat network has been successfully demonstrated at Heerlen, Netherlands (<https://mijnwater.com/en/> and Verhoeven et al. 2014). The 'geobattery' concept describes using mine workings for thermal storage and transport (Fraser-Harris et al. 2022).

Understanding the capacity for multiple mine water heating/cooling/storage schemes is an area where further data, evidence and research is needed on heat and flow processes in rock and water, plus monitoring of at-scale systems, for example using the advanced sensing and monitoring capabilities of the UK Geoenergy Observatory in Glasgow (ukgeos.ac.uk).

Question 8: What economic impact could the deployment of mine water geothermal systems have on the areas in which they are deployed?

Former coal mining areas in central and northern England, south Wales and central Scotland commonly suffer from the loss of heavy industries with associated deprivation and fuel poverty. Mine water heat has the potential to help drive levelling up in such priority areas (BEIS 1922 Committee). Data on economic impacts is limited, however NELEP (2021) estimated that if 42 projects that were under consideration by the Coal Authority were implemented this would deliver 4500 direct jobs and 9-11,000 in the supply chain.

Part 2: Extended responses

Question 1: What role can geothermal technologies take in the transition to net zero in the UK?

Summary:

The main role of geothermal technologies in the transition to net zero in the UK are:

- 1) decarbonisation of heating/cooling of buildings (especially in new builds, off grid areas, via heat networks) as well as for use in agricultural processes.
- 2) power production where geothermal gradients are high enough, initially feeding power to the national grid at locations distal from major power sources. In addition to power, these systems can also provide heat for purposes outlined above.

In countries with similar geology and geothermal potential to the UK, geothermal technologies are contributing to significant CO₂ savings. In Germany, for example, geothermal technologies saved 3.5 million tonnes of CO₂ equivalent in 2021. The geothermal industry also provided €14.9 billion since 2000 and created 24,500 jobs (Abesser & Walker 2022). In the Netherlands, the use of geothermal energy saved 176 million cubic meters of natural gas in 2019, which is equivalent to a CO₂ reduction of 333,000 tons (ThinkGeoenergy, 2021a).

Further details:

Shallow geothermal

Ground source heat pumps can deliver heat to individual buildings as well to heat networks that supply multiple properties. Deployment is most effective when GSHP heat source is considered in the building design and GSHP installation incorporated in the build phase. However, ground source heat pumps have successfully been retrofitted to existing properties, including individual houses, office buildings, blocks of flats as individual installation or as part of small heat networks (Kensa, 2022).

Mine water geothermal has access to very high volumes of water in disused mine systems which makes them ideal for operating large-scale open-loop GSHP systems, for example to provide heating and cooling to a few hundreds of homes via heat networks (Example Heerlen-see 1922 BEIS backbench committee report), or for low-temperature industrial or agricultural use (see Lanchester Wines case study). The first heat network using a mine water source is currently under construction in Gateshead (see 1922 BEIS backbench committee report). The network has the capacity to supply the energy needs of the equivalent of 5,000 homes (<https://www.gateshead.gov.uk/article/21170/From-the-industrial-revolution-to-a-green-revolution>).

Deep geothermal systems access deep, hot aquifers / hot rocks that can supply heat directly to large-scale district heating networks.

Paris supplies geothermal heating from its deep geothermal aquifer to around 250,000 homes via 50 heat networks. Munich supplies around 50,000 homes with geothermal heating, saving about 75,400 tonnes of CO₂ per year compared with gas (see further details in Abesser & Walker, 2022). In terms of heat-related use in the UK:

- A deep geothermal borehole (1.7 km) that can deliver geothermal water (at 76 °C) to the Southampton District Energy Scheme (SDES).
- A 4.5 km deep borehole (second deepest onshore UK) has been drilled close to the Eden Project, and work is underway to connect it to the heating system of the Eden biomes.
- Another deep geothermal well is planned at Stoke-on-Trent to supply low-carbon heat to the UK's first at-scale, deep geothermal heat network in the Etruria Valley.

In terms of power production in the UK:

- A 5 km deep production borehole (deepest onshore UK) and a 2.5 km deep injection borehole have been drilled near Redruth, Cornwall, as part of the United Downs Deep Geothermal Power project. This is an at-scale demonstration project with power plant construction expected to start shortly, and export of power to the grid is expected by the end of 2023.
- A second deep borehole is planned close to the Eden Project, and when run as a re-circulating system with the existing borehole will also be used for power production.
- Planning applications are being considered for 4 more sites in Cornwall for deep drilling and associated powerplants.

In addition to heating of buildings, geothermal energy can reduce CO₂ emissions of a wide range of agricultural and horticulture applications (IRENA, 2022). In the Netherlands, geothermal heating of greenhouses is seen as one of the key factors for the 30% reduction in CO₂ emissions in the greenhouse sector between 2010 and 2014 (ThinkGeothermal, 2015), with individual operators reporting CO₂ savings of up to 9,000 tonnes /year (ThinkGeoenergy, 2021b). Geothermal water is also being used to heat water at fish farms in Iceland and Kenya, in order to maximise growth rates of tilapia (a tropical fish that needs warm conditions).

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Question 2: What barriers (technological, regulatory, or otherwise) are there to deploying operational geothermal technologies in the UK?

Summary:

Through its research and extensive stakeholder engagement, BGS has identified several common themes in relation to barriers to deployment of geothermal technologies in the UK:

- 1) Shortage of demonstration projects that prove the resource and determine the economic case in different UK geological settings.
- 2) Absence of geothermal technologies in UK energy policy and renewable targets.
- 3) Insufficient incentives and financial support mechanisms/ risk sharing schemes for geothermal projects.
- 4) Lack of tools, open access data and data sharing obligations that enable the industry to identify best locations for geothermal installations.
- 5) Absence of recognition of geothermal energy as a natural resource in UK legal and regulatory framework.
- 6) Lack of awareness and data relating to geothermal project cost and risk profiles.
- 7) For deep systems, lower-cost drilling technology, plus also technology optimised for drilling hard crystalline rocks.
- 8) Low numbers of district heat networks.

Other themes that are not currently holding back development but need consideration as the industry develops, include:

- 9) Approaches to social engagement and acceptance.
- 10) Improved understanding of cumulative environmental impacts and requirements for monitoring.
- 11) Updating of the regulatory framework to better accommodate geothermal operations.

Further details:

1) Shortage of demonstration projects that prove the resource and determine the economic case in different UK geological settings

Geothermal technologies are mature and have been used for many decades in different geological settings across Europe and worldwide. While their component parts are well understood, the interaction between technology and geological setting varies from location to location. Understanding this interaction is key to project success as it influences the different project stages, determining for example the duration and success of the drilling process (i.e., costs) as well as the ability to produce heat and/or power at the anticipated rate and scale (i.e., project feasibility). Pilot projects that demonstrate the entire project life cycle from exploration via drilling / installation to operation are one of the main tools for de-risking this process. They are of particular importance for nascent industries and in areas that have not previously been exploited, providing valuable data relating to the geology and resources, informing drilling and operational strategies as well as demonstrating the economic case. The latter is particularly relevant for expensive projects such as deep geothermal or mine water geothermal scheme – to inform financial risk profile and estimate payback periods / returns on investments. While some research and projects are ongoing, developments are slow and not at the scale required to build market confidence.

2) Absence of geothermal technologies in UK energy policy and renewable targets

Geothermal energy is generally absent from policy documents and renewable targets. While ground source heat pumps/ shallow geothermal heat networks are considered in the Sixth Carbon Budget (CB6), deep geothermal heat or power generation were not included. Recognition has improved in the last year and more recently, the 2050 Pathway Review and the Heat and Buildings Strategy identify geothermal district heating as an area that needs further research in the UK. Geothermal energy also received one mention in the UK Energy security strategy – but not in the proposed Energy Bill. However, none of these policy documents defines a clear role for geothermal in the energy transition or identifies clear targets for developing geothermal technologies as part of the UK decarbonisation and net zero efforts.

3) Insufficient incentives and financial support mechanisms for geothermal projects

Compared to other renewables, there is also a lack of stable, long-term policies and incentives in the UK that support the development of geothermal technologies. Support mechanisms in the form of grants, feed-in tariffs and risk sharing agreements/ insurance schemes, are especially important during early stages of market development and for technologies that are perceived by investors as high risk.

Offshore wind in the UK, for example, has moved in the last 10-15 years from being perceived as a risky investment to a favourite for pension funds and other investors who need to be assured of long-term sustainability and returns. This journey was enabled by a combination of coordinated government support including policy and creation of finance mechanisms (from the carbon budgets in the Climate Change Act to Contracts for Difference and the formation of the Green Investment Bank) and strong support for research and collaboration, including demonstrator projects (such as the

Carbon Trust's Offshore Wind Accelerator and the formation of the Offshore Renewable Energy Catapult) (Brown, 2018).

Such support is not available for geothermal energy: the principal mechanism to support domestic and non-domestic geothermal heat installations, the Renewable Heat Incentives (RHI), is now closed for new applications and there are concerns that geothermal electricity cannot access the main subsidy for large-scale renewable projects. Contracts for Difference (CfD), because geothermal cannot compete on price with more developed technologies like Offshore Wind or with Advanced Conversion Technologies (ACT).

For domestic installations and schemes <45 kW, the RHI has now been replaced by an upfront grant scheme (the Boiler Upgrade Scheme (BUS)) that offers capital grants for air source heat pumps (ASHPs), biomass boilers and GSHPs. While the simplified approach of changing from a tariff to an upfront grant is generally welcome, the scale of the funding (£450 million over three years) is widely seen as insufficient to assure industry and consumers and too low to achieve the Government's targets of 600,000 heat pump installation per year by 2028. Only 30,000 homes per year would be able to benefit from BUS - the same as current installation levels. Furthermore, the grant covers less than 50% of the capital costs of a typical GSHP, excluding additional costs for heat distribution systems, controls and ground works, making affordability a challenge for many homeowners.

There has been no replacement of the non-domestic RHI. This means that there are currently no government grants or incentives for large geothermal heat projects, such as large GSHP installations, mine water geothermal projects or deep geothermal heat projects >45 kW unless they are part of a heat network or a rural community project (see Abesser & Walker, 2022 p. 41 for details on available government support schemes).

Furthermore, drilling and construction account for up to 65% of the total project cost. These high upfront investment costs and the geological risk of not achieving the required temperatures or water flows present a major barrier to the development of deep geothermal heat and power projects and mine energy projects in the UK. Risk insurance that covers the risk of not achieving the required flow rates or temperatures or longevity of supply are considered essential during early stages of geothermal market development (Boissavy, 2022; Dumas et al., 2019).

4) Lack of tools, open access data and data sharing obligations that support identification of best locations for geothermal installations

To develop geothermal resources, geoscientists need a reliable understanding of the subsurface. They drill boreholes to characterise the composition of rocks at depth, to measure subsurface temperatures, and to sample the chemistry of groundwater in aquifers. They also use geophysical methods, including magnetic surveying and seismic imaging, to reveal the three-dimensional subsurface structures and to track the movement of fluids.

Acquiring these datasets is costly, and such cost can often not be justified during the initial development of technologies with unproven economic returns. Where available, projects therefore make use of existing datasets. Data sets are available in the UK, held in private and public data collections of the extractive and construction industries. However, data access restrictions and inconsistencies in data formats mean that the data are not readily available for research (Dickinson & Ireland, 2022) or use by industry – e.g. to identify where opportunities exist for geothermal developments.

The success of the geothermal developments in other countries has closely been linked to the availability of government-funded online tools/ Map Viewers that highlight where favourable conditions exist for the exploitation of geothermal heat or electricity generation.

Examples of such tools include the

- **Bavarian Geothermal Atlas (Germany)** which was developed by the Bavarian Geological Survey (funded by the Bavarian State) to show where favourable conditions exist for the exploitation of geothermal heat or electricity generation, including detailed maps of depths, thickness and temperatures of the resource
- **ThermoGIS – Netherlands** (<https://www.thermogis.nl/en>) - ThermoGIS is a public, web-based geographical information system with the main goal of supporting companies and the government to develop geothermal energy in the Netherlands. Created by the Dutch geological survey (TNO) (funding by the Dutch Government) based on available subsurface data and its broad knowledge of the Dutch subsurface.
- **Deep geothermal Energy portal – Denmark** (<https://eng.geus.dk/products-services-facilities/data-and-maps/deep-geothermal-energy-portal>) is an online tool provided by the Danish Geological Survey (GEUS). It compiles knowledge of geothermal energy to enable stakeholders in the geothermal energy industry and the authorities to understand the characteristics of the subsurface, the geological uncertainties as well as the density and quality of the geological data about the Danish land and coastal areas.

In various countries, including Germany, The Netherlands and Denmark, data sharing obligations for subsurface data exists which mean that the best possible data is available for consideration in such tools and that these tools can be updated and maintained when new data sets become available. In Denmark, for example, state -issued licences for geothermal resources include an obligation for all data that are acquired during exploration and drilling, including seismic data, samples and cores, to be sent to the national geological survey (GEUS). Information is kept confidential for the first five years but then become publicly available to support geothermal exploration of the area.

Similarly, the German government has recently (June 2020) passed a new law for geological data (Geologiedatengesetz (GeolDG)) that regulates the national recording, transmission, safekeeping and provision of geological data through their national Geological Survey (BGR) (BGR, 2022).

Such arrangements exist for some industries in the UK, but not for geothermal energy projects including deep, shallow or mine energy. This means that geological data and subsurface knowledge relating to these technologies remains fragmented as data are kept by individual project owners.

In addition to data access, BGS has also identified a lack of sub-regional scale data specific to geothermal resource. For example, BGS might have a basin-wide study and a single deep borehole 100km or more from the site is interest. This data resolution is insufficient for a potential operator who wants to develop a single site. Higher-resolution studies by the BGS would bridge this gap – i.e., by targeting specific areas (e.g. Eastern part of the Cheshire Basin, or granites of SW England) where there is geothermal interest but where the area is too big for site operators to investigate.

5) Absence of recognition of geothermal energy as a natural resource in UK legal and unclear regulatory framework

Geothermal energy is not recognised by law as a natural resource in the UK (like water or gas). As a result, there are no clear rules defining ownership, regulation or management of the geothermal resource. This means that there is currently no regime or regulatory mechanism (like a licensing

regime) in the UK for balancing the interests of different users of a particular heat reserve or preventing unsustainable extraction of heat (Abesser et al., 2018).

Regulation

Activities are controlled under existing regulations developed for petroleum exploration or water resource use and protection, and as part of the planning process. At current levels of deployment, this approach is generally regarded by regulators and industry as being adequate for managing potential environmental and operational impacts – although there is a perception that rules for deep geothermal energy are less stringent than for other extractive industries, and that rules are implemented differently by different local authorities and/or for different geothermal technologies. Developing a consistent set of rules and clear guidance for the regulation of geothermal energy will be important going forward to enable upscaling of industry while maintaining public support for the technology.

Also, in areas of high deployment of shallow geothermal systems (e.g. in London), evidence of interference between geothermal systems is starting to emerge – e.g. observed as an increase in abstraction temperatures that cannot be explained by operation of the GSHP system. This highlights that changes may be needed of how geothermal energy use is managed and how geothermal systems are regulated and monitored (see also response to question 4). For example, closed-loop systems in the UK currently do not require any environmental licencing or registration irrespective of the size of heat load that they abstract from or re-inject to the subsurface.

The Environment Agency (through Defra – DEFRA, 2021) has recently consulted on amendments to the Environmental Permitting (England and Wales), including regulatory controls for heat pollution and a requirement for closed-loop GSHPs to comply with the Ground Source Heat Pump Association (GSHPA) standards under the General Binding Rules (GBR). While the amendment will not address the issue of managing the thermal resource itself, they would enable the EA to regulate heat pollution from groundwater activities and potentially also to register large scale-closed loop systems. The utility of the amendments will depend on how they are implemented, specifically how environmental thresholds and the GBRs are defined.

Licensing

The lack of licencing procedures and leading authority for deep geothermal exploration and operations in the UK has been mentioned by stakeholders as a barrier to some investors who like to see use of the resource guaranteed for the lifetime of their planned geothermal operations. In addition to guaranteeing use of the resource to operators, licencing has also been used in other countries to ensure the delivery of joined benefits to local communities and shared value creation as well as to ensure data sharing. In Denmark, for example, the planning systems requires that operators create local benefits (education, sports facilities, etc.) alongside their developments. Furthermore, the state-issued licences geothermal resources include an obligation for all data that are acquired during exploration and drilling, including seismic data, samples and cores, to be sent to the national geological survey (GEUS). Information is kept confidential for the first five years but then become publicly available to support geothermal exploration of the area. A similar process exists for UK offshore hydrocarbon developments. This process of licencing can also more effectively manage and maximise the available resource than a first-come, first-served user driven approach.

6) Lack of technology awareness and data relating to geothermal project cost and risk profiles.

There is little knowledge of costs and risks related to the installation of mine water and deep geothermal systems as there is no obligation to report or share such data. While geothermal systems are limited in the UK, learning from other industries, and sharing of knowledge and data from existing projects or similar operations (e.g. from deep drilling for onshore oil and gas) could support modelling of financial risks and of the economic case related to the installation of geothermal systems. The absence of reliable data has been quoted as the reason for why deep geothermal is not included in the UK energy policy and underpinning models – such as the CB6 (see also point 2 in this section). As a result, awareness of the contribution that geothermal technologies could make to the UK energy transition remains low amongst policy makers and planners.

7) For deep systems, lower-cost drilling technology, plus also technology optimised for drilling hard crystalline rocks

Drilling and testing of boreholes makes up 65-70 % of the overall project costs of a geothermal project (Arup, 2021). High costs of drilling present a barrier to industry. Most of the costs come from deployment and daily charges for the drilling rig and specialist crew. Drilling in hard crystalline rock (like the Granite in Cornwall) generally takes longer than drilling in softer rock. Innovations to optimise drilling and reduce drilling costs is a priority for developers and investors to make deep geothermal resources more accessible and heat or power heat or power production from depths more than 4–5 km more cost-efficient.

8) Low numbers of district heat networks

Compared to other countries that use geothermal successfully, the UK has only got a small numbers of district heat networks. Although the UK's Climate Change Committee (CCC) predicts that around 20% of UK heat will need to come from heat networks by 2050, the UK currently still only has 2,000 district heating schemes. Widespread utilisation of geothermal resources will require investment in heating infrastructure for district heating, as part of new housing projects as well as retrofitted to existing housing stock. Linked to that, legislation is needed in England and Wales to give statutory rights to heat networks for accessing private land for construction or maintenance as well as to regulate heat networks (Abesser & Walker, 2022). A Heat Networks (Scotland) Act was passed in 2021 to accelerate the deployment of heat networks in Scotland through the introduction of a regulatory system aimed at boosting consumer confidence in the sector and providing greater certainty for investors.

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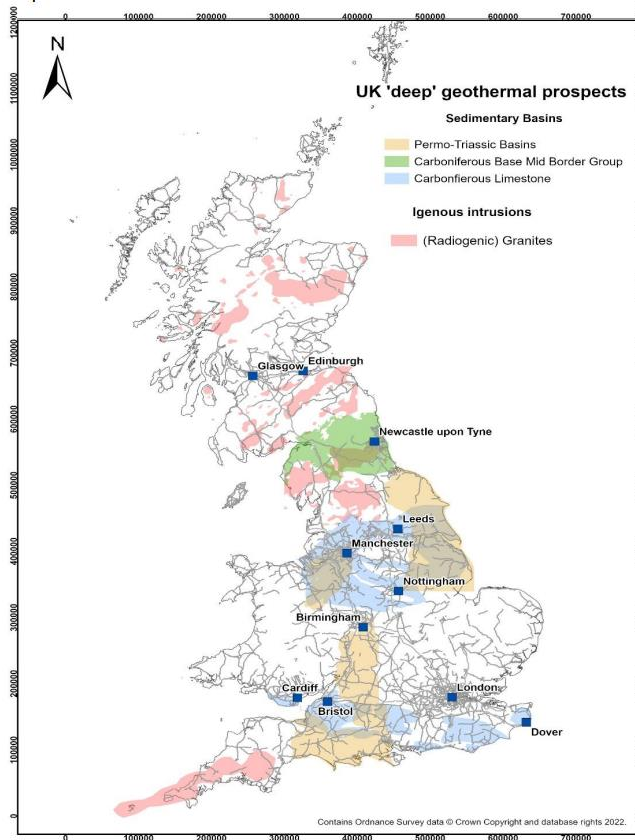
Question 3: What is the scale of the potential market for geothermal energy sources and which geographic or other geological types are most suitable for exploitation of this natural resource?

Summary:

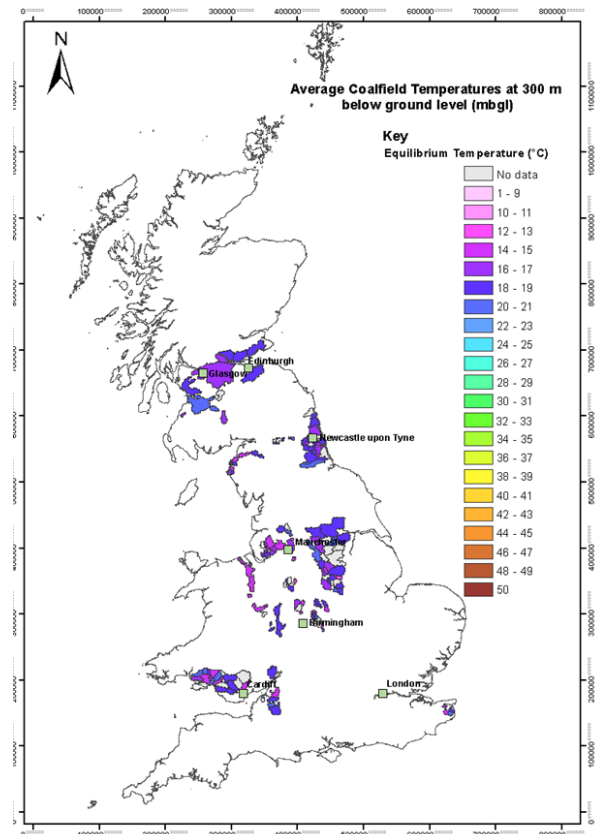
Geothermal resources are distributed across all of the UK (Map 1+2). District heating networks and agriculture use could provide a UK-wide potential market for geothermal heat. Shallow geothermal systems/ heat networks can be developed in most geological settings, but specifically where shallow, highly productive aquifers are present. Potential for mine geothermal exists in areas of coal fields

(Map 2) while opportunities for geothermal district heating (without GSHP) exist in a number of deep sedimentary basins (yellow, blue and green areas in Map 1).

Potential for power generation is currently limited to radiothermal granites (red areas in Map 1) but drilling innovation and reduction in drilling costs as well as the development of unconventional technologies has potential to unlock geothermal resources that currently cannot be exploited cost effectively. This will make deep geothermal for heat and power assessable in many parts of the country.



Map 1: Distribution of deep geothermal targets in Great Britain (© UKRI 2022)



Map 2: Extent of potential mine water resources in Great Britain illustrated using mine temperature map at 300m depth from Farr et al (2020)

Further details:

Shallow geothermal

The availability of different types of GSHP systems (closed-loop; open-loop; hybrid; mine water systems) and the flexible design options mean that deployment of shallow geothermal technologies is feasible almost anywhere in the UK.

Disused mine workings occur beneath many cities and towns and the interconnected galleries and shafts create a very large groundwater resource. The distribution of UK coal fields and temperatures at different depths illustrates the potential for mine water heat recovery schemes at different locations across GB (Farr et al, 2020). The coincidence of towns and cities, particularly areas of fuel

poverty and regeneration, with the mine water resource offers significant opportunity to match demand and resource.

Deep geothermal

Most of the UK's deep geothermal resources are found in deep onshore sedimentary basins which are widespread across the UK (map 1). The temperatures in these basins are estimated to be in the range of 40°C to over 60°C, and hence these systems are most suited to provide direct-use heating, including district heating. BGS has undertaken detailed mapping and investigation of this resource since the 1980 and estimates that the geothermal heat resource contained within these basins is one hundred to two hundred times (e.g. Busby, 2014) the UK's domestic heat demand. However, as heat currently cannot be transported over long distances (because of high distribution losses along the way), opportunities for developing geothermal heat are limited to areas of high heat demand, for example for domestic heating, horticulture or industry. Many major population centres in the UK lie above or adjacent to sedimentary basins (or hot sedimentary aquifers - HSAs) as shown in map 1 and table below:

Administrative Regions	Geothermal Resource	Main urban areas	Accessible Resource Base based on figures from Downing and Gray (1986) in EJ/km²
Aberdeenshire, Highlands, Cornwall, Cumbria, Northumberland	Radio thermal Granites	Aberdeen, Carlisle, Exeter, Plymouth	4.29 EJ/km ²
Northern England: Cheshire/Greater Manchester, Tyne and Wear, County Durham, Northumberland	Permo-Triassic Sandstone, Carboniferous Limestone, Carboniferous Fell Sandstone	Chester, Greater Manchester, Liverpool, Stoke-on-Trent, Durham, Newcastle, Sunderland	1.36 EJ/km ²
North Yorkshire, Humberside, Lincolnshire	Permo-Triassic Sandstone, Carboniferous Limestone	Hull, Lincoln	1.31 EJ/km ²
Northern Ireland	Permo-Triassic Sandstone	Antrim, Ballymena, Lisburn	1.17 EJ/km ²
Central Belt, Scotland	Devonian-Carboniferous Sandstone	Stirling, Edinburgh, Glasgow,	1.15 EJ/km ²
South Wales	Carboniferous Limestone, Devonian-Carboniferous Sandstone	Cardiff, Swansea	1.00 EJ/km ²
Worcestershire, Warwickshire, Gloucestershire, Oxfordshire	Permo-Triassic Sandstone	Birmingham, Gloucester, Worcester	0.98 EJ/km ²
Weald-Wessex Basin	Permo-Triassic Sandstone, Carboniferous Limestone	Bath, Bristol, Bournemouth, Southampton	1.09 EJ/km ²

The UK has great theoretical potential for geothermal power generation (Busby and Terrington 2017). However, commercial project development to date focuses on regions where temperatures in excess of 160 °C occur within the economic range of deep drilling, currently around 5 km depth. In the UK, these temperatures are only found at drillable depths of 5 km in areas of radiogenic granites whose distribution is shown in map 1.

Granites provide potential for direct use heat /power generation in Cornwall e.g. Penzance, N England e.g. Lake District and NE Scotland e.g. Cairngorms. The most prospective granite is found in Cornwall, in southwest England, where temperatures at 5 km depth can reach up to 200 °C. However, northern

England and central eastern Scotland also have potential, though less is known about subsurface conditions there. In areas like Cornwall, where temperatures are high enough for electricity generation, geothermal energy can be fed into and distributed via the national electricity grid. This can be especially important in areas where the grid is distal to major power stations, but the grid needs to be 'smart' enough to accept local power input (also an issue for solar and wind installations). The capital expenditure (CAPEX) for deep geothermal is heavily linked to drilling costs, and so even small improvements in drilling technology would be highly beneficial in (i.e., reduction of costs to a certain depth, or allowing drilling to higher temperatures). Large drilling rigs can reach depths of 7 km, and Busby and Terrington (2017) show that at this depth many areas of the UK reach temperatures of 200°C. There is, however, a lack of data on the fluid flow properties of rocks at this depth.

There are also a large number of boreholes across the UK that have been drilled for oil, gas, unconventional hydrocarbons, coal bed methane or other purposes. Some are exploration boreholes, whilst others were developed for production. A small number of these systems may be suitable for re-use for geothermal purposes (Watson et al. 2020) – provided there is a nearby consumer (e.g. horticulture or agriculture use). Re-using abandoned hydrocarbon wells for the production of geothermal heat and electricity could reduce costs of geothermal projects. Apart from economic and technical challenges, a number of regulative changes and legal challenges need to be addressed, including the relationship with the decommissioning regime and liability issues. Under current licencing arrangements, it is not possible to transfer from an oil and gas licences to geothermal use. Clearer assignment of responsibilities (authority responsibility for geothermal energy) and introduction of geothermal licencing regime may be needed to address this.

Furthermore, development of unconventional technologies has potential to unlock geothermal resources that currently cannot be exploited cost effectively. In conjunction with improvements in drilling technologies and reduction in cost, we anticipate that more of the deep, hot subsurface will become accessible for exploitation, and as a result deep geothermal opportunities are likely to grow to include all parts of the UK.

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Question 4: Are current government support schemes sufficient to grow geothermal energy deployment in the U.K.?

Summary:

As highlighted in response to question 2 (point 3), government support schemes are likely to be insufficient to grow geothermal energy deployment in the UK. While support is available for small

GSHPs and heat networks, there is currently no government support for geothermal heat projects > 45kW, and geothermal is unlikely to be able to win subsidy for geothermal electricity generation under Contracts for Difference (CfD) because of direct competition with more advanced technologies like Offshore Wind and ACT.

In addition, there are no risk sharing mechanism available for geothermal energy projects. Geothermal risk mitigation schemes are used in France, Netherlands, Switzerland and Poland to attract private capital by de-risking geothermal drilling and construction. Such schemes are considered the key mechanisms for addressing pre-development risks in geothermal during early market development stage (Dumas, 2019; Boissavy, 2022) and could provide valuable support for the geothermal industry in the UK.

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Question 5: What environmental concerns are associated with geothermal technologies, and are they appropriately accounted for in regulations?

Summary:

Development and exploration of geothermal energy systems can have minor environmental impacts on subsurface temperatures and groundwater quality. They may also be associated with the emission of some greenhouse gases, indirectly through using non-renewable electricity for the operation of heat pumps or directly through releasing gases contained in deep geothermal fluids. Geothermal schemes, if not executed optimally, can also carry some drilling and operational risks, including induced seismicity although these would typically be of very low magnitude.

Activities are controlled under existing regulations developed for petroleum exploration, water resource use and protection, and planning. As a result, responsibilities and interests for geothermal regulation are split between different authorities including local planning authorities, environmental regulators, Coal Authority and Health and Safety Executive (for deep drilling). While individual regulatory frameworks are well-established, environmental impacts are not accounted for holistically by a single regulatory framework, and there is also no standard requirements for ongoing monitoring of operational systems and feeding back data to regulators, hence cumulative impact of systems are

unknown. In addition, there is no system for licensing, ownership and management of geothermal resource (abstraction/ injection of heat) itself.

While regulators and industry regard existing regulations as sufficient at the current low levels of system deployment, a review of regulations will be needed as numbers increase. Cumulative environmental impacts of shallow geothermal system deployment need to be investigated and understood in more detail, especially in dense urban settings and mine water environments, and regulation updated accordingly to (1) protect the environment from pollution and (2) enable better management of the resource. Experience with regulation of deep geothermal systems is limited in the UK. Stakeholder feedback suggests future reviews should consider (3) a licensing regime for larger projects and (4) ensure that regulation is proportional to the anticipated risks and applied consistently across the energy sector.

Further details:

Environmental risks and impacts vary depending on technologies and are discussed separately in the following sections.

Shallow geothermal: The main environmental impact of ground source heat pump systems relates to their thermal footprint and the risk of thermal interference between different systems and other subsurface infrastructures. It is of main concern in areas of high systems density.

The heat transfer taking place between the GSHP and the subsurface during operation of a GSHP systems induces some changes to the subsurface temperatures around the scheme. Usually, these changes are assumed to lie within the range of 4 to 8 °C above/below the undisturbed subsurface temperature in the direct vicinity of the scheme, and this is consistent with monitoring undertaken by BGS of a small open-loop scheme in Cardiff (Boon et al., 2019), where temperature changes of up to 4°C were observed. These thermal impacts of GSHP can affect their own efficiency or that of other shallow geothermal systems nearby (Herbert et al., 2013; Abesser et al., 2022). A heightened risk of “thermal interferences” has been identified in central London where many GSHP schemes are within 250–500 m of each other, and, according to the Environment Agency, the proximity and density of these systems (in conjunction with the local hydrogeology) is likely to make interference effects unavoidable (Fry, 2009). Interference within / between systems not only decreases the efficiency of the GSHP system (i.e., more electricity is required to operate the scheme) but can lead to progressive deterioration in systems performance, resulting in abandonment or need for system modification (Birks 2019). There is also a risk of interference with other subsurface infrastructures (train tunnels, cable tunnels, waste water pipes, basements) which often rely on the “cooling properties” of the subsurface while adding their own thermal footprint to it (usually release of heat), thus influencing the subsurface’s capacity to provide cooling or heating. Heat is currently not considered as a resource and hence thermal recharge to and abstraction from the subsurface is unregulated.

GSHP also carry some risk of **groundwater pollution**, mainly from input of chemical substances (anti-freeze compounds and corrosion inhibitors) into the subsurface due to engineering failures (e.g. leakage from defective borehole heat exchanger pipes, closed loop systems) (Banks and Birks 2020). The extent to which such incidents occur in the UK is difficult to assess as closed-loop GSHP systems are not regulated or monitored, and the locations of these systems are largely unknown.

Recommended regulatory updates include monitoring requirements for shallow geothermal systems above a certain size, including GSHP and mine energy systems, as well as a standard requirement to register closed loop systems including of anticipated thermal loads.

Mine water geothermal: Potential environmental impacts from mine water heat schemes include hydrogeological and surface water system impacts (water levels, thermal impacts, chemical impacts), ground motion and subsidence, and changes in gas migration pathways (e.g. Preene and Younger, 2014; Crowdthermal, 2020). Prior knowledge from active coal mining and management of groundwater post-mine abandonment forms an excellent base upon which potential impacts can be mitigated by appropriate subsurface characterisation and monitoring, and by engineering design. The type and scale of impact is likely to vary depending on the nature of the scheme (open or closed loop), the scale of operation and the local conditions.

Deep geothermal energy exploration and production is associated with potential direct and indirect environmental impacts including subsidence and induced seismicity, noise pollution, groundwater contamination and exposure of site staff to saline waters and possibly also naturally-occurring radioactive materials (NORM) if they are concentrated in the production process (Abesser & Walker, 2022). Responsibilities for regulation of these different aspects are split between different authorities including local planning authorities, environmental regulators and Health and Safety Executive (for deep drilling).

With only two deep geothermal systems currently in development, the regulatory system has not been fully tested, but some general observation can be drawn from application of the system to date:

- Local authority in charge of decision related to whether environmental impact assessment is required and if/ how to undertake monitoring for induced seismicity
- Steep learning curve for council and potential reliance on industry to supply risk management procedures
- Use of mining and blasting regulation for management of induced seismicity is regarded by industry and local council as best method for managing induced seismicity risks – however, in the absence of national guidance other council may adopt different procedures
- Perception by some operators in other industries that rules for geothermal energy are less stringent than for other extractive industries (e.g. shale gas)
- Lack of coordinating body for geothermal application process / and resulting long time scales for permitting and regulation is seen by industry as barrier to faster roll out of projects
- Some of the regulations (taken from oil and gas regulation) are seen as less applicable to geothermal systems in the UK – regarded as adding unnecessary costs and time to already very tight projects.

Considering the state of development of deep geothermal in the UK, it is too early to assess the effectiveness of regulation. Introduction of a licencing system may offer insurance to investors and enable conditions to be imposed relating to data sharing (e.g. Denmark example). Furthermore, it is important to gather project experiences and operational data early on and to develop best practice guidelines for deep geothermal that can then be adopted by local authorities in all parts of country.

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Question 7: How does the density of mine water systems affect their efficiency? Could widespread uptake of geothermal systems in dense population centres lead to a reduction in their ability to provide heat?

Summary:

Widespread use of GSHP systems in densely populated areas can lead to risk of thermal interference (see also response to Question 5). A heightened risk of “thermal interferences” has been identified in central London where many GSHP schemes are within 250–500 m of each other, where interactions of adjacent GSHPs are increasingly of concern as more systems are being installed (Environment Agency, 2018; Fry, 2009). Recently there have been reports of suspected interference (Herbert et al. 2013; unpublished PhD thesis 2022), but these could not be proven because locations of GSHPs and/or their thermal loads to the subsurface are not recorded.

Interference risks can be mitigated by managing the deployment (locations, thermal loads, operational strategies) of such systems. At minimum, this requires recording locations of GSHP systems (above a certain size), including their thermal loads, management and monitoring of the system and their operations and reporting back to the regulator.

There is potential for multiple mine water schemes in densely populated coalfield areas. Depending on the size/flow rates/temperature drop of each scheme, the depth utilised, the spacing, the local geology and hydrogeology there is a possibility of heat depletion and interactions between schemes that could reduce efficiency if not managed, and cause challenges for scheme operators.

Conversely, there is a huge opportunity for integrated heating/cooling/thermal storage using the mine systems (as well as the urban subsurface) for example to store heat in summer months and use heat

in winter months. Using the mines as a heat source and store within a heat network has been successfully demonstrated at Heerlen, Netherlands (<https://mijnwater.com/en/> and Verhoeven et al. 2014). The 'geobattery' concept describes using mine workings for thermal storage and transport (Fraser-Harris et al. 2022).

Understanding the capacity for multiple mine water heating/cooling/storage schemes is an area where further data, evidence and research is needed on heat and flow processes in rock and water, plus monitoring of at-scale systems, for example using the advanced sensing and monitoring capabilities of the UK Geoenergy Observatory in Glasgow (ukgeos.ac.uk).

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