Government
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Future of the Subsurface: Geothermal Energy Generation in the UK

June 2024

Foresight

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Artwork credit: Cleo Zhang

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Overview

- **This document is an annex to the *Future of the Subsurface* report completed by the Foresight team in the Government Office for Science. It has been informed by a literature review and stakeholder engagement, and draws on a series of UK and international case studies to highlight current issues and potential solutions for subsurface space management. The document structure is outlined below, along with key points from each section.**

- **Background:** The review begins by introducing geothermal energy. Geothermal energy is energy in the form of heat that is stored below the Earth's surface. It derives largely from within the Earth, though at shallow depths heat is partially provided by solar radiation. The temperature of geothermal heat and extraction technology used varies by depth and geology. Near the surface, shallow geothermal heat is stored in the ground, aquifers, and in flooded coal mine workings. It can be extracted by ground source heat pumps and is suitable to be used for heating. Deep geothermal energy is extracted from depths greater than 500m, and it can be suitable for either direct-space heating or power generation depending on temperature and depth.

- **Current UK Status:** The review then introduces the current UK status, and some UK examples of geothermal applications. Geothermal heat provided 0.3% of annual heat demand in the UK in 2021, which included 43,700 ground source heat pumps, deep geothermal direct-use and mine geothermal schemes. Geothermal heat is not regulated as a natural resource and whilst geothermal developments are regulated, the particular regulations governing them vary by the type of heat extraction technology used and in each devolved administration of the UK. Current examples of geothermal applications in the UK include a pilot scheme to provide geothermal heat as a utility, a scheme providing heat to homes from flooded mine workings in Gateshead, and the first geothermal power plant which is under development in Cornwall.

- **International Examples:** The review then considers some international examples. Outside the UK, the US, Indonesia and the Philippines lead in geothermal energy development, whilst Sweden and the Netherlands have ambitious programmes for expanding geothermal use. France and Germany are also looking to expand their geothermal energy usage and have developed ambitious targets and strategies to increase its use. As France and Germany have similar geology to the UK, they are presented as potential examples to follow.

- **Challenges and opportunities:** the review then highlights some challenges and opportunities related to geothermal energy production in the UK. There are significant benefits of geothermal energy compared to other forms. Geothermal energy is low carbon, and is available constantly and domestically, meaning it can contribute to net zero whilst also improving energy security. The most significant opportunity geothermal energy presents is decarbonising heating buildings which accounts for around 17% of UK emissions through deploying geothermal heat schemes at scale. However, significant barriers to the effective deployment of geothermal schemes include complexity and gaps in regulation, high project costs and a lack of accessible subsurface data.

- **Example systems interaction:** the review ends by showing an example systems interaction. The availability and extraction of geothermal heat is affected by, and affects, many other parts of the subsurface system. External factors such as conditions at the surface can also have an effect. The review outlines one example interaction developed in the project in consultation with stakeholders, based around transport tunnels and heat.

Background

Geothermal energy varies by depth and can be exploited through different extraction technologies. In the UK, the subsurface heat gradient is relatively low compared with other countries such as Iceland, meaning its temperatures are generally more suited to heating, rather than power generation. This section gives an overview of geothermal energy by depth in the UK.

Shallow Geothermal Energy

Shallow geothermal energy is the low-grade heat resource (~10–25°°C) which is found in the shallow subsurface, up to depths of 500m.[1] This is stored in the shallow ground, groundwater (aquifers) and flooded coal mines, and is typically exploited through ground source heat pump (GSHP) systems to provide heating or cooling. GSHPs extract heat or cool from the ground either via 'closed-loop' systems which circulate a heat carrier fluid through pipes installed in the ground to abstract heat (a borehole heat exchanger), or 'open-loop' systems where groundwater is pumped from aquifers or flooded mines to extract the heat.[1]

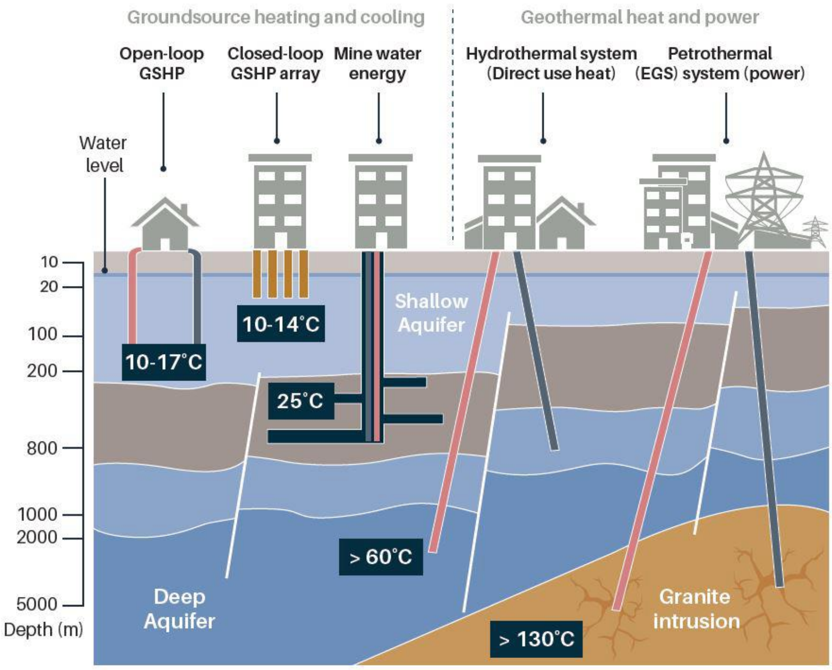

Figure 1: Image showing different types and ranges of geothermal systems. Source: [British Geological Survey © UKRI. All rights reserved.]

GSHPs offer a low carbon alternative to heating buildings compared with traditional methods such as using gas boilers. Although GSHPs generally have higher upfront costs than air source heat pumps (ASHPs) which extract heat from the air, they are more efficient and therefore tend to have lower running costs. This is because the ground has a more stable temperature than outside air so that in winter the temperature of the ground is much higher than that of the air. This means that a ground source heat pump does not need to use as much electricity to upgrade the energy from the ground to usable heat compared with an air source heat pump, making it more efficient.[2] GSHPs are operated using electrical energy and have operational efficiencies of up to 400%.[2]

Given that heat may be stored in a variety of settings and depths in the subsurface (e.g. ground, aquifers, flooded mine workings) and the design flexibility of different types of GSHPs, shallow geothermal systems are feasible almost anywhere in the UK. GSHP systems vary in scale from supplying individual buildings, to district-scale applications.

According to the International Energy Agency (IEA) Geothermal Annual report 2022, the UK has an estimated 43,700 installed GSHP systems.[3] In comparison, Germany has over 440,000 (in 2020), and France over 210,000 (in 2018).[3]

Deep Geothermal Energy

Deep geothermal systems require the drilling of wells of greater than 500m depth to reach higher temperature heat resources.[4] Depending on temperature and depth, deep geothermal energy can be suitable for direct-use space heating, and/or industrial processes. Exploration priorities include areas with the highest geothermal gradient (higher temperatures nearer the surface), most suitable target geology to minimise the distance and expense of drilling, and formations and structures with preferential hydraulic properties (most developments rely on the production and re-injection of water). The UK's deep sedimentary basins offer potential and areas around heat-producing granites have above average geothermal gradients.[5,6] Drilling costs are much more significant to extract deep geothermal energy compared with shallow.

There are two categories of deep geothermal energy:

(i) Hydrothermal systems (hot sedimentary aquifers)

Sedimentary basins (deep geological basins filled with consolidated sediments) are dispersed across Great Britain and parts of Northern Ireland and typically contain deeply buried sandstone and limestone.[7,8] Groundwater circulation within these rocks forms hydrothermal systems which comprise three key components: heat, water, and permeable rocks.[9] Hydrothermal systems can occur in a diverse range of geological settings, although generally there is no physical indicator of their presence at the surface (e.g. hot springs).

Many major UK population centres are above or adjacent to sedimentary basins or hot sedimentary aquifers, which have temperatures estimated to be between 40 ˚C to 60 ˚C making them most suited to provide direct-use heating.[5] Heat currently cannot be economically transported over long distances because of high distribution losses along the way, so opportunities focus on areas of high heat demand or in developing new heat users (e.g. horticulture, heating greenhouses).[5]

(ii) Engineered geothermal systems

Engineered geothermal systems (EGS) can be used in areas where underground rock is hot but there is not enough natural permeability or fluids present to extract the heat. This could facilitate and extend geothermal energy production beyond traditional hydrothermal regions.[10] Deeply buried rocks (up to 9 km depth) in the UK have potential for geothermal power generation through this technique. Currently there are no EGS in UK, but some countries such as the United States are exploring the technology further.

Current Status in UK

Geothermal sources including GSHPs, deep geothermal direct-use and mine geothermal schemes supplied 0.3% of the UK's heat demand in 2021, using only a fraction of the UK's estimated accessible geothermal heat.[9] This section covers different aspects of the geothermal energy in the UK, including its legal status, current governmental support, and examples of geothermal applications and developments.

Regulation

In the UK, geothermal energy is not recognised as a natural resource, unlike other natural resources such as water or gas. There is no bespoke regulatory system for the licensing, ownership and management of geothermal heat.[9] Whilst geothermal developments are regulated, and the particular regulations governing them vary by the type of heat extraction technology used. However, these vary in each devolved administration of the UK.

Therefore, there is no overarching geothermal regulatory regime, and instead it comprises of a number of different regulations, planning permission granted by Local planning authorities (LPA) overseen by the devolved administrations, Coal Authority Planning, and health and safety laws, none of which explicitly regulates the extraction of heat (Scottish Government , 2017).[11,9,8,] For example, some closed loop geothermal schemes may not require any planning permission at all. This may lead to overextraction of geothermal heat and unintended interactions with other subsurface resources and infrastructure.[12] Introduced in October 2023, new closed loop ground source heat pumps are now subject to General Binding Rules. These include not being within 250m of protected sites or ancient woodland, not within 50m of a well or spring or borehole supplying water used for domestic/food production. The system must be fully sealed and must not cause pollution of surface water or groundwater, however there is no defined threshold for releasing heat. Any divergence of the binding rules must apply for a bespoke permit.[13] Another example is the rules governing shallow open loop schemes in flooded coal mine workings, which focus on water and access to property. Geothermal heat is not included in their regulations.

Section 43 in the Infrastructure Act (2015) states that "a person has the right to use deep-level land in any way for the purposes of exploiting petroleum or deep geothermal energy." Deep-level land in this instance is land at any depth of at least 300m below the surface.[14] Whilst geothermal is a renewable resource, there is potential for geothermal heat to be extracted at a higher rate than it can be replenished. Therefore, multiple geothermal operations extracting from the same geothermal heat source has the potential for one operation's extraction to interfere with the other and reduce their efficiency. A lack of legal recognition and licensing explicitly targeting geothermal heat exacerbates this risk further.

McClean and Pedersen's review of the regulation of geothermal energy in the UK describes it as 'piecemeal' has suggested that the current regulatory framework does not address the high upfront costs of both shallow and deep geothermal systems.[12] Additionally, current regulation does not do anything to prevent the over abstraction of geothermal heat or have a mechanism for balancing the interests of multiple users.[12] The lack of *bespoke* planning rules or regulation applicable to geothermal installations means there is a 'regulatory gap'.

Government financial support

There are a number of different sources of governmental financial support available to new and existing geothermal schemes depending on whether they produce heat or electricity. Although the geothermal sector does not currently have a bespoke package of long-term policy targets and financial support from the UK government, some government incentives and financial support schemes cover specific geothermal installations.

The funding available varies across the devolved administrations. For example, in England, the Green Heat Network Fund operates aims to use targeted financial support to incentivise the heat network market transition to low carbon sources. The scheme covers geothermal heat as a source of low carbon heat.[15] The Boiler Upgrade Scheme, which is open to people in England and Wales, offers grants to cover part of the cost of replacing fossil fuel heating systems with a heat pump or biomass boiler, and includes ground source heat pumps.[16]

Support for geothermal projects specific to Scotland has included the Geothermal Energy Challenge Fund which was part of the Low Carbon Infrastructure Transition Programme. This made grants available to explore the technical and economic feasibility, as well as environmental sustainability of geothermal resource sites.[17] The Heat Network Fund offers capital grants to businesses and organisations in the public, private and third sectors to develop heat network projects in Scotland.[18]

In Northern Ireland, geothermal energy potential is being explored through a multimillion-pound project funded by the Department for the Economy. This project, GeoenergyNI, is being delivered by the Department for the Economy with scientific support from the Geological

Survey of Northern Ireland. Its objective is to investigate geothermal feasibility in two locations in NI to show its potential for heating and cooling, with the ultimate aim of encouraging further private sector investment into geothermal technology in Northern Ireland.[19]

Shallow geothermal energy

Shallow geothermal heat can be extracted through ground source heat pumps, which extract heat from the ground or from mine water. The UK has 43,700 shallow ground source heat pump installations.[3]

One innovative initiative is setting up infrastructure to provide geothermal heat as a utility where participating residents will get their energy from a shared ambient network of ground source heat pumps. The project is being run by Kensa Utilities and funded by the European Regional Development Fund, and it is taking place in Stithians in Cornwall over a two-year period.[20] This project is thought to be the first of its kind where homeowners will pay a monthly charge to access the heat network. This network also mirrors the existing gas grid and is designed to accommodate future connections, giving households the option to switch over their heating system at a later date. Additionally, customers can choose their energy provider.[20]

Mine Water Heat

Mine water heat is a specific type of shallow geothermal heat stored in flooded shallow coal mine workings, which 25% of properties in the UK are located above.[21] This is shown through the work of BGS and the Coal Authority who have mapped the geothermal mine heat potential in Great Britain.[22] There are a number of schemes in development to utilise this potential, involving The Coal Authority, academics, local authorities and central government.[23]

The **Gateshead Mine Water Heat Network** is currently the UK's largest scale mine water heat network. It is operated by the Gateshead Energy Company and has been live since March 2023. This scheme uses a 6MW water source heat pump to recover heat from disused coal mines 150m beneath Gateshead and supply it to a range of building types, including several offices and 350 council-owned homes. In the future, the scheme will supply heat to further buildings including a hotel development and privately-owned homes and is projected to estimate 72,000 tonnes of CO2 over 40 years.[23]

Other schemes in development include Seaham Garden Village, which is a domestic mine water heat scheme. This could provide heat to 1,500 new homes and have an estimated lifetime saving of 63,989 tonnes of CO2 over a 25-year period.[23]

Deep geothermal energy

There are currently 32 deep geothermal projects at different stages of development in the UK, including four which are operational, several which are under development, and more than 20 which have been assessed at the pre-feasibility and/or feasibility phase, although many of these have been stalled.[4] Two of these projects are outlined below.

The **United Downs Deep Geothermal Power (UDDGP)** project is under development and will be the first geothermal power plant in the UK, as well as the first integrated deep geothermal power and heat project in the UK.[24] The project's aim is to produce power and heat from the hot granite rocks beneath Cornwall at the United Downs Industrial Site near Redruth. Two deep directional wells have successfully been drilled for the plant, with the production injection wells reaching depths of over 5km and 2km respectively.[24] The plant is expected to start producing power in 2024 and will deliver electricity (2MWe) and low carbon heat (up to 10MWth) to a large housing development at Langarth, which is being developed by Cornwall Council.[25]

The **Eden Geothermal project** is supplying heat to the Eden Project to decarbonise its power supply.[26] The scheme took more than a decade to deliver and has been operational since June 2023. The length of its well is over 5km and circulates water from the ground through a loop within the well to extract heat.[27]

International examples

This section highlights some international examples where geothermal energy is showing promising developments. Globally, the US, Indonesia and the Philippines lead in the development of geothermal energy (Think Geoenergy , 2023). Sweden and the Netherlands have ambitious programmes for expanding their use of geothermal sources. France and Germany are also looking to expand their geothermal energy usage, and they have similar geology to the UK and are therefore highlighted below as potential examples that the UK could follow.[9]

The US, Indonesia, and the Philippines

The US is a world leader in geothermal energy representing around a quarter of geothermal capacity installed worldwide, and geothermal accounts for around 0.4% of the country's electricity generation.[28] There are a number of initiatives across the US looking to capture the opportunities of geothermal energy, including data capture, retrofitting unused oil and gas wells, federal tax credits, and research into EGS.[29]

Indonesia is located on the Pacific Ring of Fire and is home to approximately 150 active volcanoes and ranks 2nd worldwide to the US in installed generating capacity. It is home to around 40% of the potential global geothermal resources.[30] However, geothermal accounts for just 6% of the country's power supply, and there are challenges to scaling due to high costs and uncertainties associated with exploration and drilling.[30] The Indonesian government aims to have renewables cover 23% of electricity generation by 2025, but it is currently behind target.[30]

In the Philippines, deep geothermal accounts for around 10% of total power generation.[31] Their government has banned the construction of new coal-fired power plants and aims to increase the share of renewables to 35% in 2030 and 50% in 2040, including 8% of geothermal by 2030.[32] A lot of the success in scaling geothermal in the country has been a result in increased foreign investment, with 100% foreign ownership being allowed for large-scale geothermal projects since 2020.[32]

Sweden

Around a fifth of all buildings in Sweden rely on geothermal heat pumps for heating and cooling, making it the world leader in usage of shallow geothermal, which covers 10% of total heat demand in the country.[33] The growing demand for heat pumps has been largely driven by consumer awareness of their financial and energy savings and environmental benefits.

The energy crisis in the 1970s led to a goal of becoming independent from fossil fuel imports, and Sweden created a Commission for Oil Independence in 2005, and this has remained a constant focus in national energy policy since, with fossil fuels making up only 3% of share in heating fuels. This push to move away from oil heating provided a boost in research and development in heat pump technology, alongside promotion by governments, information campaigns, grant payments for heat pumps, and a CO2 tax which was introduced in 1991.[34] Sweden plans to fully decarbonise district heating by 2030 and to be carbon negative by 2050, and geothermal contributes to these energy goals.[35]

The Netherlands

As of 2022, the Netherlands had around 28 operating geothermal projects, with potentially 70 further projects in the pipeline over the coming years.[36] Deep geothermal projects are mostly drilled for heating greenhouse complexes, whilst shallow geothermal is mostly used for single houses.[37]

The country has an ambitious target for geothermal energy to meet 5% of the total energy demand for heat in 2030 and 23% in 2050.[38] In 2018, the Dutch geothermal sector released a master plan for geothermal energy, outlining a common ambition in the sector, and what is required from the government to help realise their ambitions. This plan pointed out the importance of district heat networks for reaching net zero.

Subsurface data is publicly available in the Netherlands, and this tackled barriers such as geological uncertainty and risks to determine investment, reducing costs and barriers highlighted later in this review.[39] The amendment of the Mining Act introduced a new licensing system that applies specifically to geothermal energy, allowing organisations to start extracting geothermal energy immediately after drilling during exploration phase and the construction of an extraction facility.[40] This will allow for faster application and decision periods, and reduced investment risk. The Dutch government also put in place a risk-guarantee fund to mitigate the geological risk of deep geothermal drilling, covering 85% of the investment in case of complete failure, encouraging further investment in the sector.[41]

France

In France, heat produced by deep geothermal energy is mostly used to supply urban heat networks.[42] For example, the city of Paris has been using geothermal energy for heating since 1969 and geothermal energy supplies heat to 250,000 households from 50 heating networks.[9] The Middle Jurassic carbonate is the main aquifer used in the Paris region and is the most productive in Europe in terms of geothermal potential.[43] Geothermal energy is also being used to cool the Olympic village this year, which will remove the requirement for traditional air conditioning.[43]

France aims to increase its share of renewable energy to 38% by 2030 and is including geothermal energy as a major part of its plans to reach net zero by 2050.[44] The French Government has launched an action plan that aims to accelerate the development of surface and deep geothermal energy in mainland France with the aim to increase the number of deep geothermal schemes by 40% by 2030.[45]

Germany

Germany is home to one of Europe's largest geothermal reserves and currently has 42 geothermal power stations, with around 420,000 ground source heat pumps providing heating to buildings across the country.[9] The industry has generated around €14.9 billion since 2000 and has created around 24,000 jobs.[9]

The groundwater in the state of Bavaria has favourable temperatures for deep geothermal use, and most of Germany's geothermal plants are located here. Munich for example has six geothermal plants, and 50,000 homes are supplied heating from geothermal energy as of 2020, achieving carbon savings of 75,400 tonnes per year when compared to natural gas heating.[4] A seventh geothermal plant is planned to be built this year, and it will supply heating for a further 75,000 residents in Munich from 2029.[46]

The Prime Minister for Bavaria has announced a faster expansion of geothermal energy for heat generation in Bavaria, with a target of 25% of Bavarian heating requirements to be covered by geothermal energy by 2050.[47] This included 10 million euros in investment into geothermal research.[48]

References

In 2022 the German government published a key issue paper highlighting strategies for developing geothermal projects, with a plan to increase the production of geothermal energy tenfold by 2030 and 100 additional geothermal projects by this time.[48]

Future challenges and opportunities

Geothermal energy is a valuable resource which could be further utilised to help decarbonise the heating sector and as a source of renewable energy in the transition to net zero. However, there are significant challenges which could act as a barrier to deploying geothermal energy schemes at scale and realise its full potential. This section outlines some of these challenges, as well as opportunities in developing geothermal energy applications.

Challenges

Regulation and governance - complexity and gaps: the regulation of geothermal developments is complex and varies by devolved administration. Although there are regulations which apply to geothermal developments including environmental licensing and local planning regulations, geothermal energy is not regulated as a natural resource and there is no bespoke regulatory regime for geothermal installations, leading to a 'regulatory gap'. There is no regulation or licensing to prevent the over abstraction of geothermal heat or balance the interests of multiple users which could become an issue as the number of geothermal schemes increases.[12]

These gaps can create a lack of ownership and lead to uncertainties over access and investment returns, presenting barriers to the effective scaling up of geothermal technologies. However, it is also worth considering whether the lack of 'red tape' can promote rather than hinder the take up of geothermal technologies in certain circumstances, though of course this must be balanced with wider subsurface management considerations and environmental protection.

High project costs and funding: high project costs, the low maturity of the sector, and specific financial and geological risks associated with geothermal projects mean that it is currently very challenging for geothermal projects in the UK to secure the funding they need.[4] Deep geothermal projects have high capital expenditure costs which vary depending on the number and depth of boreholes, although Arup have estimated that these are typically between £2 to £4 million per MWth of heat capacity provided. High costs are mainly due to drilling and testing, which is estimated to cost between £1.6 to £1.8 million per km depths for 1-2 km vertical wells (Arup, 2021). In one study conducted by BGS in partnership with Arup, stakeholders considered substantial upfront costs to be 'one of the main barriers to wider uptake of geothermal energy in the UK' and have 'identified a need for financial support and risk-sharing mechanisms for geothermal projects like those available in other European countries'.[4]

Government support and investment: governmental support and investment has been identified as a challenge to deploying geothermal projects and developing the geothermal sector. In one study, geothermal industry stakeholders perceived the support available for geothermal projects as poorer compared with the support available for other renewable energies, such as wind or solar.[4] Additionally, the POST geothermal study states that geothermal stakeholders believe that in order for the geothermal sector to develop in the UK, a "route to market' is needed.[9] Both ground source heat pumps and deep geothermal energy schemes have been identified as needing targets, which can then be supported by governmental legislative, revenue or subsidy support. Government risk-sharing schemes have also been highlighted as a key mechanism which could be used to realise the potential of deep geothermal heat.[9]

Supply chains: the Future Homes Standard (FHS) is due to come into effect in 2025, requiring all new homes in England to be heated by low-carbon heating sources. One study states that industry stakeholders view the FHS optimistically, though concerns remain over manufacturing capacity and supply chains.[9] Although some elements of the geothermal supply chain exist in the UK, the limited number of geothermal projects means that these are not coordinated. Some aspects of the supply chain such as heat exchanger and power plant technologies are mature enough to be deployed for geothermal heat generation. However, some current projects have had to source equipment and skills for more specialist aspects, such as deep drilling, from outside the UK.[4]

Geothermal data availability and accessibility: a lack of geothermal data availability and accessibility challenges the effective deployment of geothermal heat projects. For shallow geothermal developments, data needs to be more accessible, available digitally and interoperable across all geological types. This includes the need to better map and identify areas with shallow heat potential. For deep geothermal developments, further mapping work is still needed to identify areas with direct deep geothermal heat potential (Jones, 2023). The main datasets which are helpful relate to geological information and legacy data from deep boreholes[4,49]. The categories of data can vary according to the type of geothermal project but include temperature, water chemistry, thermal conductivity, aquifer depth, and permeability or transmissivity.[7] Production testing, including of exploration wells, is also needed.

Opportunities

There are significant opportunities to develop new geothermal energy applications, which as well as decarbonising heat could be used to provide cool and energy storage. Deploying more geothermal applications could bring benefits including increased energy security, opportunities to generate jobs, and contribute to net zero. Opportunities are covered below in more detail, as well as applications of geothermal energy which could become more feasible in the future, such as using it for power generation or co-delivering geothermal energy with mineral extraction.

Improved energy security: geothermal energy can play a key role in improving the energy security of the UK.[1] It's available at all times of the day and year and is extracted domestically, meaning it can reduce reliance on imports. For example, in the heating sector, 80% of domestic heating is still delivered by gas boilers. Therefore, an increase in utilising geothermal energy for heating could reduce reliance on gas imports.[1]

Job creation and economic growth: there is significant potential for geothermal projects to stimulate economic growth and create jobs in the UK. Countries geologically similar to the UK such as Germany have created a significant number of jobs through geothermal projects.[50,] Geothermal projects in the UK have already generated jobs and contributed to local economies, for example the Eden Geothermal Project has generated an estimated 254 total jobs throughout the project.[4] This demonstrates that deploying geothermal technology at scale could create even greater effects.

A study by the Durham Energy Institute has identified a list of 45 local authority locations with the greatest likely deep geothermal potential. This list includes 6 of the top 10 local authorities with lowest economic resilience, while 44% of the list fall within the top 100 locations qualified for the UK Community Renewal Fund.[51] This overlap was highlighted in Dr Kieran Mullan MP's 'Dig Deep' report on deep geothermal energy, which states that 'investment in deep geothermal is investment that is likely to contribute to the levelling up agenda'.[51]

Developing **mine water heat** could also generate jobs and economic benefits. The Coal Authority estimate that 25% of the UK's built environment is located above abandoned coal mines, meaning that there could be significant levelling up and energy security opportunities underpinned by the development of heating and cooling systems using flooded mine workings.[21] Based on an initial feasibility work, the Coal Authority has identified 42 points of contact for mine heat which are at a good enough point to progress.[4] If these were to proceed, they could create 4227 jobs directly and an estimated £293 million gross value added (GVA). Indirect and induced economic effects could create an additional 9-11,000 jobs and an additional £400-500 million GVA.[4]

Improvements to geothermal management data availability: there are opportunities to improve the availability of geothermal data and the mechanisms for making decisions about geothermal developments to help realise the potential of geothermal projects.

For data, improvements could include creating **an open access geothermal portal**. There is data and information and geothermal resources which already exists and are held by organisations such as BGS and the GSNI. Local authorities could use this data to identify opportunities to utilize geothermal heat in their local areas if it was presented in a format which was accessible to local energy planners.[9]

Managing geothermal heat at a systems level could also facilitate utilising the different aspects of geothermal heat, such as managing supply and demand, and using the ground as buffer for inter-seasonal heat.[9] In areas with high system density, there is a higher risk of thermal interference for example, in central London where many large GSHP schemes are within 250-500m of each other.[9]

Extending, improving and/or streamlining regulation and governance could help facilitate the development of geothermal applications. Changes to the planning process or legislative changes to license or manage geothermal heat as a resource could help with the systems management of geothermal heat which would be needed to manage multiple co-existing uses. Whilst regulators and many in industry regard this as a functional system, there is consensus among industry that streamlining regulatory processes could promote and facilitate the wider uptake of geothermal technologies.[4]

Technological innovations and new applications of geothermal energy: as well as existing geothermal technologies, there are further applications being developed where geothermal energy or heat is delivered alongside other functions.

Geothermal energy storage systems: the ground can be used for 'underground thermal energy storage' to store excess heat, such as from renewables or industry.[9] Geothermal storage technologies are longer duration than other energy storage technologies, meaning they can store energy securely and reduce energy losses whilst inactive.[9] This makes geothermal storage particularly attractive as long-duration energy storage will be essential to support a secure and flexible energy system in the net zero transition as the UK's energy system continues to move towards renewables and away from fossil fuels, as these have often been used to manage variations in energy demand.[9]

Co-delivering geothermal energy with mineral extraction: geothermal water from deep rock can contain rare earth minerals, such as lithium. One innovation is combining mineral and geothermal energy extraction from water brought to the surface.[52] Geothermal energy could also power the mineral extraction itself and produce zero carbon minerals.[53] There is currently a pilot plant which has extracted lithium from geothermal waters at the United Downs Geothermal Test site in Cornwall.[54] This could offer greater domestic supply of scare minerals and through a much more environmentally sustainable method to mining.

Integrating geothermal energy with other renewables: geothermal energy could be used to provide a baseload fallback supply of energy at the same site as intermittent renewable technologies (e.g. solar and wind). Not only is geothermal continuously available throughout each day and year, ensuring a baseload power supply, but the hybrid integration of renewable technologies at the same site can sometimes offer greater results than the sum of the individual technologies alone.[52] Solar can increase heat for geothermal systems, while geothermal systems can store excess solar energy.

Example systems interaction

The availability and extraction of geothermal heat is affected by, and affects, many other parts of the subsurface system. External factors such as conditions at the surface can also have an effect. To illustrate some specific subsurface interactions, we have isolated and refined three example interactions, chosen in consultation with stakeholders as particularly interesting and illustrative of subsurface challenges, one of which is shown below. These include both 'feedback loops' and linear chains of interactions, described below. Further information about the example interactions, including their development, is shown in the main *Future of the Subsurface report*.

Figure 2 depicts the potential consequences of an increased use of transport tunnels below ground.

Through the use of transport tunnels heat is ejected that for a long time was absorbed by the surrounding ground. However, the capacity of the ground to absorb heat is limited, so that transport tunnels today retain heat and overheat. Without efforts to reduce heat in the tunnels, the heat could reduce train usage.

On the other hand, the excess heat could be harvested as geothermal heat, for example through fitting the tunnel liner with loops to extract heat from the tunnels, or through extracting heat ejected to the ground, which could be fed into district heating networks or supplied to nearby buildings. This happens in Islington, where waste heat from London Underground network feeds into a district heating network, which is used to heat 1,350 homes, two leisure centres and a school.

Interactions with the wider subsurface system

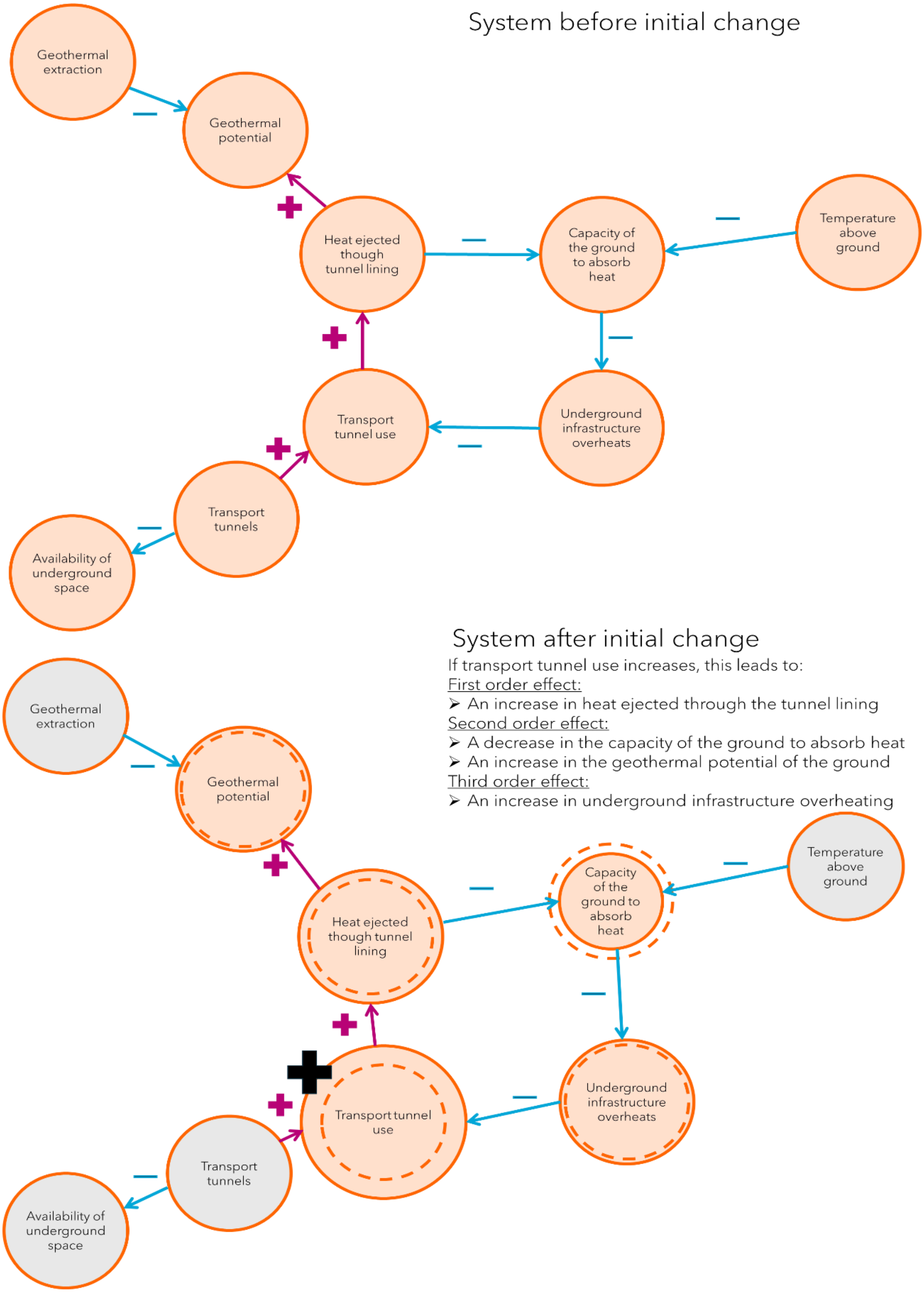

Figure 21: This figure shows an example interaction highlighting how increasing the use of transport tunnels could impact the ground through the heat this produces.

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