A deep geothermal energy white paper

The case for deep geothermal energy – unlocking investment at scale in the UK

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Contents

1. Introduction

This report is commissioned by the North East Local Enterprise Partnership (NE LEP) and funded by the Department for Energy Security and Net Zero (DESNZ) and the North East and Yorkshire Net Zero Hub. It aims to provide an evidence-based assessment and 'case making' document to help accelerate the development and deployment of deep geothermal energy projects in the UK. This commission follows and is intended to complement the Mine Energy White Paper, led and procured by the NE LEP during 2020 and 2021, on behalf of the UK Mine Energy Taskforce.

This paper is supplemented by a more detailed report (referred to as the 'full report'), which contains more detailed analysis of the geothermal landscape and provides the methodologies, data and references that have informed the development of this paper.

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Drill rig at the Eden Geothermal Project, Cornwall, UK. (© Toby Smith, 2023)

2. Geothermal Energy in the UK

Geothermal energy is the energy generated and stored in the form of heat beneath the surface of the Earth. It can provide an ultra-low-carbon source for heating, cooling and power generation.

Exploitation of deep geothermal systems requires the drilling of deep wells to reach higher temperature heat sources at depths of more than 500 m. Although the geothermal energy potential is enormous, the current high costs of drilling restrict the economically viable exploitation of geothermal energy to areas with specific geological settings. As technologies improve and new extraction methods develop, the areas where geothermal exploitation is economically viable would increase.

Most of the UK's onshore deep geothermal potential is found in deep sedimentary basins that are dispersed across the UK (Figure 1).

Deep sedimentary basins typically contain deeply buried limestones and sandstones. Where groundwater circulation occurs within the deeply buried rocks (> 500m), they form hydrothermal systems (also called deep geothermal aquifers or hot sedimentary aquifers). Temperatures within these basins are estimated to be 40–60°C but could reach 100°C or more in some of the deepest parts.[4] This temperature range makes these systems most suited for geothermal heating applications such as district heat networks, horticulture and industry. These hot sedimentary aquifers have large heat resources[5], but estimating the economically useable fraction of heat has not yet been possible as it requires more detailed knowledge of the deep subsurface that needs to be developed from targeted exploration (e.g., geophysical surveys, drilling of wells and project development).

In addition, granites found in Cornwall, the North of England, Scotland and Northern Ireland have also been identified as proved and potential geothermal targets for power and/or heat production. Indeed, the whole country has geothermal potential with the sedimentary basins and granites representing the more accessible portions of the national geothermal resource.

Deep geothermal projects progress through the project development stages summarised in Figure 2. Several deep geothermal projects are currently progressing in the UK and are at different stages of development.

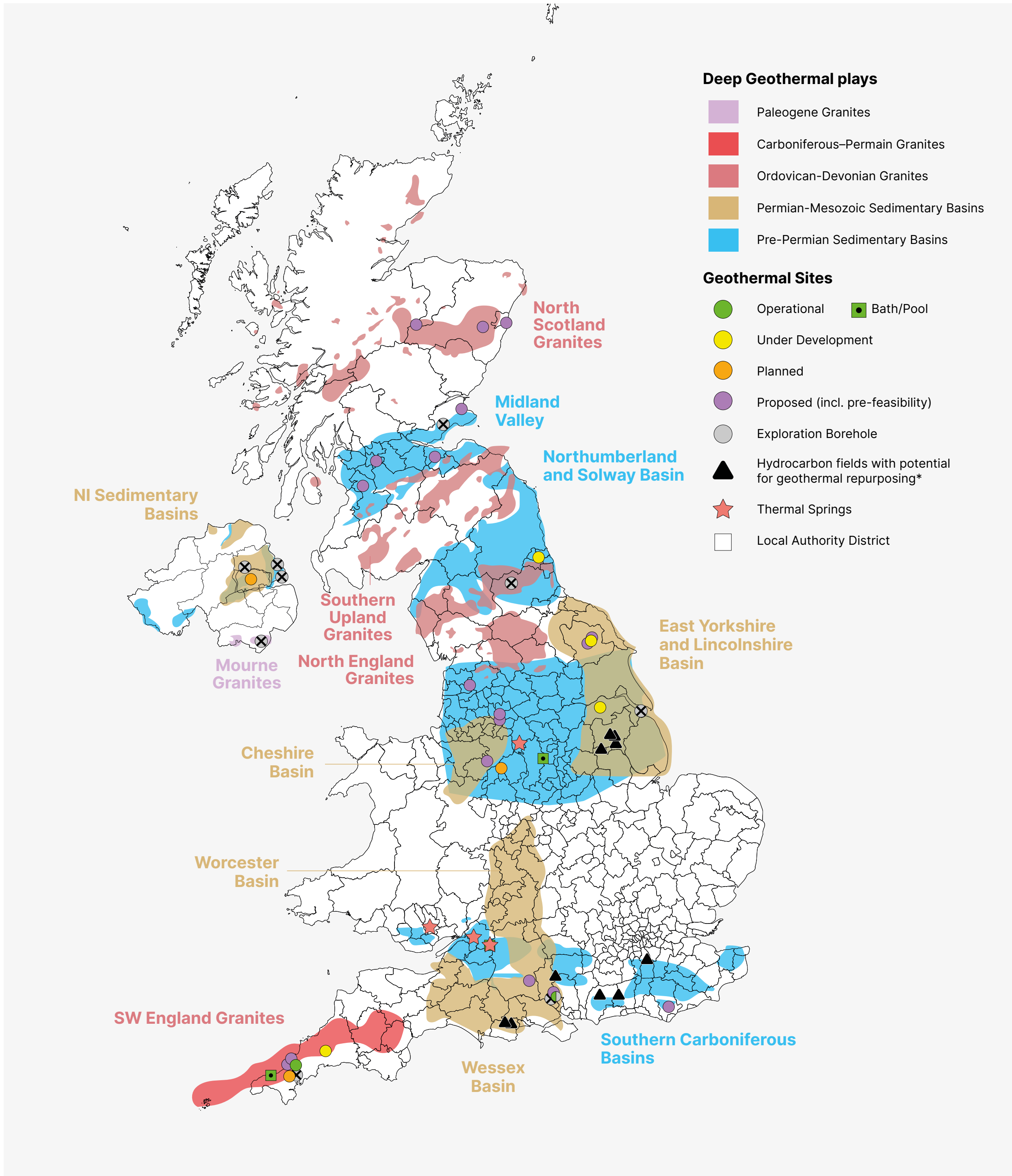

Figure 1: Map showing the location of the potential deep geothermal targets across the UK alongside selected onshore hydrocarbon fields (triangles), occurrences of known thermal springs (stars) and geothermal projects at different stages of development from pre-feasibility to operational (See Appendix 1 of full report for data sources). Southampton is shown as part-operational to highlight that it is not currently operational and was initially drilled as an exploratory borehole. Note that the map only shows the extent of the geothermal basins / granite intrusions. There is great variability in terms of reservoir properties and temperatures within individual basins as well as drillability of the (overlying) rocks. More detailed site-specific studies and investigations are required to confirm feasibility for geothermal exploitation of a site/area (see Project Road Map in Appendix 2 of the full report).

4 Busby (2014). Geothermal energy in sedimentary basins in the UK. Hydrogeology Journal, vol. 22, pp. 129–141.
5 More detailed information of the resource potential can be found in the full report.

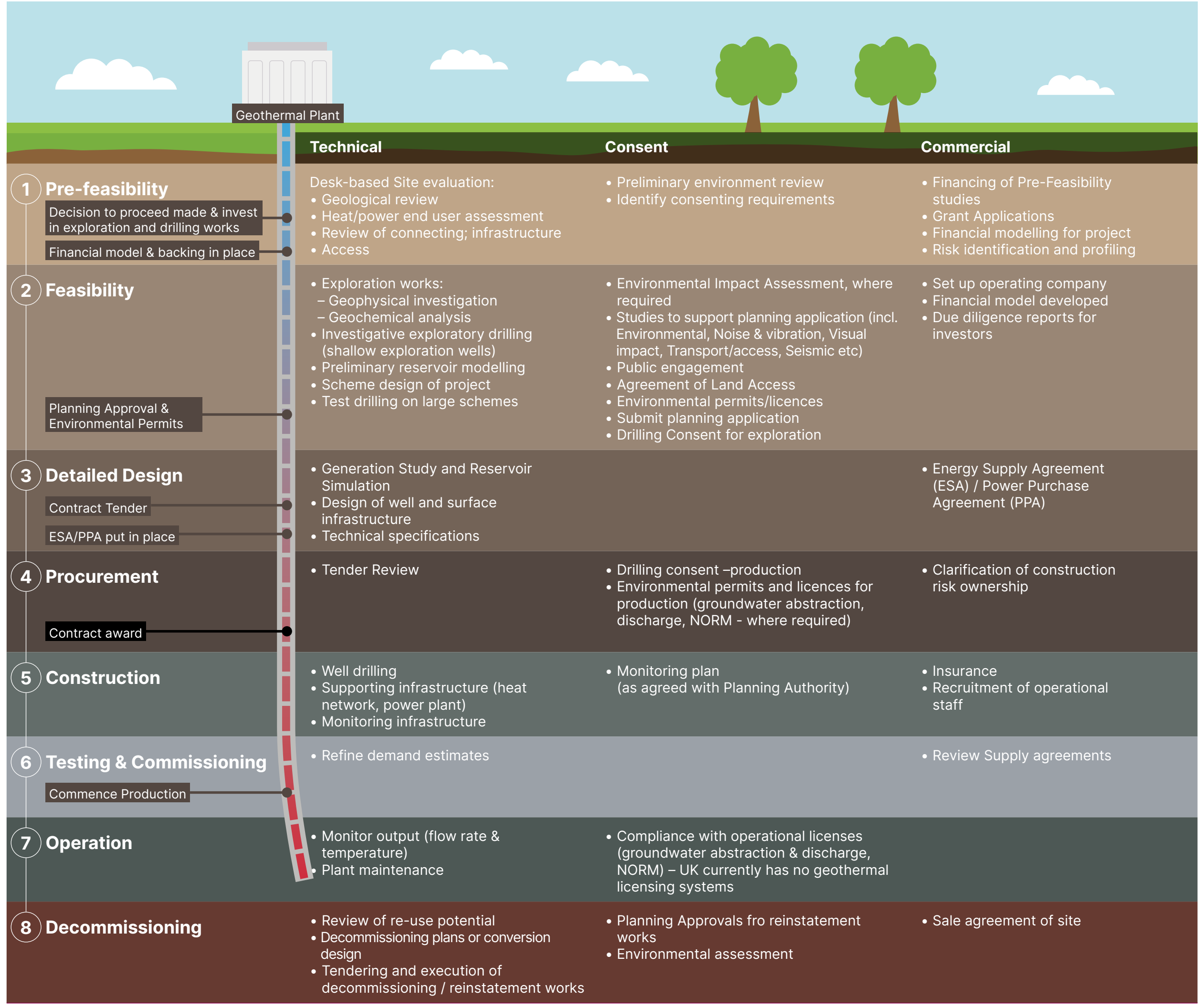

Figure 2: Roadmap for development of a deep geothermal project
(a more detailed description of individual project stages is included in the full report[6]).

Stages 1–2: Pre-feasibility and feasibility

More than 20 projects have been assessed at the pre-feasibility and/or feasibility stage, but many of them have stalled due to economic challenges, competition with other low-carbon sources (mainly biomass) or high geological and financial uncertainty. Two projects in Cornwall have recently achieved planning permission.

Stages 3–6: Procurement, construction and testing

Several deep geothermal projects are under development in the UK. The United Downs Deep Geothermal Power project has completed drilling and well testing. The power plant design is currently being finalised with construction expected to start later in 2023. The Eden Geothermal Project completed its first phase of development, supplying renewable heat to the Eden Project including the biomes, a plant nursery as well as offices and buildings on site. A second phase of development will expand the project to include geothermal power production.

Stage 7: Operation

There are currently four operational projects in the UK that use deep geothermal energy. Only one, the Eden Geothermal Project (operational since June 2023) pumps hot water directly from deep wells. The other three projects use geothermally heated water from geothermal springs or from shallower wells (using heat pumps) for recreational use including thermal baths, spas and a heated swimming pool. The Southampton Geothermal Well was the first (and for a long time the only) deep operational geothermal project in the UK. It has been in operation since 1986 but is currently not producing.

6 More information is available in the full report

3. Opportunities and benefits

In France, Germany, Belgium and the Netherlands, which have similar geology to the UK, deep geothermal energy has been shown to offer environmental, economic and technical advantages, including reductions in greenhouse gas emissions, economic impetus and job generation. Operational projects in the Netherlands are reported to have saved 342,000 tonnes[7] of CO2 compared to using gas in 2021. In Germany, the geothermal industry is reported to have generated €16.7 billion[8] and created 35,900[9] jobs since 2000. These applications have also demonstrated the feasibility of using deep geothermal sources for large-scale district heating and cooling as well as the long-term availability of the resource. Paris, for example, has been using geothermal energy for heating since 1969, today supplying geothermal heat to 250,000 households via 50 heating networks.[10]

Net Zero: Decarbonisation benefits

It is estimated that individual projects in the UK could deliver savings of between 2,400 tonnes[11] and 14,000[12] tonnes of CO2 equivalent per year (compared with natural gas) for geothermal heating and power operations respectively. They could achieve total savings of 72,000 tonnes (geothermal heating project) and 700,000 tonnes (geothermal power project) of CO2 equivalent over their estimated thirty-year and fifty-year operational lifetime, respectively. For comparison, the UK domestic heating emissions arising from the use of fossil fuels was 80 million tonnes CO2 equivalent in 2019.[13]

A regional assessment of the available heat in the main sedimentary basins in England, Wales and Scotland is provided in the full report that complements this work.[14]

The public sector estate is one of the main emitters of greenhouse gases (for heating) in the UK, with large buildings (for example hospitals, prisons, army barracks) having predictable and continuous heating requirements. Developing geothermal projects for NHS hospitals with high heat demand that overlie potential geothermal targets could save emissions between 1.3–22.7 kt CO2 equivalent per year for individual hospital sites in England. Developing geothermal projects for the 30 top-ranking hospital sites (based on heat demand) could save emissions of 281 kt CO2 equivalent per year (for details see full report14). For comparison, present day emissions from NHS England's hospital estate and facilities are around 2,300 kt CO2 equivalent per year.[15] Hence, geothermal projects at these 30 hospital sites could deliver up to 12% of emissions savings.

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7 Provoost & Agterberg (2022). Country Update for The Netherlands. European Geothermal Congress 2022, Berlin, Germany.
8 Bundesministerium für Wirtschaft und Energie (BMWi) (2021). Zeitreihen Erneuerbare Energien. Time series for the development of renewable energy sources in Germany, Status September 2022.
9 Bundesministerium für Wirtschaft und Energie (BMWi) (2023). Bruttobeschäftigung durch erneuerbare Energien 2000 bis 2021.
10 Arup & BGS (2022). Research into the Geothermal Energy Sector in Northern Ireland. Geothermal Technology and Policy Review. 86 pp.
11 Hill of Banchory Consortium (2016). Hill of Banchory geothermal energy project: feasibility report. Scottish Government.
12 Geothermal Energy Ltd. Manhay Deep Geothermal Project
13 DEFRA (2022) Official Statistics: Carbon footprint for the UK and England to 2019
14 More information is available in the full report.
15 NHS England (2022). Delivering a 'Net Zero' National Health Service
16 The values represent the estimated Heat in Place (PJ/km2). See full report for detail on the methodology.

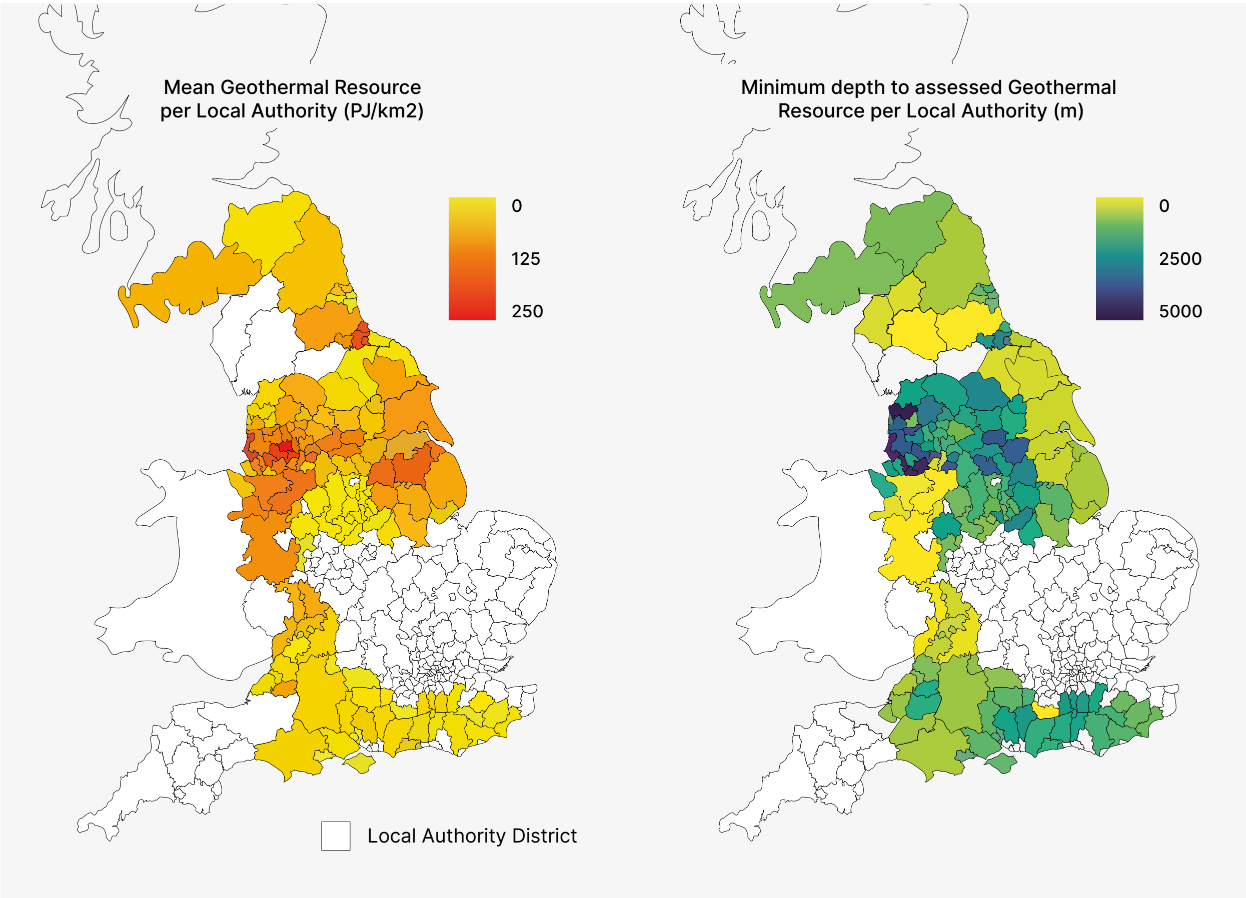

Figure 3: Map of geothermal opportunities for deep geothermal heat projects in the assessed deep sedimentary basins averaged across Local Authority Districts (LAD) (only areas of the assessed deep sedimentary basins are shown. Granites were not included in the analysis; the geothermal potential of the Midland Valley Scotland is under assessment and not included in the figure; Northern Ireland data are not available. Due to limited data, it should be noted that geothermal potential may exist elsewhere). Left: Distribution of mean geothermal resource (PJ/km2) per LAD. Right: Minimum depth (m) to an assessed geothermal resource averaged across local authority district. Maps were derived by extracting point data for each LAD from the geothermal resource grids and average values across the LAD within GIS software to give a mean heat in place resource (PJ/km2). The maps are only indicative and more detailed, area-specific investigations will be needed to better constrain temperature and depth of the potential source for the areas shown.

Local authority districts in England that have a deep geothermal aquifer, and therefore a potential hot water supply at depth, have been mapped as shown in Figure 3. Figure 3 (left) shows estimates of the available geothermal heat potential averaged across each local authority district in (PJ/km2).[16,17] Darker colours (reds) show areas where a larger amount of heat is available. It represents all the heat that is stored in the subsurface (heat in place) across the district. Only a small proportion of this heat will be extractable.[17] Figure 3 (left), therefore, provides an indication of where higher temperatures (and/or a larger number of geothermal heating projects) may be achievable relative to adjacent areas. Figure 3 (right) shows the estimated (vertical) depth to the topmost geothermal aquifer (averaged across the local authority district). It gives an indication of the minimum drilling depth. Lighter colours in Figure 3 (right) (i.e. yellow and green) show areas where a geothermal aquifer is available at shallower depth, i.e. less drilling might be required to reach the geothermal aquifer. It is important to note that both figures should be considered separately, i.e. it is not possible to infer from Figure 3 (left) what temperatures might be achievable at the minimum drilling depth mapped in Figure 3 (right).

Heat networks play an important role in decarbonising heat and support delivery of the UK's net zero commitments.[18,19] They are uniquely able to unlock otherwise inaccessible large-scale renewable heat sources,[18] including geothermal. For example, district heating networks in Paris (France) provide geothermal energy for about 0.7 million people,[20] and in Munich (Germany) geothermal district heating network delivers geothermal heating to around 50,000 homes, with saving of more than 75,400 tonnes of CO_2 per year (compared with gas).[21]

Economic Benefits: Green Growth and North Sea Transition

As well as emissions savings, geothermal projects can provide economic stimulus and contribute to job generation.

There are currently 32 deep geothermal projects at different stages of development in the UK (Figure 1, see Appendix 1 in full report). Some projects have been paused at the pre-feasibility and/or feasibility stage but could be revived given the right incentives.[22] If progressed, these projects could create over 1,000 direct jobs and 2,500 indirect jobs in the short-term[23] as well as bringing economic stimulus to the respective local areas. In the long-term, Arup (2021)[23] estimates that building the sector to reach 360 projects by 2050 could create over 10,000 direct jobs and a further 25,000 indirect jobs.

The United Downs Deep Geothermal Power project in the UK estimates that it has contributed £1.5 million to the local economy in Cornwall across a range of sectors (Figure 4)[24]. The estimated numbers of Full Time Equivalent jobs at the Eden Geothermal Project during different phases of project development are shown in Table 1.

The development of deep geothermal energy in the UK (onshore and offshore) could provide a unique opportunity to the oil and gas sector to transition their jobs, skills, knowledge and economic activity to a low-carbon technology.

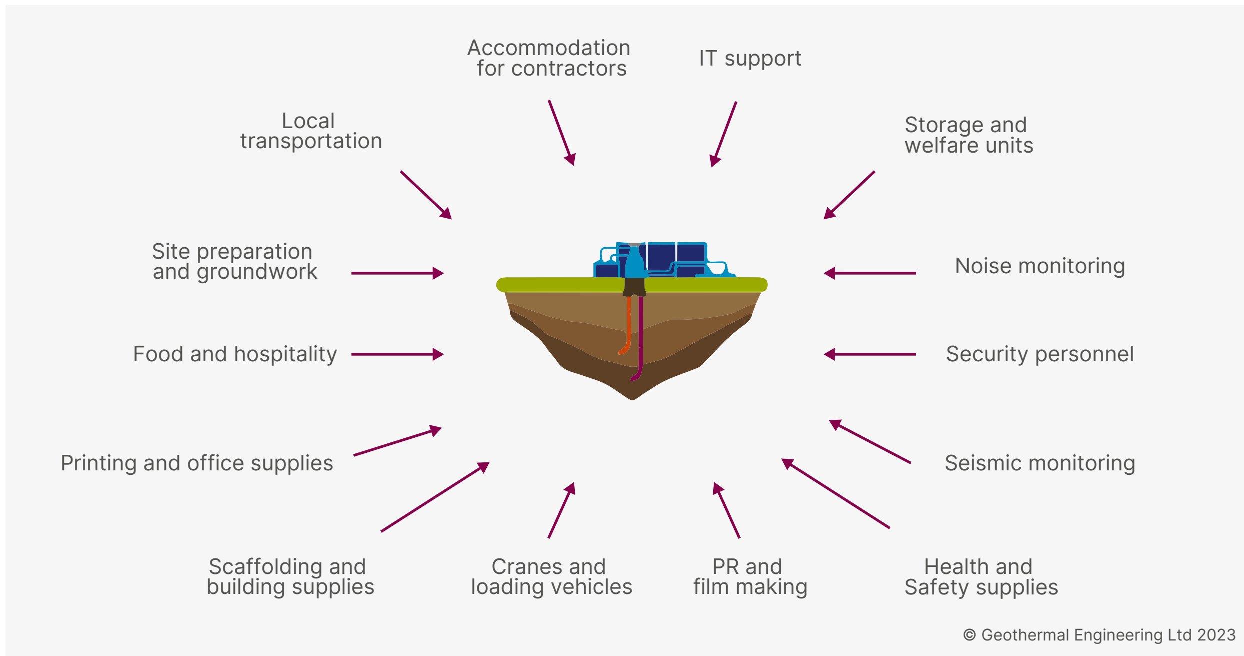

Figure 4: Sectors that have benefited from the development of United Downs Project in Cornwall, which contributed £1.5 million to the local economy (reproduced with permission from GEL).

16 The values represent the estimated Heat in Place (PJ/km2). See full report for detail on the methodology.

17 A methodology for converting heat in place to heat recovery capacity is given in Jones et al., (2023). It is based on several assumptions relating to aquifer properties and operational/technical parameters. An example calculation is given in the full report. It estimates that a heat resource of 100 PJ/km2 could return recoverable heat between 7.5 and 9.5 MW.

18 DLUHC (2022). Business rates heat network relief: local authority guidance 2022-23.

19 CCC (2016). Next Steps for UK heat policy.

20 Boissavy et al. (2019). Country Update for France. European Geothermal Congress.

21 Abesser & Walker (2022) Geothermal Energy. POSTbrief 46.

22 Townsend et al. (2020). "On The Rocks" – Exploring Business Models for Geothermal Heat in the Land of Scotch, Proceedings World Geothermal Congress 2020, Reykjavik, Iceland, April 26 – May 2, 2020.

23 Calculated based on Arup (2021) Deep Geothermal Energy – Economic Decarbonisation Opportunities for the United Kingdom.

24 Geothermal Engineering Ltd. Future Sites.

Core staff	Site preparation	Drilling (1 well)	Testing & monitoring	Heat main installation	Heat operation
Permanent	4 months	6 months	variable	8 months	permanent
7 FTE core staff	+ 4 FTE	+ 6 FTE		+ 6 FTE	+ 1 FTE
	~15 contractors	Drill crew & contractors: 24-hrs operation alternating crews with 35 - 40 staff each = ~150 FTE	~12 contractors including 24- hrs seismic monitoring	~25 contractors	
Number of jobs (FTE)	26	164	19	37	8

Table 1: Estimated numbers of Full Time Equivalent (FTE) jobs at the Eden Geothermal Project during different phases of project development

Social Benefits: Recreation and levelling up

In many parts of the UK, opportunity areas for district heating[25] coincide with deep geothermal prospects as well as with areas of deprivation (Figure 5). Investment in geothermal projects in these areas could contribute to the UK Government's levelling up agenda, through addressing energy poverty and creating green jobs.

Use of geothermal energy for heating spas and swimming pools has been reported in many countries to provide considerable social benefit for tens of thousands of people each year. The Jubilee Pool in Penzance reported visitor number of over 40,000 people for the 2017 season. In 2020, a geothermal pool was added becoming the first geothermally heated lido in the UK. In addition to a Locals' Discount of 20% for people living in Penzance, the pool offers free access to the geothermal hot zone for people from the most deprived communities in the area as well as tailored therapies and programmes for up to 180 people per week.[28]

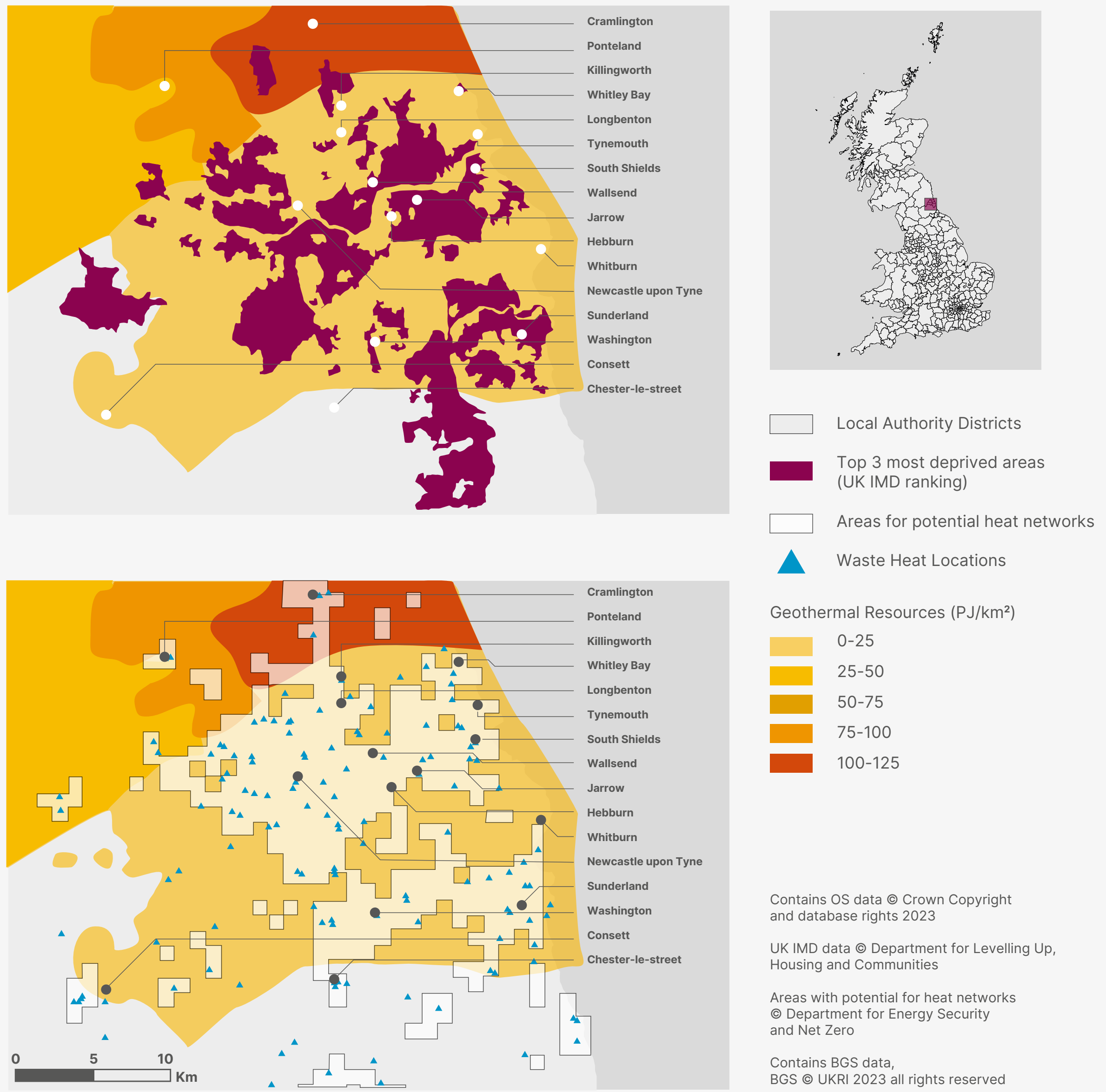

Figure 5: Map of North Tyneside, Newcastle, South Tyneside, Gateshead and Sunderland local authority districts. Top: shows the distribution of the Palaeozoic Middle Border Group assessed geothermal resource (PJ/km2)[26] in relation to the most deprived areas.[27] Bottom: shows the distribution of the Palaeozoic Middle Border Group assessed geothermal resource (PJ/km2)[26] in relation to areas of potential heat networks and industrial waste heat sources.[25]

25 BEIS (2021). Opportunity areas for district heating networks in the UK: Second National Comprehensive Assessment. UK GOV.
26 Rollin et al. (1995). Atlas of geothermal resources in Europe: UK revision. Technical report WK/95/07, British Geological Survey, Keyworth, UK
27 UK Index of Multiple Deprivation (IMD)
28 Jubilee Pool (2018). Jubilee Pool Penzance: Project Business Plan

Energy security

Geothermal energy is available in many parts of the UK, 24 hours per day. It can provide heat independent of the weather and help the UK to diversify the renewable sources that can be used to decarbonise heating. A well-developed geothermal sector has potential to produce geothermal heating and cooling (and some electricity) in the UK, with little reliance on external factors like European skills and supply chains. It does not require critical minerals for construction of its infrastructure. This security of supply of geothermal energy makes it an attractive energy source that could significantly reduce our reliance on third country suppliers of gas, thereby contributing to increase Energy Security in the UK. Furthermore, geothermal energy provides a decentralised energy source that is available over a wide geographical range (Figure 1).

Links to other technologies and shared benefits

The UK has about 2,100 onshore wells that were drilled for oil and/or gas, coal bed methane or other purposes. A small number of these wells may be suitable for re-use for geothermal purposes[29,30] provided they have not yet been fully decommissioned and there is a nearby consumer (e.g. horticulture or agriculture use). Re-using abandoned hydrocarbon wells to produce geothermal heat and electricity could reduce costs of geothermal projects because it avoids the high capital costs associated with drilling.

There is increased interest in combining geothermal energy production with other energy technologies, including Carbon Capture and Storage (CCS) concepts and Underground Thermal Energy Storage (UTES). Such synergies have potential to deliver co-benefits and cost reductions to geothermal projects.

Lithium is found in the geothermal waters in Cornwall and Weardale. If proven economical, co-production of lithium and geothermal energy could provide an additional value stream for geothermal energy and contribute to the UK's security of resources, although the overall contribution is likely to be small.

29 Watson et al. (2020). Repurposing hydrocarbon wells for geothermal use in the UK: The onshore fields with the greatest potential. Energies, vol. 13, 3541.
30 Environment Agency (2022). Specific environmental risks from repurposing oil and gas wells

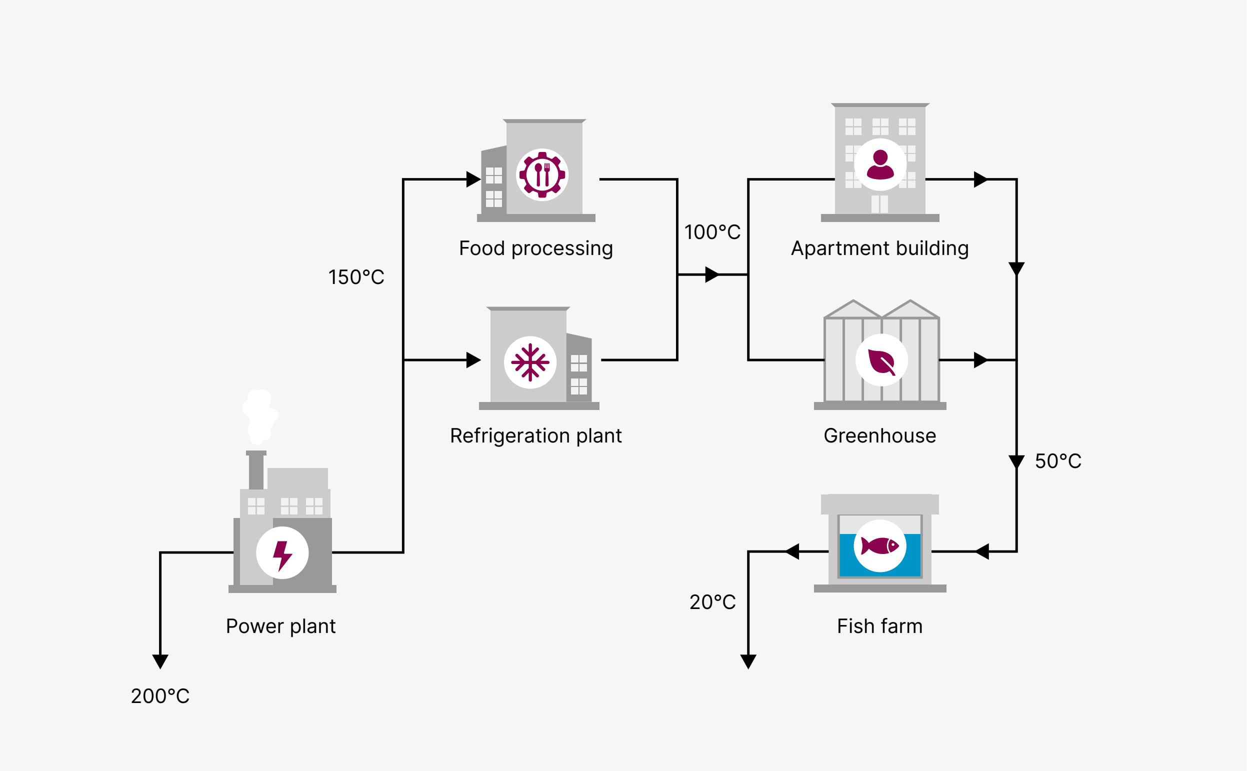

Figure 6: Cascaded use of geothermal heat and power. Adapted from Brophy et al. (2015).[31]

Delivering benefits to multiple users

Geothermal projects can deliver benefits to a range of end users with different heating requirements (i.e. consecutive use of the produced steam/water for more than one application, typically with decreasing temperature requirements) (Figure 6). This, so called, "cascaded use" of heat and/or power increases net efficiency of a geothermal plant and improves the economic feasibility of the project.

Future technologies

Future technologies will play an important role in unlocking geothermal resources that currently cannot be exploited cost effectively. Technology developments, in particular improvements in drilling technologies, and associated reductions in costs are expected to make more of the deep, hot subsurface accessible for exploitation.

As new technologies become available, the geothermal energy resource that is economically exploitable is likely to expand in many areas of the UK.

31 Brophy et al. (2015). Cascaded Uses of Geothermal Energy. Presentation.

4. Challenges and constraints to geothermal developments in the UK

Stakeholder engagement was an important part of this study. This included a review of existing stakeholder evidence (including 31 submissions to a parliamentary inquiry on geothermal technology undertaken by the Environmental Audit Committee in 2022)[32] and reports[33], a virtual stakeholder workshop (34 participants), an online stakeholder survey (59 respondents) and stakeholder interviews (7). Stakeholders that have participated in the engagement for this report include representatives from the geothermal industry (developers, consultants, drillers, service providers), regulators, the finance sector and academia – are listed in the acknowledgements.

Technology Awareness

Stakeholders highlight that awareness of geothermal energy technologies varies amongst different public groups and that many policy makers (central government and regulators) and potential end-user or clients (local councils, site and building developers) are less aware of geothermal technology options. Countries such as France, Germany and the Netherlands have defined specific targets and strategies for growing their geothermal sector (Box 1).[34,35]

The role for geothermal energy in the UK energy transition is currently not yet defined and there are no targets for developing deep geothermal technologies as part of the UK decarbonisation and net zero efforts. This is seen by many stakeholders as a key barrier for the development of a deep geothermal sector in the UK.

31 Brophy et al. (2015). Cascaded Uses of Geothermal Energy. Presentation.
32 Arnhardt et al. (2023). Geothermal Technologies - Analysis of written evidence from the Environmental Audit Committee inquiry, BGS Internal Report, IR/23/001
33 Abesser et al. (2023). Visualising geothermal regulations for the UK. Research brief. Unconventional Hydrocarbons in the UK Energy System (UKUH) project. Newcastle University.
34 Cariaga (2023). France publishes action plan to accelerate geothermal development. ThinkGeoenergy.
35 Cariaga (2022) Germany aims for 100 new geothermal projects by 2030. ThinkGeoenergy.

Geothermal policy in the Netherlands

In the last 10 years, the Netherlands has seen an increase in deep geothermal systems from 7 to 31 operational plants. The success has been attributed to the government support for geothermal energy in the form of long-term government visions and financial support.

There is a clear commitment from the government to developing geothermal energy in the Netherlands, first defined in 2011 in the form of a vision for geothermal and later (in 2018) translated into a masterplan for geothermal energy, with clear targets and policy support measures. This national geothermal energy strategy was developed by industry foundations (Platform Geothermie, Warmtenetwerk), the Dutch Association of Geothermal Operators (DAGO) and the geothermal energy regulator (Energy Beheer Netherland – EBN) in collaboration with the Ministry of Economic Affairs and Climate and the Ministry of the Interior and Kingdom Relations.

The Netherlands have adopted the pragmatic approach of developing regulations as the sector develops. This results in regular revision and updates to regulation and legislation by the Ministry of Economic Affairs and Climate (MEAC), which regulates geothermal energy.

Various policy mechanisms have been put in place to support the country's geothermal ambition, including the Stimulation Sustainable Energy production scheme (introduced in 2012) and the government guarantee scheme on drilling risks (introduced in 2010). The schemes are commissioned by MEAC and administered by the Netherlands Enterprise Agency (RVO). They are considered as a key component in the success of deep geothermal in the Netherlands[36].

Government support has been accompanied by the long-term availability of data, including a dedicated online information system (ThermoGIS) and seismic surveying (SCAN). ThermoGIS is developed and maintained by the Geological Survey of the Netherlands (GSN – TNO) with funding from the EU and the Dutch Government. SCAN is funded by the Dutch Government and executed by GSN-TNO and EBN.

36 Mijnlieff et al. (2013). Geothermal energy and support schemes in The Netherlands. European Geothermal Congress, Pisa, Italy.

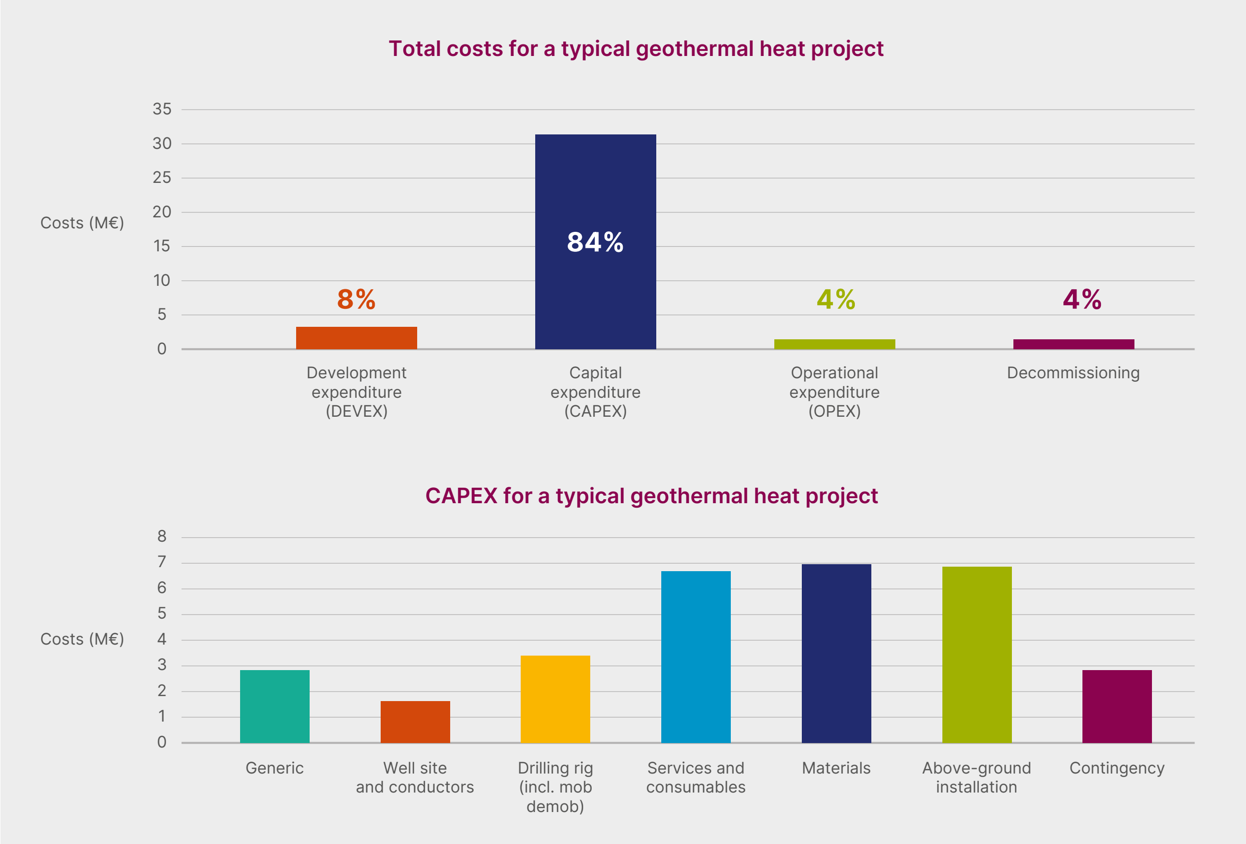

Figure 7: (a) Overall project costs and (b) breakdown of CAPEX for a generic geothermal heat project (source: EBN).[40]

Project Costs and Risks

It is currently very difficult for geothermal projects in the UK to secure the necessary project funding due to the relatively low maturity of the sector, high upfront costs, and the geological and financial risks inherent to geothermal projects.

As discussed in the full report and illustrated in Figure 7, geothermal projects have high upfront capital expenditure (CAPEX), most of which is spent on drilling and materials. An indication of drilling costs was obtained from published data. Arup (2021)[37] estimated costs in the order of £1.6 to £1.8 million per km depth for 1–2 km vertical wells in the UK. Drilling costs for 2km deep wells in the Paris Basin are reported to be £1.8 to £2.2 million per km,[38] and £2 to £3 million per km in the Netherlands based on wells 3km in depth.[39]

These high upfront costs are considered by stakeholders as main barriers to wider uptake of geothermal energy in the UK as they make it difficult to obtain project finance under current technology awareness and market conditions. Stakeholders have identified a need for financial support and risk-sharing mechanisms for geothermal projects like those available in other European countries.

Government Support and Investment

Stakeholders reported that it is difficult to get funding for geothermal projects due to limited availability of financial support mechanisms. As for other renewable technologies, government incentives are important during early stages of market development to build investors' confidence and drive cost reductions. Current deep geothermal developments in Cornwall, for example, were only able to start with initial support from the European Union's European Regional Development Fund (ERDF) and from the local authority.

Local councils and public sector organisations are seen by stakeholders as key potential users of geothermal energy for decarbonising their estate. However, uptake of the technology by these organisations is currently inhibited by the high capital costs of both heat networks and geothermal projects. Furthermore, limited data availability and the resulting risks associated with unknown geological conditions make it difficult to justify investment into deep geothermal projects against lower risk options. The Heat Networks Delivery Unit (HNDU) provides support to local authorities in England and Wales through the early stages of heat network development, including for techno-economic feasibility – but not including drilling costs.

37 Arup (2021). Deep Geothermal Energy – Economic Decarbonisation Opportunities for the United Kingdom.
38 Antics (2021). Planning geothermal district heating projects. Lessons learned from France
39 EBN (2021). Whitepaper Integraal Kostprijsreductie Programma Aardwarmte Kostprijsreductie Aardwarmte, December 2021.
40 EBN (2021). Whitepaper Integraal Kostprijsreductie Programma Aardwarmte Kostprijsreductie Aardwarmte, December 2021.

Geothermal risk insurance in France

France is one of the pioneering countries in the development of deep geothermal district heating. Its success is thought to be linked to consistent technology support (since 1980s) and city scale deployment (right market conditions) to existing district heat networks (e.g., Paris Basin).

Figure 8 shows how the two risk mitigation schemes have contributed to geothermal success in France (for details see Boissavy, 2017).[41] The fund received an initial contribution from the state. This was topped up by premiums paid by the beneficiaries and by financial income arising from investing the surplus available cash. Over its lifetime, the long-term fund guaranteed investment worth €260 million for drilling and 63 geothermal operations nationwide. State payments came to €8 million. For every €1 put up by the state, €33 of investment came from other income.[41]

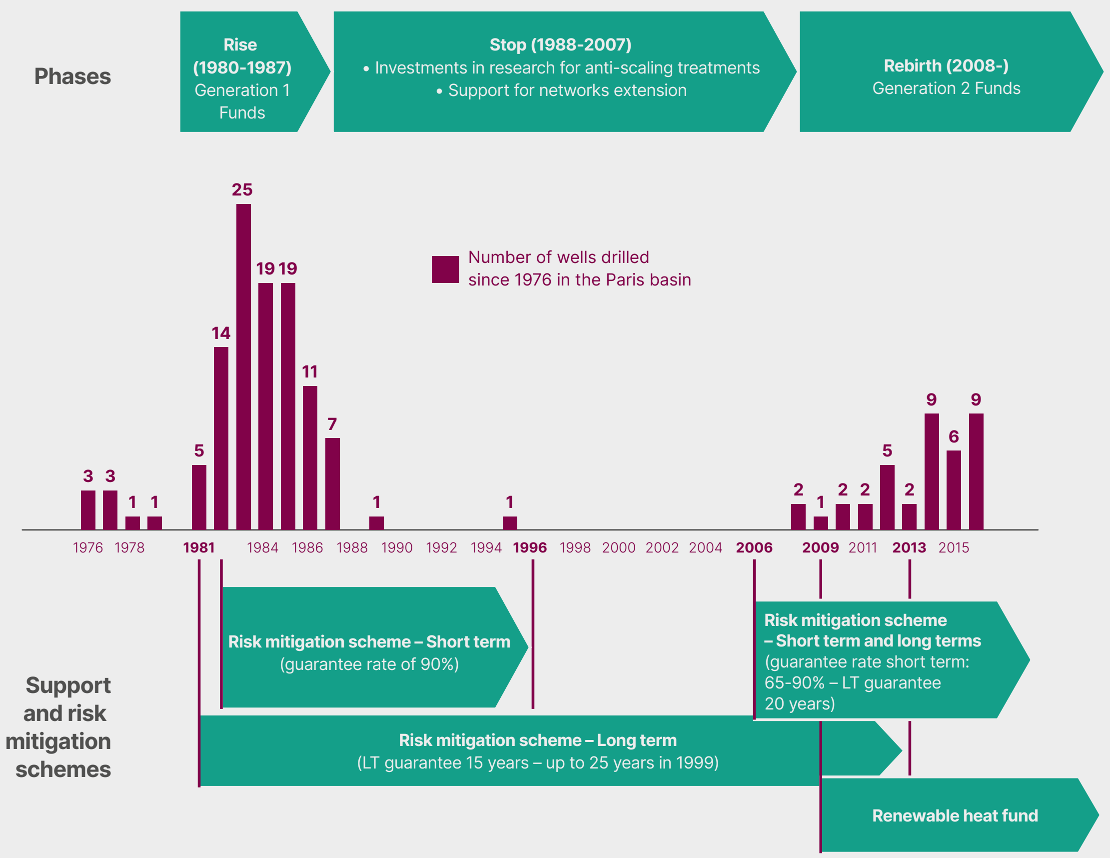

Figure 8: Risk mitigation and geothermal market development in France (Reproduced with permission © ADEME) Note that drilling of new wells stopped between 1988 and 2007 when government support for drilling risk (i.e. short term) was unavailable, despite there already being a somewhat established industry. It was restarted when support was reintroduced.

Overall, the support available for geothermal project in the UK was seen by most stakeholders as poorer compared to support given to other renewable technologies, such as wind, solar and hydrogen. Availability of long-term and consistent policies and technology support has been linked to the success in these sectors through encouraging investment and engaging the supply chain (see example for UK offshore wind in Abesser & Walker, 2022).[42]

For deep geothermal heat projects, there is currently no dedicated government support available in the UK, except for public sector organisations or in conjunction with heat networks. Contracts for Difference (CfDs) is the Government's main mechanism for supporting low-carbon electricity generation. Under current conditions, the likelihood of a geothermal bid being successful in a CfD auction is very low because geothermal power competes against more developed technologies such as offshore wind or Advanced Conversion Technologies (ACT) and because there is no guaranteed minimum allocation for geothermal power projects.

A summary of common support scheme options that are successfully being utilised in other European countries to support geothermal energy is included in the full report.[43]

41 Boissavy (2017). The successful geothermal risk mitigation system in France from 1980 to 2015, European Geologist Journal, vol. 43.
42 Abesser & Walker (2022) Geothermal Energy. POSTbrief 46.
43 More information is available in the full report.

Data Availability and Accessibility

Data availability and accessibility issues are seen as a barrier by developers and by potential clients and/or users, specifically for identifying opportunities and locations for geothermal developments across the UK. Main datasets of interest for developers are subsurface geological information (temperature measurements, seismic interpretation, rock properties) and legacy well data from deep boreholes. Such data exist for some parts of the UK (e.g. Figure 10 in full report), but currently this data sits across (and is owned by) a range of organisations. In the absence of a common data platform, this data can be difficult to identify and access.

In countries like Germany and the Netherlands, accessibility of relevant data through web-based geographical information system and data portals has been linked to an increase in interest in geothermal energy. Data access is also seen as beneficial for geothermal policies and regulation, e.g. to formulate a regulatory approach and/or make decisions about geothermal risk coverage, financing, licencing and permitting. The Dutch geothermal data platform (ThermoGIS), for example, is used to calculate the likely heat output of a projected geothermal doublet to inform the government's risk insurance and to help developers to obtain bank financing.[45]

Countries, such as Germany, Denmark, the Netherlands and Switzerland, have data sharing obligations, defined by law or as part of a subsidy or licencing conditions, whereby any geological data collected as part of geothermal investigations or drilling need to be deposited with a specified public authority. Such obligations exist in the UK for some activities, including drilling of wells deeper than 15 metres for abstracting water[46] or deeper than 30m for 'minerals'. While some of the data cannot be disclosed outside of the receiving organisation, i.e. BGS, the National Geoscience Data Centre (NGDC) data deposit process encourages the deposited data to be made open.

The British Geological Survey, through hosting the NGDC (part of the NERC Environmental Data Centre), acts as the repository for subsurface information for much of the UK. It holds data from its own historical projects (such as the UK geothermal programme of the 1980s[47]) but also from UK onshore drilling, e.g. for the UK hydrocarbon industry. As the national geological survey, BGS had access to some unreleased and confidential data, e.g. for undertaking resources assessments. While confidential, only processed derivatives of this data, such as maps (e.g. Figure 1 and Figure 3), could be made publicly available while the data itself could not be shared due to commercial restrictions.

Following recent changes in data management practice and responsibilities, some of the previously restricted data sets have now become available. For example, in June 2023, the North Sea Transition Authority (NSTA) authorised the release of all well data for onshore hydrocarbon boreholes held by BGS. This data is now available free of charge via the BGS Geoindex.[48]

There are still restrictions on other important data sets, including BGS's Geothermal Data Catalogue (Rollin et al., 1987) which limit their availability for public release and/or commercial use. Derived from many different sources, such legacy data often comes with uncertainties in terms of data quality and Intellectual Property Rights (IPR). BGS has started a programme of work focussed on reviewing this data, and resolving outstanding IPR issues, with the aim of releasing validated data packages as and when available. Accelerating this process to match industry demand is likely to require additional funding.

UK Geothermal supply chain

Some elements of the supply chain exist in the UK, but these are not coordinated because of the limited number of UK deep geothermal projects. Drilling skills and some equipment are thought to be available and heat exchanger and power plant technologies are sufficiently mature for deployment for geothermal heat and for power generation. However, current projects had to source some specialist equipment and skills (e.g. deep drilling) from outside the UK.

Having a pipeline of consecutive projects is regarded as important by stakeholders to help develop skills, generate momentum for the industry and engage the supply chain companies, as well as to build confidence and encourage investment.

Technology Innovation

Drilling remains the most expensive element of a geothermal project. With standing times for drilling rigs of £40k/day, technology innovation for faster, more efficient drilling and well completion is seen by most stakeholders as a priority for innovation.

Regulation and Licencing

Currently, the regulation of geothermal energy projects falls into the remit of multiple regulators, which operate at local to national level. This is not unique to deep geothermal especially as it is regarded by regulators as a complex and still emerging technology.

Stakeholders from industry reported that the absence of a coordinating body for the geothermal application process resulted in long timescales for permitting and regulation. This is seen by stakeholders (industry) as a barrier to faster roll out of geothermal projects.

Although the North Sea Transition Authority (NSTA) has experience in regulation of a similar resource (i.e. oil and gas), it currently has not been given the remit (or legal basis) for regulating geothermal energy and would require direction from the responsible government department, i.e. the newly formed Department for Energy Security and Net Zero.

With respect to licensing, geothermal energy is not recognised as a natural resource in the UK (in the same way as minerals or water). This leads to uncertainty in the status, ownership, and regulation of geothermal energy.[49] Introduction of a licensing system is seen as important by some stakeholders as it offers assurance to investors and heat customers of their right to exclusive use of the resource over the run-time of their operation and a clear route for development.

In other countries, such as Germany, Belgium , France and the Netherlands, existing legislation was amended, or new regulation passed that defines geothermal heat as a natural resource with clear rules of ownership, regulations, and licensing arrangements. In the Netherlands, for example, the resource is owned by the state, but exploration and exploitation activities generally require authorisation from the private landowner.[50] In Belgium, defining resource ownership and licensing was regarded as an important step to create the confidence of financers and project developers in deep geothermal projects.[51]

By way of comparison, other subsurface energy production activities in the UK typically require licences. The exploration and extraction of oil and gas, for example, requires petroleum exploration and development licences issues by the NSTA under the Petroleum Act 1998.[52]

44 Abesser & Walker (2022) Geothermal Energy. POSTbrief 46.
45 Blake et al. (2020). An assessment of geothermal energy for district heating in Ireland. Geological Survey Ireland.
46 Water Resources Act 1991 (legislation.gov.uk)
47 Downing & Gray (1986). Geothermal energy – the potential in the United Kingdom. BGS.
48 BGS (2023). A new open dataset to benefit onshore geoscience research.
49 Abesser et al. (2023). Visualising geothermal regulations for the UK. Research brief. Unconventional Hydrocarbons in the UK Energy System (UKUH) project. Newcastle University.
50 Borović et al. (2021). HotLime Partners' Legislation Synopsis. GeoERA
51 VITO (2020). The Balmatt project and bringing geothermal to Belgium. TWI blog 24 January 2022.
52 Petroleum Act 1998 (legislation.gov.uk)

5. Recommendations: Building a UK deep geothermal sector

There is wide consensus amongst stakeholders that the potential exists across the UK to develop geothermal energy projects and that a route to market is needed to support development of this nascent industry in the UK.

Stakeholder evidence collected from a range of sources[32, 33,53] has highlighted the challenges that the industry is facing (Chapter 4). Using these, together with input from the stakeholders listed in the acknowledgements, policy measures to address these barriers were identified and an attempt was made to determine prioritisation. Whilst there was strong agreement that deep geothermal energy needs more visibility in government strategies, stakeholder views differed with regards to the prioritisation of other policy measures. This meant that there was no consensus on which are the most important policy measures in the near term. In our full report,[54] we have therefore discussed the evidence that we gathered from stakeholders, together with experiences from other European countries. We have used this evidence to develop a set of recommendations, using the short-term, medium-term and long-term framework of Figure 9, that could support the development of a geothermal sector in the UK.

Overarching recommendations

The geothermal sector in the UK is at a nascent market stage, where technology visibility and investor confidence are low and where sector specific public support is needed to build a pipeline of successful projects that showcase the technology.

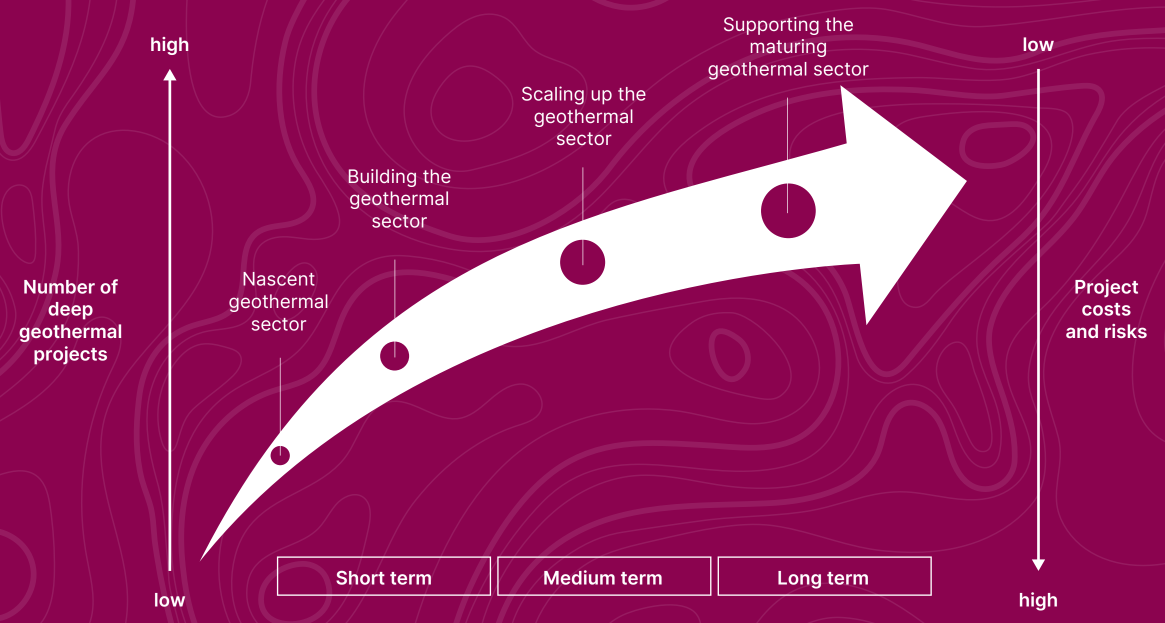

Figure 9: Route to developing a geothermal sector in the UK in the short-term (< 5 years) , medium-term (5-15 years) and long-term (>15 years).

Recommendation 1: Reviewing financial support for geothermal energy

In the UK, existing policy schemes offer only very limited funding opportunities for geothermal heat or power projects. Therefore, a review of the available incentive schemes for geothermal energy is recommended as well as consideration of new schemes that could support the development of a self-sustaining sector. This should include a review of existing funding for public sector schemes for heat projects with view of identifying adjustments that would facilitate funding of public sector geothermal projects.

Providing incentives for geothermal heating projects and for public sector decarbonisation are seen as a priority. However, geothermal power projects and cascading heat use also have an important role in developing the sector, and incentives should reflect this. Incentives should be guaranteed for a sufficient length of time to build investor confidence and provide assurance that incentives can be relied upon for the longer term to match their long-term investment profile. The level of support should be considered against other renewable technologies to create a level playing field.

It is not in the scope of this report to develop recommendations for specific funding support mechanisms. From the geothermal landscape review and from stakeholder engagement, we have identified support mechanisms that have been used in other countries as well as the mechanisms that the industry would like to see deployed in the UK – as detailed in the full report. An important conclusion is that support mechanisms should be adapted over time to reflect market maturity.

Short-term

Measures should be designed to encourage rapid technology uptake and the development of pilots. Examples of such measures could include Feed-in-Tariffs (FiT) or Contracts for Difference (CfD) with funding ringfenced for geothermal technologies.

Medium-term

As the market develops and several geothermal pilot projects are operational, measures should be introduced that support the scaling up of technology deployment. Examples of such measures could include finance mechanisms, such as rolling funds, that enable development of multiple projects in parallel rather than funding that is delivered on a project-by-project basis.

Long-term

As the market matures, mechanisms should be adapted to support continuous growth until the market is fully matured, e.g. by providing a combination of (reduced) tariffs combined with risk sharing schemes. Examples of such measures include a combination of Feed-in-Tariff and a geothermal insurance scheme to cover drilling risks (Dutch model) or a loan scheme with risk sharing options for drilling (German model).

Financial support for the development of demonstrator projects could be beneficial in the short to medium term as they can deliver multiple benefits including showcasing the technology and raising awareness. Where information is openly shared, such pilot projects can also have an important role in developing technical, organisational, and administrative experience. Stakeholder feedback suggests that a minimum of five demonstrators should be supported.

53 Abesser et al. (2020). Unlocking the potential of geothermal energy in the UK. British Geological Survey Open Report, OR/20/049.
54 Reference to full report

Recommendation 2: Signposting the role of geothermal in UK Net Zero efforts

Clear signposting of the role that geothermal energy could play in the UK's decarbonisation efforts has been identified as a key priority for the UK sector.54

Short-term

1. We recommend that consideration is given to how visibility of geothermal energy technologies could be improved in UK government strategies and what role technology-specific targets could play in attracting investment into geothermal projects and encouraging engagement of the supply chain.

Long-term

2. As more geothermal projects come online and operational data become available, a better understanding of the economically useable geothermal resource will develop which will enable the definition of long-term targets for the sector. Setting such targets was shown to play an important role in the development of offshore wind in the UK. Measures to improve data availability, accessibility and sharing (as outlined in Recommendation 3) could accelerate the improvement in our understanding of the subsurface and the available geothermal resource, thereby supporting the formulation of geothermal targets.

Recommendation 3: Improving data availability and accessibility

Like other sectors,[55] the growing geothermal sector will require greater access to timely and transparent data, including seismic reflection and borehole data, which are essential for identifying and assessing geothermal opportunities and risks. We recommend that consideration is given to improving data availability and accessibility for the geothermal sector. Several measures have been raised by stakeholders and found to be important (see full report). Further engagement is necessary to clarify how these might be implemented and what overall impact they will have on the sector.

Short-term

1. As the cost of data acquisition can be very high (Chapter 3), use of existing data is often the only mechanism for initial site selection for many geothermal projects. Currently, relevant data for geothermal projects sit across (and are owned by) a range of organisations and can be difficult to access.[56] Legacy data sets often lack details relating to data provenance and quality, which has prevented their release for open use. To maximise the value and enable open sharing of this data, we recommend that consideration is given, in the short-term, to supporting the review and processing of legacy data and the development of formats through which validated data sets can be made openly available and shared. This will enhance the availability of data relevant for geothermal projects.

Medium-term

2. In the medium-term, to enhance data accessibility, we recommend that consideration is given to the development of a single data platform through which these validated, publicly available data sets (recent and legacy) and geothermal information can be made available to stakeholders and the public.

Long-term

3. As utilisation of geothermal energy increases, acquisition of new data will be needed to identify future geothermal opportunities in areas where less data and subsurface knowledge are available. Government supported exploration programmes could be used to fill in subsurface data gaps in key areas (see Chapter 2) to accelerate the development of geothermal energy (and delivery of associated benefits). Such programmes were successfully implemented in the past – e.g. the UK Government provided £20 million for seismic data acquisition in 2015 to revitalise UK Offshore Oil and Gas exploration.[57]

4. Whilst Government may choose to play a role in data collection (Recommendation 3.2), there needs to be wider sharing of data across the sector to reduce risks and costs and maximise the benefits of the available geophysical and geological data – private or public. This could be achieved through the introduction of data sharing obligations. Such obligations already exist in other sectors. In the UK oil and gas sector, for example, data sharing is mandated as part of the licensing conditions, but other data sharing models could be considered. For example, the Geological Data Act[58] in Germany mandates that all data and results from all geological investigations are made available to the national geological authority within three months of collection. The geological authority, in return, is responsible for collecting and securing geological data and making it available to the public.

55 Wood (2014) UKCS Maximising recovery review : final report
56 Dickinson & Ireland (2022). Digging into data access: The need for reform. Geoscientist, Summer 2022, pp 32–37.
57 James (2016): Oil and Gas Authority – Information & Samples
58 Geological Data Act (2020) (in German)

Recommendation 4 – Reviewing the legal status, regulation and licencing of geothermal energy

With only a few systems currently in development, the UK regulatory system for deep geothermal has not been fully tested. However, the absence of a coordinating body for the geothermal application process is seen by stakeholders as a barrier to faster roll out of geothermal projects, and many stakeholders have found the regulatory requirements for deep geothermal projects to be somewhat difficult or extremely difficult.[54]

Medium-term

1. There is currently no regulatory body with a remit for managing the UK geothermal energy resource. Consideration should be given to identifying a regulatory body that could take on the effective stewardship and regulation of geothermal energy. Further stakeholder consultation, including potential regulators, is recommended to identify a suitable regulatory body.

2. To ensure that the potential regulator is provided with the appropriate remit, resources and legal powers, a review of existing legislation is recommended to clarify the status and ownership of geothermal energy. Some changes to the legislative framework may be needed to ensure that geothermal energy is recognised as a natural resource that can be licenced, regulated and managed.

3. As the UK's experience in the development, operation and regulation of geothermal projects grows, it is recommended that consideration is given to reviewing (and streamlining) existing regulations. Further engagement with the responsible regulator(s) and stakeholders will be required to investigate if available regulations and processes are suitable for geothermal operations and for supporting timely and effective decision making. Such a review could include development of regulatory guidelines for deep geothermal energy projects that can be shared and adopted by industry, local authorities and regulators to ensure that the regulatory processes are understood and applied consistently across the country.

Long-term

4. Consider developing a licencing system for the exploration and operation of deep geothermal projects. This will become more important as the sector matures and demand on deep geothermal resource increases. In addition to providing security for developers and investors, licencing enables regulators to manage the sustainable use of the UK's deep geothermal resources. Licences should specify ownership and conditions of use, including monitoring and reporting requirements. They could also be used to specify additional conditions, e.g. related to requirements for data sharing (Recommendation 3) or public engagement.

Other considerations

From the geothermal landscape review and stakeholder engagement, we have identified other considerations that are seen as important by different stakeholders for developing a geothermal sector. While responsibility for some of these could be regarded to sit with individual stakeholder groups (e.g. industry), government support could be instrumental in initiating and/or facilitating some of these activities. Further engagement is necessary to better understand the existing interactions within/ between the different stakeholder groups and industry initiatives and to identify where and how government support could be beneficial.

Recommendation 5 – Understanding public perception of geothermal energy

There is limited practical knowledge in the UK of public attitudes towards geothermal technologies. While stakeholders consulted in this study perceive public acceptance of geothermal energy as largely positive, other studies suggest that negative perception from other subsurface energy technologies (e.g. shale gas) might have affected the perception of deep geothermal energy (perception spillover) and influenced the conditions that deep geothermal would be expected to meet.[59] While ongoing projects have not met any major opposition, recent planning applications have highlighted public concerns in relation to noise and fear of "industrialising the countryside". Public acceptance will become more important as the sector grows.

Short-term

1. We recommend that a wider consultation with stakeholders, including the public, is considered to gain a better understanding of public perceptions (and apprehensions) in relation to geothermal projects. Such knowledge would inform public consultation procedures and social science approaches to behavioural change. It would benefit the sector as a whole, including developers, operators and regulators, by enabling early dialogue and implementation of actions that address public concerns and enable a positive public experience with geothermal energy.

Recommendation 6 - Facilitating communication between stakeholder groups

A few stakeholders have identified the need to form a strategic stakeholder body (or industry task force).[32] This option was not further investigated in our engagement as the representation of industry interests and coordination between stakeholder groups is typically led by national trade associations. However, the UK approach is very disjointed, with different interest groups and associations leading separate conversations at local levels of interest and limited connections nationally or across the sector (i.e. between the ground source industry and deep geothermal heat and/or power projects).

Short term

1. UK Government could have a role in supporting communication between the different stakeholder groups in this sector and work with the geothermal community (e.g. through consultations and with existing groups – identified in the full report[60]) to establish an overarching stakeholder/industry body. Further consultations with stakeholders are needed to better understand what role government could play in facilitating such communication and how it would benefit the sector.

Medium term

2. Consideration could be given to engaging experts from industry, academia and regulators in the formation of specialist groups (similar to Northern Ireland's Geothermal Advisory Committee) that advise the Government on decisions relating to building the geothermal energy sector. Such groups could support some of the activities identified in the above recommendations, e.g. the review of regulation (Recommendation 4.3) or supporting the development of a licencing system (Recommendation 4.4).

59 Westlake et al. (2023). Perception spillover from fracking onto public perceptions of novel energy technologies. Nature Energy, vol. 8, pp. 149–158.
60 More information is available in the full report.

Glossary

Aquifer: underground layers of water-bearing, permeable rocks that contain and transmit groundwater and from which groundwater can be extracted.

Boreholes: deep, narrow holes made in the ground, either vertically or inclined, often to locate water or oil.

CAPEX (capital expenditure): This is the major spending required to drill and complete wells for long term use.

Deep geothermal: term used widely to refer to systems at a depth of more than 500 m below the surface. In this document, the term is used to mean system that produce heat in the 50–200°C range of medium temperature (steam or water).

District Heating: communal heating systems that deliver heated water to a large number of homes and buildings via a heat network.

Geothermal reservoirs: underground zones of porous or fractured rock that contain hot water and/or steam. They can be naturally occurring or human-made.

Grams of carbon dioxide (equivalent) per kilowatt-hour (gCO2(eq)/kWh): a measure of carbon intensity for a technology or power system (PN 383).

Groundwater: water that exists in pores and fractures in the rocks and soils beneath the land surface where it forms saturated zones (aquifers).

Heat network: a distribution system of insulated pipes that takes heat from a central source and delivers it to domestic or non-domestic buildings.

Hot sedimentary aquifers: see hydrothermal systems.

Heat pump: a device that transfers and "upgrades" heat from a colder space to a warmer space using mechanical energy.

Hydrothermal systems: (also referred to as "hot sedimentary aquifers"): geothermal systems that contain fluid, heat and permeability in a naturally occurring geological formation or sedimentary basin for the production of heat or electricity.

Joule (J): the standard unit of energy. One joule is equivalent to the energy released as heat when an electrical current of one ampere passes through a resistance of one ohm for one second. One joule equals one watt-second or 0.00028 watt-hours.

Kilowatt (kW): a unit of power equal to one thousand (10^3) watts.

Kilowatt-hour (kWh): a unit of energy equal to one thousand (10^3) watt-hours.

Megawatt (MW): a unit of power equal to one million (10^6) watts.

Permeability: a measure of whether and how fast water can flow through a rock.

Petajoule (PJ): a unit of energy equal to one quadrillion (10^{15}) joules.

Resource (according to UNFC-19)[61]: the cumulative quantities of geothermal energy that will be extracted from the available geothermal energy source. The term is only applicable to areas where the existence of a significant recoverable geothermal energy has been proven (i.e. Known Geothermal Sources).

Sedimentary basins: low areas in the Earth's crust, of tectonic origin, in which thick deposits of sediments accumulate over geological time periods.

Watt (W): a unit of power - the rate at which energy is transferred or converted.

Watt-hour (Wh): a unit of energy equivalent to using one watt of electricity for one hour. One watt-hour is equal to 3,600 joules

61 UNECE (2019) Supplementary Specifications for the application of the United Nations Framework Classification for Resources (Update 2019) to Geothermal Energy Resource.