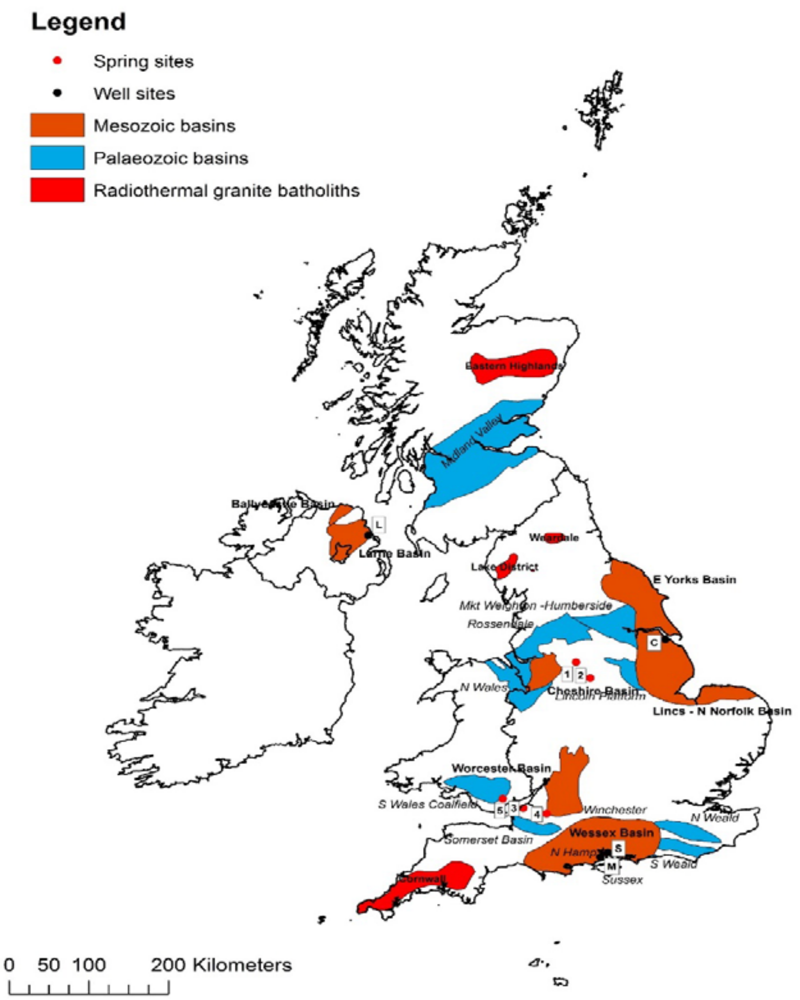
Unlocking the potential of geothermal energy in the UK

Decarbonisation and Resource Management Programme

Open Report OR/20/049



BRITISH GEOLOGICAL SURVEY

DECARBONISATION AND RESOURCE MANAGMENT PROGRAMME

OPEN REPORT OR/20/049

Unlocking the potential of geothermal energy in the UK

Corinna Abesser, Jonathan P. Busby, Timothy C. Pharaoh, Andrew J. Bloodworth , Robert S. Ward

Keywords

Geothermal energy resource, UK, regulation, policy support, decarbonisation.

Map of potential geothermal resources in the UK.

Bibliographical reference

ABESSER, C, BUSBY, J P, PHARAOH, T C, BLOODWORTH A J, WARD, R S. 2020. Unlocking the potential of geothermal energy in the UK . *British Geological Survey Open Report*, OR/20/049. 22pp.

Keyworth, Nottingham British Geological Survey 2020

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of UK Research and Innovation.

British Geological Survey offices

Nicker Hill, Keyworth,
Nottingham NG12 5GG

Tel 0115 936 3100

BGS Central Enquiries Desk

Tel 0115 936 3143
email enquiries@bgs.ac.uk

BGS Sales

Tel 0115 936 3241
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South,
Edinburgh EH14 4AP

Tel 0131 667 1000
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road,
London SW7 5BD

Tel 020 7589 4090
Tel 020 7942 5344/45
email bgslondon@bgs.ac.uk

Cardiff University, Main Building, Park Place,
Cardiff CF10 3AT

Tel 029 2167 4280

Maclean Building, Crowmarsh Gifford,
Wallingford OX10 8BB

Tel 01491 838800

Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB

Tel 01232 666595
www.bgs.ac.uk/gsni/

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

UK Research and Innovation, Polaris House,
Swindon SN2 1FL

Tel 01793 444000
www.ukri.org

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report is intended to provide technical information that complement the BGS Science Briefing Note: ***Deep impact: Unlocking the potential of geothermal energy for affordable low-carbon heating in the UK*** [1]. *It gives a general overview of the deep geothermal opportunities that exist in the UK (although regional geothermal potential is not discussed here) as well as of financial, policy and regulatory actions that are needed to support the effective development and exploitation of deep geothermal resources in the UK. The recommendations are applicable to the UK government and its departments as well as to devolved administrations in Scotland, Northern Ireland and Wales, and devolved policy areas, such as heat policy and planning, in the respective nations.*

Following the introduction, the report is organised in three sections. In Section 1, details are given of the UK's deep geothermal resources and how and where they could be utilised. Section 2 focuses on the experiences of continental Europe and the policies that have enabled the growth of a geothermal industry. Section 3 considers key policies and regulatory actions identified as necessary to drive the development of the UK geothermal sector from its current status of infancy to a mature technology that is universally recognised and utilised by a wide range of stakeholders, end-users and supported by investors.

Acknowledgements

This document is the outcome of a workshop and wider consultation undertaken by the British Geological Survey (February - May 2020), who has extensive technical expertise in geothermal resource mapping and provides objective and authoritative geoscientific data, information and knowledge to inform UK Government on the opportunities and challenges of the subsurface environment. We have engaged and consulted with a wide cross-section of geothermal stakeholders including industry advisers, consultants, contractors, academics, local authorities and regulators that have informed the writing of this paper. We gratefully acknowledge contributions from the following individuals and organisations / companies:

- Bestec (UK) Limited
- John Beswick, Marriott Drilling
- Professor Maeve Boland, University College Dublin / Geological Survey Ireland
- Nick Cameron, BP
- Eden Geothermal Ltd
- EGS Energy Limited
- Dr Aidan Foley, Mott MacDonald Ltd
- Dr Ryan Law, Geothermal Engineering Ltd
- Ove Arup and Partners Limited (Arup)
- Riccardo Pasquali, GT Energy UK Ltd
- Storengy UK
- David Townsend, TownRock Energy

as well as from a number of other contributors who wish to remain anonymous.

We would also like to express our gratitude towards Dr Vanessa Banks and Ms Jo Booth from the British Geological Survey for their valuable support in organising and facilitating the workshop

Contents

Foreword i

Acknowledgements ii

Contents iii

Summary iv

1 Introduction 1

2 Section 1: Deep geothermal energy..1

2.1 Hydrothermal systems 1

2.2 Engineered Geothermal Systems –EGS (‘Petrothermal’)...4

2.3 Geothermal finance and risks 4

3 Section 2. Geothermal developments in Europe 5

4 Section 3. Policy and regulation support for the UK geothermal sector........................8

4.1 Risk sharing and financial support 8

4.2 Streamlined regulations and a national licensing system 10

4.3 Geothermal targets linked to government goals and policy 11

4.4 Government-supported research, data sharing and skills transition 11

FIGURES

Figure 1. Different ground source (left side) and deep geothermal (right side) energy technologies. 2

Figure 2. Map of potential geothermal resources in the UK, including existing geothermal wells 3

Figure 3. Geothermal risk and cumulative investment costs (after Dumas et al. 2019 [23]) 5

Figure 4.Geothermal developments in the Munich area, Germany, by the city’s utility company Stadtwerke München (SWM). 6

Figure 5. Support schemes for Geothermal adapted to technology maturity (from Dumas et al. 2019 [23]) 9

Summary

Geothermal energy provides an indigenous, low-carbon and green alternative to conventional heating and power generation. With an estimated heat potential of 328 x 10^{18} J_{th} [2] and a power potential of 2280 MW_e [3], **geothermal energy resources in the UK are sufficient to deliver about 100 years of heat supply for the entire UK and to provide an equivalent of 85% of Scotland's and 9% of England's current electricity demand** [based on 4]. Available 24 hours a day and 365 days a year, geothermal energy can offer a widely applicable, affordable and constant baseload supply of heat (and power) plus the potential for significant inter-seasonal thermal storage for waste heat and cold. Hence, use of this resource could make a significant contribution to the decarbonisation efforts of the UK.

There is no strict definition for "deep geothermal", but the term has been adopted by the UK government to refer to heat resources derived from a depth of >500m. Subsurface temperatures at that depth are around 25°C, increasing to 39°C, 89°C and 139°C, at 1000m, 3000m and 5000m, respectively, for most parts of the UK. While these temperatures (classed as low-enthalpy) are below the economic threshold for conventional (steam turbine) power generation (which is > 160°C), they are sufficiently high to provide heat for direct-use space heating as well as for a variety of heat-intensive industrial processes and agricultural applications. In conventional hydrothermal systems, the heat is transported by groundwater, circulating within deep aquifers. It is exploited via a so called "doublet system" consisting of two deep boreholes (drilled to depths of 5km or deeper): one for abstracting hot water and one for re-injecting the cooled water (after heat extraction) back into the deep aquifer system.

There are a number of places in the UK onshore where such hydrothermal systems could provide a geothermal resource. These often coincide with areas of high heat demand; for many areas of the UK it would be technically feasible to exploit geothermal resources for space heating using district energy schemes.

Medium to high-enthalpy geothermal potential is limited in the UK to areas where geological features, e.g. the presence of radiogenic granites, have resulted in increased heat flows (e.g. Cornwall, Northern England and Scotland). While temperatures at economically-drillable depths (currently ~5km) are sufficiently high (> 200°C) for power generation with binary-cycle power plants or for industrial and residential (direct-use) heating, granites are not naturally porous (typically <1% pore space) or water-bearing. Hence, the heat is abstracted by injecting water into the system and circulating it through natural fractures in the rock between two deep boreholes or through engineered pathways. Resource estimates indicate that the geothermal resource base in the UK for such, so called Engineered Geothermal Systems (EGS), is around 700 times that for direct use (hydrothermal) systems.

Despite this vast availability, geothermal resources in the UK are not yet properly recognised. At the time of writing, the installed capacity for direct use heat is only ~2 MW_{th} and there is no operational EGS scheme in the UK, although two EGS projects - the United Downs Deep Geothermal project (UDDGP) and the Eden Geothermal project - with a combined investment of around £40 Million, are in the process of being developed at two sites in Cornwall.

In other European countries such as France, the Netherlands and Germany, which have similar geothermal potential, geothermal energy is contributing ever more significantly to the decarbonisation of the energy mix. As well as a considerable annual emissions saving (e.g. Germany: >1.7 Million t CO2 equivalent in 2017 [5]), the geothermal industry also provides considerable economic stimulus (e.g. Germany: 13.3 B€ since 2000 [6]) and contributes to job generation (Germany: >22,000 jobs [7]). Experience in these countries has shown that the success of geothermal development is closely linked to their governments' commitment to support this technology through policies, regulations, incentives and initiatives. Such success is linked specifically to 1) the availability of a long-term, stable regulatory framework and 2) the willingness of the state to share economic risks. These measures need to be aligned with the maturity of the geothermal market.

Government support is required at the beginning of geothermal development in order to encourage and guide financing from the private sector; investors have been shown to take over when the market becomes more established. To support geothermal development in the UK and enable it to progress from its currently early-development stage into a more mature market, a number of specific government-led measures are required. These would demonstrate the long-term commitment to the technology and

guarantee the long-term government support and funding structure needed by private finance investors to match their long term investment profile.

Key recommendations include: RISK SHARING AND FUNDING SUPPORT

- Continued provision of **long-term guarantees for financial incentives**, such as the Renewable Heat Incentive (RHI), Contracts for Difference (CfD) or Feed in Tariffs (FITs) and consideration against other renewable technologies to create a level playing field for geothermal technologies and encourage investor confidence.
- Introduction of a **publicly-funded risk insurance scheme** that bears part of the early exploration risk of a geothermal project.

STREAMLINED REGULATIONS AND NATIONAL LICENSING SYSTEM

- Short-term adjustments that **streamline the regulatory processes**, improve communication between industry and the regulator, develop expertise in regulation and monitoring of geothermal energy and lead to swifter decisions.
- Long-term changes in the definition of Geothermal energy that recognises its status as a natural resource and enables development of a **national licensing system** (administrated by a sector-specific regulatory body) that defines: (1) the protection and management of the geothermal resource and its long-term sustainability; (2) the protection of the geothermal user from other external parties depleting or damaging the geothermal resource and (3) third party rights to consider to enable establishing ownership and licensing rules.

GEOTHERMAL TARGETS LINKED TO GOVERNMENT GOALS AND POLICY

- A **geothermal roadmap** with quantifiable targets that links advancement of geothermal energy to government goals and policy objectives such as the Clean Growth Strategy or a Green Heat Roadmap (as called for by MPs and the former Minister for Climate Change Lord Duncan in 2019 [8, 9]).
- Bold, **interventionist measures** (e.g. delivered through the planning process) to achieve renewable heating targets and replace fossil fuels − which currently still are the cheapest option.

GOVERNMENT-SUPPORTED RESEARCH , DATA SHARING AND SKILLS TRANSITION

- **Government-funded geothermal research** and demonstrator development to improve data availability and raise the base level knowledge of the sub-surface and geothermal energy potential to a level that will reduce exploration risk and provide confidence for private investment.
- **Data sharing obligations** that require all subsurface exploration data to become open access data in a short time scale to enable the sharing of best practice and a rapid increase in early stage geothermal development.
- Promotion and support for the diversification and **transition of the UK's oil drilling and associated service industries** into geothermal

1 Introduction

The global climate emergency and the UK commitment to its 2050 decarbonisation target provides strong drivers for identifying low-carbon alternatives to current fossil fuel-dominated energy sources. The UK Committee on Climate Change stated that only decarbonisation of heating in the UK could deliver the major reduction in emissions needed to meet the 2050 target [10]. Various low-carbon options need to be pursued in the transition to low-carbon power, heating and cooling; no one option may dominate, as natural gas currently does [11].

Geothermal energy (the energy stored in the form of heat beneath the earth's surface) provides a home-grown, nationally secure, low-carbon and green alternative to conventional heating and power generation. With an estimated contained accessible subsurface heat resource of up to 328 x 10^{18} Joules (J) (sufficient to deliver about 100 years of heat supply for the entire UK at present consumption rates) [2], and to provide up to 2280 MW_e capacity for generating electrical power_from 4.5 km depth [3] (sufficient to provide an equivalent of 83% of Scotland's,9% of England's or 200% of Wales' current electricity demand[1,2]), geothermal sources have the potential to make a significant contribution to the decarbonisation efforts of the UK, especially in the decarbonisation of heating. In contrast to the intermittency of wind and solar, geothermal energy is available 24 hours a day and 365 days a year, offering a widely applicable, affordable and constant baseload supply of heat (and power) plus the potential for significant inter-seasonal thermal storage for waste heat and cold.

However, available geothermal heat resources remain unused in the UK with no operational schemes and only two separate deep geothermal projects currently under development in Cornwall (at United Downs, near Redruth and at the Eden Project site in Bodelva). In contrast, in countries such as France, the Netherlands or Germany that have similar resources, geothermal energy is contributing ever more significantly to decarbonising the energy mix. Their experience has shown that geothermal development is closely linked to their government's policies, regulations, incentives and initiatives [12], and specifically to the availability of a long-term, stable regulatory framework and the ability to insure the economic risks of development [13]. Similar measures and a long-term commitment to support geothermal developments are required in the UK to empower the important role of geothermal exploitation in the energy transition, specifically in the decarbonisation of heat. That decision must commit to supporting the development of the geothermal sector in a similar way that other renewable, low-carbon technologies (e.g. wind and hydrogen) are being supported. The UK will then be able to make use of its vast, widely available and renewable geothermal heat resources.

2 Section 1: Deep geothermal energy

Geothermal energy is the energy stored in form of heat below the earth's surface. Its potential is inexhaustible, comparable to that of the sun. A number of ways exist by which geothermal energy can be sub-divided, but experts have yet to agree on standardised definitions. In this briefing paper, we have adopted the definition of the UK government which refers to heat resources derived from a depth of >500m as "deep geothermal". We focus on two main types of systems: Hydrothermal systems (Direct use) and Petrothermal systems (also referred to as Enhanced Geothermal Systems or EGS) (Figure 1).

2.1 HYDROTHERMAL SYSTEMS

The heat of the earth increases with depth, a phenomenon described as the geothermal gradient. This heat is partly the primordial heat from when the earth was formed, and partly heat generated within the Earth's crust from the decay of mildly radioactive elements. This upward heat flux varies across the globe, but in the UK is around 27 °C/km [14]. Assuming an average annual air temperature of 12 °C,

[1] Calculation is based on energy consumption data published by BEIS. (2019 Sub-national Electricity and Gas Consumption Regional and Local Authority, Great Britain, 2018-19 https://www.gov.uk/government/statistical-data-sets/regional-and-local-authority-electricity-consumption-statistics..)
[2] Calculations assume that schemes are operating continuously all year around (i.e. 87,960 hours/year).

this means that subsurface temperatures at 1000 m, 3000 m and 5000 m are around 39 °C, 89 °C and 139 °C, respectively.

Whilst these temperatures are below the economic threshold for conventional (steam turbine) power generation (which is > 160°C), they are sufficiently high to provide heat for direct-use space heating (e.g. for larger scale heat networks that do not require the use of ground source heat pumps) as well as variety of heat-intensive industrial processes and agricultural applications.

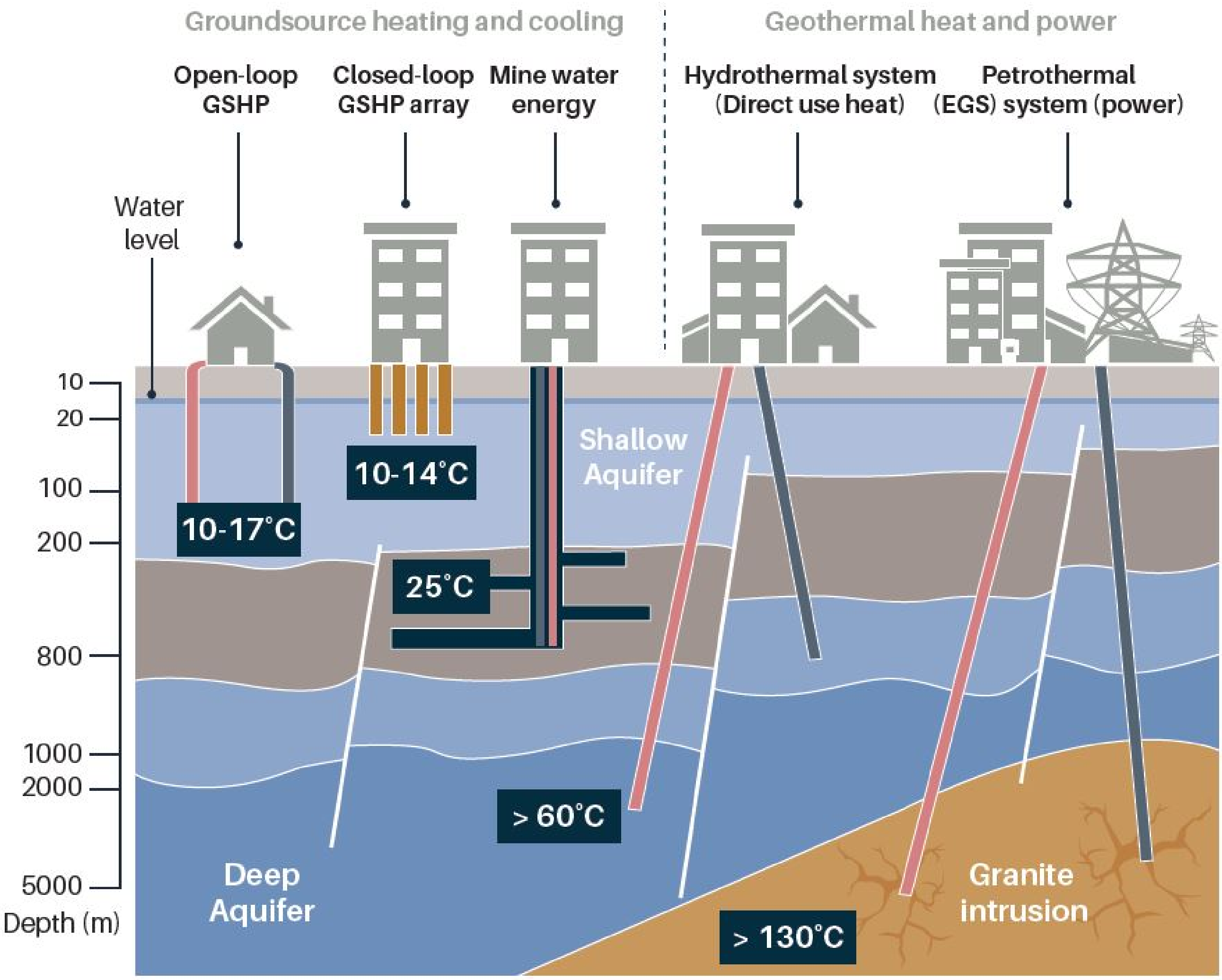


Figure 1. Different ground source (left side) and deep geothermal (right side) energy technologies.

NOTE: The focus of this paper is on deep geothermal, i.e. hydrothermal and petrothermal systems.

Exploitation of these deep geothermal resources requires a sufficiently high temperature for the use intended, saturated rock with sufficient permeability (connected pore space within the subsurface through which groundwater can move), and access to the hot water from the surface via one or more deep wells. Conventional hydrothermal systems are exploited via a so called “doublet system” – consisting of two deep boreholes (drilled to depths of 5km or deeper): one for abstracting the hot water and one for re-injecting the cooled water (after heat extraction) back into the deep aquifer system. Various onshore regions exist within the UK where such hydrothermal systems could provide a geothermal resource (Figure 2). Potential exists in regions where water-bearing rock formations are most deeply buried, exceeding 2.5km, for example, in the area around Worcester and Cheshire. The latter contains some major conurbations such as Crewe, where deep geothermal could make a contribution to future district heating schemes. Another possible hydrothermal resource is fractured limestone, which is present in the subsurface over large areas of southern England, south Wales and northern England. These strata are the source of the thermal waters at Bath, Bristol, the Taff Valley and Buxton (Figure 2). Although these areas will certainly contain porous sedimentary and/or fractured rocks (sandstones, limestones, dolomites), it is difficult to predict exactly where the rocks will be water-bearing and have sufficient permeability to provide the required water flows. Whilst various exploration techniques can reduce the resource uncertainty, drilling to great depths is required to confirm the resource.

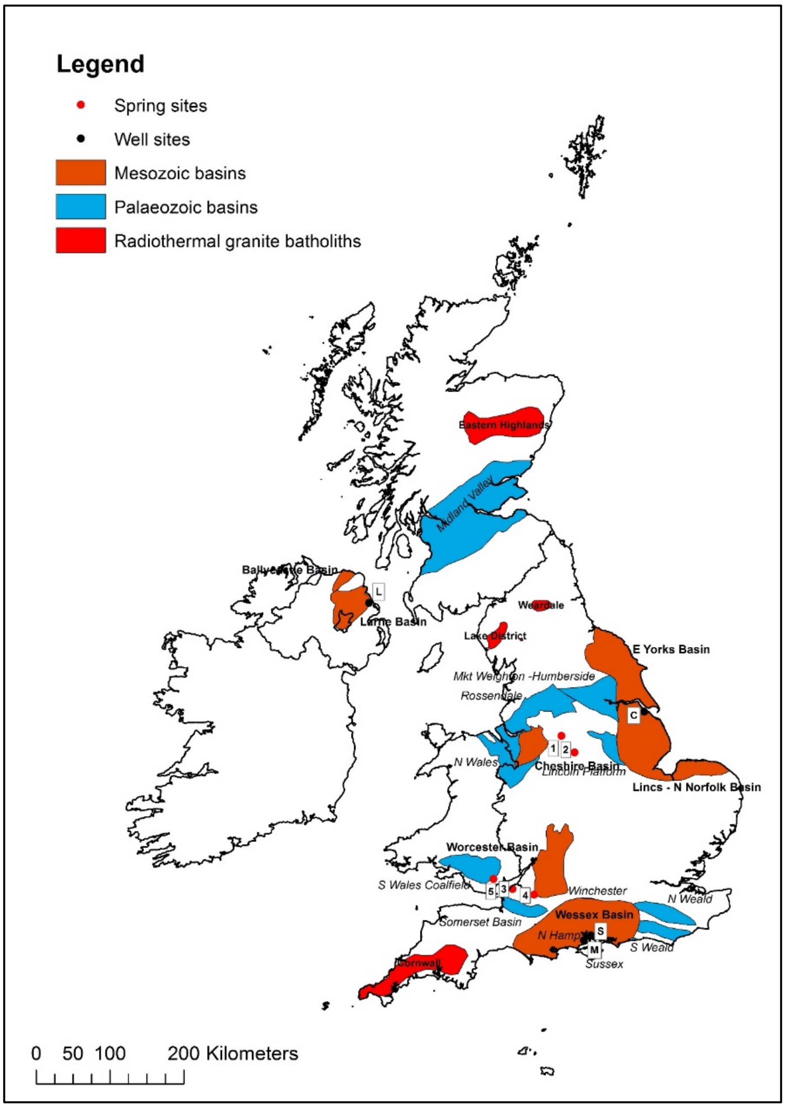


Figure 2. Map of potential geothermal resources in the UK, including existing geothermal wells

(black circles: [C] –Cleethorpe, [L]-Larne, [M]-Marchwood, [S]-Southampton) and geothermal spring sites (red circles: [1] Buxton, [2] Matlock Bath, [3] Hotwells, [4] Bath, [5] Taffs Well)

The UK's geothermal heat resource is substantial. Heat in place estimates have been made for direct use geothermal in Great Britain based on the deep geological basins. These range from 201 x 1018 J to 328 x 1018 J [14]. If exploited, this resource could supply the current annual UK heating requirements for about 100 years [2]. In reality, the actual resource and distribution is expected to be even more favourable as there is direct use geothermal potential within some of the older sedimentary basins [14], but this is difficult to quantify due to a lack of deep permeability data for these rocks.

Availability of these resources compares very favourably with the heat demand; for many areas of the UK it would be technically feasible to use geothermal heat for space heating using district energy schemes. Still, direct-use geothermal resources remain essentially unused in the UK (installed capacity for direct use heat is ~2 MW_{th}), lacking far behind deployment in other European countries with similar geothermal resource potential such as Germany (406 MW_{th})[3], France (600 MW_{th}) [15] or the Netherlands (221 MW_{th}) [16]. The UK currently holds the 26th position (before with the Czech Republic and Ukraine) out of the 28 listed European countries for geothermal direct use (i.e. heat from deep hydrothermal

[3] (https://www.geotis.de/geotisapp/geotis.php, accessed 17/03/2020)

systems) [17]. Since the exploration programme funded by the Department of Energy in the 1980s ended, which saw the drilling of a number of deep geothermal wells (Marchwood, Southampton, Larne and Cleethorpes – see Figure 2), there have been no successful developments. Even the scheme established at Southampton in the 1980s is currently out of operation, awaiting repairs to the surface heat pipes.

2.2 ENGINEERED GEOTHERMAL SYSTEMS –EGS ('PETROTHERMAL')

Medium to high-energy geothermal potential exists in the UK in areas between sedimentary basins, where there are sometimes radiothermal granites (Figure 2). Slightly raised levels of the radiogenic isotopes of potassium, uranium and thorium make these rocks significant heat sources hundreds of millions of years after emplacement, resulting in increased heat flows [18], and enhanced geothermal gradients in areas where radiogenic granites are present (e.g. Cornwall, Northern England and Scotland).

While temperatures at economically-drillable depths (currently ~5km) are sufficiently high (> 200°C) for electricity generation, granites are not naturally porous (typically <1% pore space) or water-bearing. While some of the UK granites are naturally fractured, others require stimulation of the subsurface (e.g. by hydraulic shearing or fracturing) to enhance existing fracture networks and increase permeability. In these, so called, Engineered Geothermal Systems (EGS), heat is abstracted by circulating water between two deep boreholes, through the natural or enhanced fracture network (pathways) between the abstraction and injection boreholes. The hot water is used for power generation within binary-cycle power plants or industrial and residential (direct-use) heating. Suitable geological systems exist, for example, across the Cornish Peninsula, with geological faults and granite structures offering favourable hydrogeological conditions and geothermal potential at various deep sites. Exploitation of these resources could significantly help support economic growth in this part of the country by providing jobs as well as meeting local heat and power needs.

Resource estimates indicate that the geothermal resource base for EGS in the UK is around 700 times that for direct use (hydrothermal) systems. Whereas at the time of writing, there is no operational EGS scheme in the UK, although two EGS projects, with £40 Million investment, the United Downs Deep Geothermal project (UDDGP) and the Eden Geothermal project, are in the process of being developed at two separate sites in Cornwall.

2.3 GEOTHERMAL FINANCE AND RISKS

For both, hydrothermal and EGS systems, a so-called "geologic risk" exists that permeability and yield of the targeted geothermal resource remain below expectations, especially at sites with only partially known subsurface conditions. The geologic risk is highest at the start of the project but decreases as project development progresses and more knowledge of the subsurface conditions on-site become available (Figure 3). Together with high upfront investment costs, this exploration and drilling risk presents a major barrier to wider uptake of this technology in the UK. Geothermal project development usually requires the drilling of the first well to decrease the uncertainty regarding the temperature and flowrate, which defines the capacity of the geothermal project, and therefore the revenue, which requires a large investment expenditure as noted in Figure 3.

As with other (non-geothermal) deep drilling, there is also a risk of induced seismicity caused by geo-mechanical stress changes associated with pressure or temperature changes during drilling, stimulation, production or injection of fluids. Enhanced geothermal systems — which increase subterranean water flows by injecting water into underground formations— have triggered earthquakes in some locations [19, 20]. Preparation of management and mitigation protocols specific to the deep geothermal industry can reduce the risk of high levels of seismic activity. Monitoring is important to demonstrate that regulations are being effective to identify adverse effects and inform appropriate management response.

Engaging early with the public on hazards and risks and how they are being managed will help gain public trust and acceptance of this technology. An example of successful public engagement and good monitoring practice is the United Downs Deep Geothermal Power project in Cornwall [21, 22].

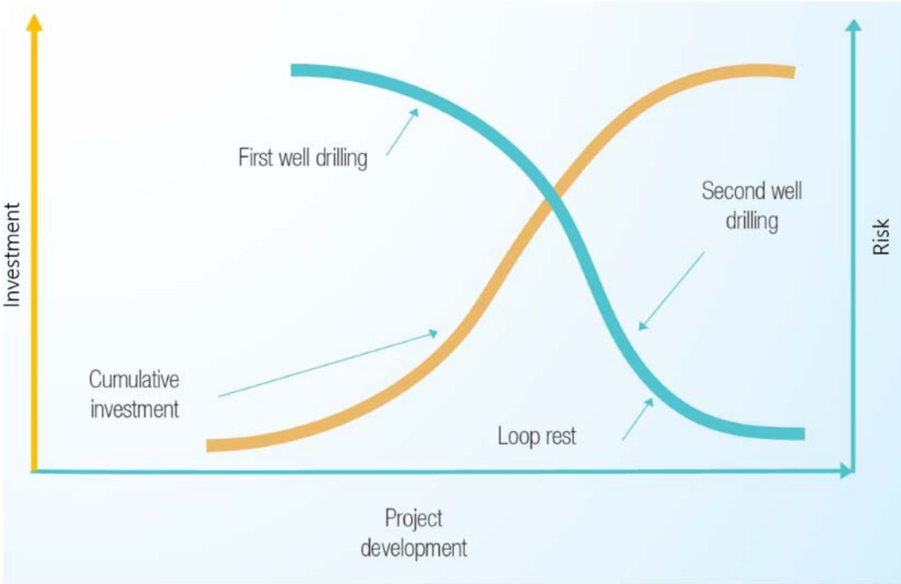


Figure 3. Geothermal risk and cumulative investment costs (after Dumas et al. 2019 [23])

3 Section 2. Geothermal developments in Europe

It has already been mentioned that geothermal energy is more developed in Europe than the UK, despite the natural resources being similar. This section provides more detail on France, the Netherlands, Germany and Switzerland, and the policies and incentives introduced by their governments that have enabled the development.

In France, there has been extensive development of the direct heat use hydrothermal resource, especially around Paris for district heating. In 2016, installed capacity attained 600 MW and is anticipated to increase to 1658 MW by 2025. More than 20 new deep boreholes have been drilled in the Ile de France in recent years, with 1700 GWh produced by 74 plants for direct heating in 2018, mostly in the Paris region [15]. Direct employment in the deep geothermal sector (electricity generation and direct uses) in 2016 was estimated at 2340 jobs (FTE[4]) [24] with an additional 500 indirect jobs (FTE) [15].

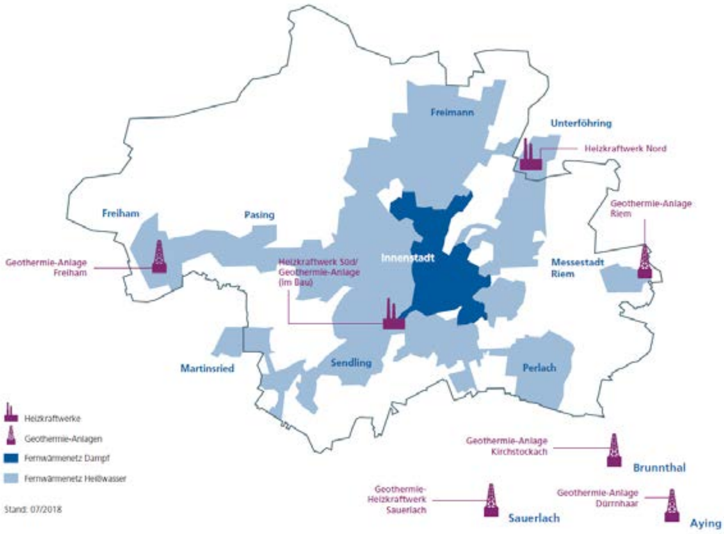
Geothermal energy (<150°C) is regulated by the Mining Code, but abstraction at temperatures >150°C requires a special research permit. The French government provides various incentives for geothermal developments, including a 30% tax credit and various insurance schemes covering geological and operational risk for shallow and deep systems. For example, the governmental risk coverage scheme for deep geothermal developments has been operational since 1981. It includes a “Short-term Risk Guarantee” (covering 60% of the exploration costs, for a fee of 5-10% depending on the risk level (in the event of total or partial failure of the drilling operations) and a “Long-term Risk Guarantee” (covering the risk of damage to the installation or the geothermal resource decreasing or disappearing during 25 years of exploitation). In 2010, about 10 M€ had been spent, exclusively for direct-use space heating projects [12]. In addition, a Renewable Heat Fund has provided a subsidy of 141M€ to 495 installations (for district heating and ground source heat pumps) since 2009 [25]. Geothermal power generation is currently supported by a feed-in tariff of 250€/MWh, but this is in the process of being replaced by a new tariff system. In addition, extensive funding is made available by the French government for deep geothermal demonstrators (with the two currently funded project receiving 43M€ and 82M€, respectively), research and innovation in order to enable the planned increase in installed capacity from currently 16.7 MW to 53MW by 2030 [15].

In Germany, a total of 180 deep geothermal installations for direct use of geothermal energy were in operation at the end of 2018, including 29 geothermal plants for district heating and/or power generation and several new plants under construction [26]. The installed capacity of these facilities currently amounts to 406 MW_{th} (heat) and 42 MW_e(power), producing 1,494 GWh (heat) and 166 GWh (power)

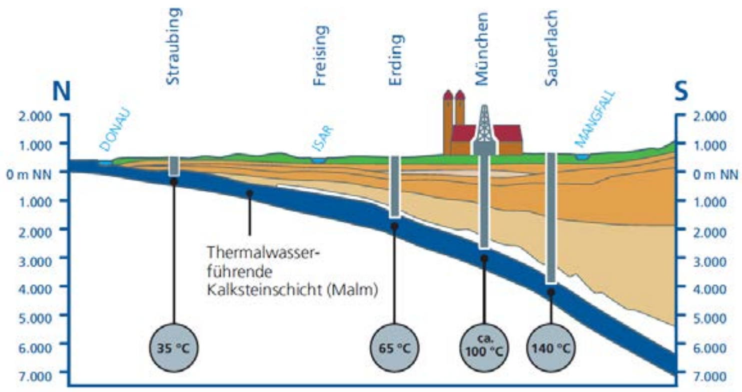
[4] FTE = Full time equivalent

from geothermal sources in 2018[5]. This translates into emission savings of >1.7 Million t CO_2 equivalent per year [5]. In addition, the exploitation of geothermal energy has created >22,000 jobs [7] and provided economic stimulus of 1.5 B€ in 2019 (13.3 B€ since 2000) [6].

Source: C. Abesser



Source: SWM



Source: SWM

Source: SWM

Figure 4.Geothermal developments in the Munich area, Germany, by the city's utility company Stadtwerke München (SWM).

Top left: Geothermal drilling at the Heizkraftwerk Süd (Heat Plant South) site in September 2018. Top right: Map of Geothermal plants (Geothermieanlagen) in the Munich area. Bottom left: Geological cross section through the Pre-Alps area showing temperatures of the thermal aquifer at depths accessed by different geothermal plants. Bottom right: Artist impression of Heizkraftwerk Süd which will supply 80,000 Munich residents with geothermal heating (after its completion in mid-2020).

[5] (https://www.geotis.de/geotisapp/geotis.php, accessed 17/03/2020)

Geothermal energy is regulated through mining law, water and water management regulations. Approval procedures vary between different regional authorities, but generally comprise of two main levels: the exploitation approval, which entitles the holder of the approval to investigate the site resources, and the mining approval, granting the right to extract the natural resource. Approval is usually granted for 50 years, and includes operational plans agreed with the relevant authority that must be followed during the operation of the plant. The total time required from identifying the location to erecting the plant and grid connection is approximately five years [13].

To support development of geothermal energy, the German government provides extensive financial support from planning and exploration to drilling and operation of plants. In addition, it supports the development of geothermal schemes by providing various incentives, such as project funding, market incentives, credit offers, feed-in tariffs of 25-30 €-cents/kWh for geothermal electricity and federal price guarantees which guarantee an above-market price for electricity for 20 years. They are instrumental for the success of geothermal schemes in Germany, providing the pledge for banks to sign off on large loans, such as the 50 M€ loan needed for developing the municipality-run scheme in Holzkirchen, which is now generating revenues of more than 10 M€/ year [27]. Most importantly, the German regulation offers long-term investment reliability with no indication that the feed-in tariff for geothermal energy could be reduced in the near future. The market for geothermal energy in Germany continues to grow with many new plants at various stages of planning and development: 52 M€ have been invested in the geothermal plant and district heating grid in Munich (Figure 2). The latest addition is the Heizkraftwerk Süd (Heat Plant South). When completed (mid-2020), the six deep boreholes drilled by the city's utility company, Stadtwerke München, are expected to have a capacity >50MW that can supply more than 80,000 Munich residents with ecological heat [28].

In The Netherlands, deep geothermal activities focus on direct use geothermal heat. In 2018, a total of 18 doublet were operational with an approximate total capacity of 221 MW_{th}, providing around 833 GWh of heat, mostly to the horticultural sector [16]. Most of the boreholes are in the 2000 – 3000 m depth range.

The Geothermal market in the Netherlands is rapidly growing, with an additional 7 (direct use heat) projects under construction and 13 projects at different stages of development [16]. Geothermal development is strongly supported by the Dutch government, through exploration programmes and through the 'Master Plan geothermal energy in the Netherlands'[29], which defines the Netherlands ambition in geothermal energy developments. It is anticipated that by 2050, geothermal energy in the Netherlands will contribute >55,000GWh (200 PJ) to residential (~4 million homes) and industrial heat networks, from around 700 installed doublets. This will generate direct employment of about 3400 jobs (FTE) by 2050, excluding the installation of heat networks and linked employment, e.g. related to the servicing and maintenance of the geothermal plants.

The exploration and production of geothermal energy in the Netherlands is regulated and licenced under the Mining Act and the Environmental Licensing Act. The licencing procedure is similar to oil and gas licencing, requiring an exploration permit and a production permit, which are issued by the Dutch Minister of Economic Affairs after consultation with relevant experts (e.g. the Dutch Geological Survey - TNO) and regulatory bodies (e.g. Netherlands Energy Management body – EBN). A new Mining Act is currently in preparation which will include a new licencing model (e.g. for tendering, multiple doublets and release of permits).

The main policy instrument for deep geothermal in The Netherlands is the SDE+ (Stimulering Duurzame Energie+) a feed-in-premium subsidy for different renewable technologies which has recently been expanded to include a wider range of deep geothermal development , such as triplets and 'dual play' wells (gas and geothermal). The Dutch government also provides a segmented drilling insurance scheme (RNES) which mitigates the cost of drilling failure. Introduced to increase the number of new projects from two doublets per year to five, the policies have contributed to the increases in capacity and production levels of new plants [16]. A current priority for The Netherlands is the establishment of about 10 pilot projects to connect geothermal energy to existing and new heat networks in the urban environment, e.g. The Hague.

Switzerland's potential for direct use geothermal and geothermal for power generation is considered to be very large [30], but only a small proportion is currently exploited. Most geothermal potential is assigned to power generation using EGS, but current geothermal energy generation of ~200 GWh (in 2017) is solely from hydrothermal direct-use heat utilisation. However, several geothermal power projects are currently in the planning phase (or have been granted permission) for developing EGS systems [31]. This is after earlier projects in Basel and St Gallen[6], both located in areas of naturally higher seismic hazard [32], were stopped when water injection during well development and testing induced minor quakes of 3.4 and 3.5 local magnitude, respectively [19].

Geothermal energy production remains an important part of Switzerland's national energy strategy 2050. Its target is to increase the installed capacity for geothermal power to > 500 MW by 2050, supplying ~4,400 GWh_{el} annually [31] . To support these developments, the Swiss government has introduced a comprehensive package of measures and incentives. These include feed-in tariffs for geothermal (of 25 €/kWh – 47 €/kWh for 15 years) and a national geothermal exploration risk guarantee for geothermal power projects which is guaranteed to run until 2030 and which reimburses up to 60% of the actual subsurface development and prospecting cost if the project fails to find a suitable geothermal resource. Geothermal direct use heat is supported under new energy legislation, introduced in 2018, which has had a noticeable impact, with 11 new, direct-use heat projects in the planning [31].

Switzerland also has a dedicated funding program for geothermal energy research and innovation. Administered by the Swiss Federal Office of Energy (SFOE), the program provides funds for geothermal research and development (13.6 M€/year) and for pilot and demonstration projects (19.2 M€ y/year). It also contributes (3.2 M€) to the European Research Area Network – to enable Switzerland's participation in GEOTHERMICA[7], a cooperation of geothermal research funding bodies from countries in the European Union and North America that develop joint research projects focussing on the testing and demonstration of novel geothermal energy concepts [31].

4 Section 3. Policy and regulation support for the UK geothermal sector

Experience in European countries has shown that the success of geothermal development is closely linked to their government's policies, regulations, incentives and initiatives. Feed-in-tariffs (FIT) with defined geothermal pricing have been very successful in attracting commercial investment in countries such as Germany, Switzerland, Austria, Spain and Greece [12]. Similarly, legislative instruments like geological risk coverage and risk insurance systems were instrumental in establishing the geothermal industry in France, Germany, the Netherlands and Belgium, and supporting its development through the early stages of market maturity.

Government support is required at the beginning of geothermal development in order to encourage and guide financing from the private sector. Investment aid in the form of grants is seen more appropriate for nascent markets while public risk insurance and public-private partnerships for risk insurance are more appropriate for intermediate and near mature markets, respectively [23] (Figure 5). Ideally, government funding should be available to finance the exploratory and preferably also the pre-feasibility phases of geothermal development (e.g. The Netherlands, France); investors demonstrably take over when the market is more established (e.g. Germany [12]). Specific measures for supporting geothermal development in the UK should include:

4.1 RISK SHARING AND FINANCIAL SUPPORT

Any form of energy abstraction that involves deep drilling contains an element of geological and economical risk. As the data acquired from exploration within a geothermal play accumulate, geological knowledge increases and the risk decreases. The European experience has shown that government aid in the forms of grants, insurance and subsidies can substantially advance geothermal exploration leading to a marked increase in the uptake of deep geothermal energy. Such grants are currently not available in the UK, although both of the current deep geothermal developments in Cornwall have been able to proceed through support from the European Union, provided by the European Regional Development

[6] Switzerland is located in a tectonically-active zone which has a moderate to average risk of naturally-occurring earthquakes (caused by the collisions between the European and the African lithospheric plates). The earthquake hazard is higher in some areas of Switzerland, including the Basel region and the St. Gallen Rhine valley.

[7] http://www.geothermica.eu/

Fund (ERDF). Negotiations over the future relationship between the UK and the EU are ongoing and, at the time of writing (July 2020), it is not yet clear whether UK organisations will be able to apply to such EU funding schemes after 1st January 2021.

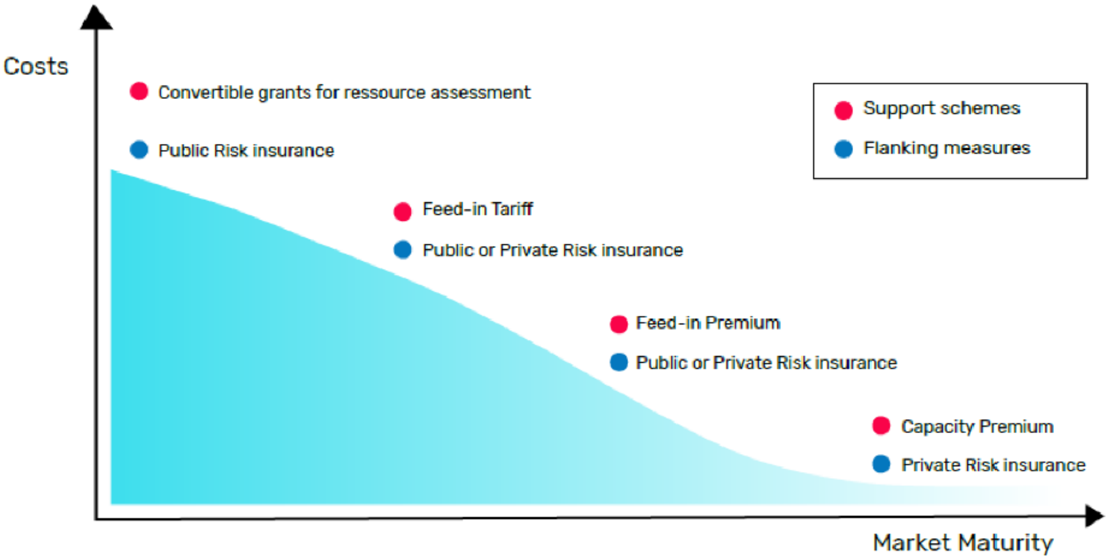


Figure 5. Support schemes for Geothermal adapted to technology maturity (from Dumas et al. 2019 [23])

To support geothermal developments and enable continued growth of this important industry in the UK, we recommend that:

- **Adequate financial incentives and support are provided for deep geothermal.** Existing incentives provided by the Renewable Heat Incentive (RHI), Contracts for Difference (CfD) or Feed in Tariffs (FITs) are welcome, but the level of support needs to be considered against other renewable technologies to create a level playing field. Furthermore, incentives need to be guaranteed for a sufficient length of time to maintain investor confidence and provide assurance that incentives can be relied upon for the longer term to match their long-term investment profile.
- Sustained, long-term government support is regarded as the main reason that the UK is now amongst the world's market leaders for offshore wind. It has encouraged off-shore wind suppliers to move their manufacturing base to the UK, creating 13,700 jobs, bringing investment into the economy and promoting rejuvenation in areas such as Hull, Grimsby, Barrow-in-Furness, Great Yarmouth, Campbeltown, and Lowestoft through the development of a UK supply chain [33].
- Within this context, the proposed closure of the non-domestic RHI (NDRHI) is of great concern as none of the replacement schemes announced by the government to date include support for geothermal plants. Hence, it is not clear if and how geothermal developments will be supported in the future. A separate £270M Green Heat Network Scheme has been announced but details have yet to be defined. According to a recent (June 2020) BEIS consultation on the NDRHI[8], the scheme is expected to cover large-scale heat pumps, solar thermal, waste heat recovery and biomass. Although not explicitly ruled out, there is currently little detail available on whether government funding for deep geothermal will be available in the future. This creates a high level of uncertainty that will deter investors, as it is not possible to build a business case for a new development with such high level of risk.

[8] https://www.gov.uk/government/consultations/non-domestic-renewable-heat-incentive-ensuring-a-sustainable-scheme, Accessed 29 April 2020.

.

- o A **publicly-funded insurance scheme** is introduced that would bear part of the risk of a geothermal project, specifically early exploration risks. This could take the form of geothermal borehole insurance whereby a proportion of the project cost is reimbursed to the developer/ owner if temperatures or flow rates are not achieved, or it could take the form of underwriting of project costs and/or grants to develop deep geothermal projects.

4.2 STREAMLINED REGULATIONS AND A NATIONAL LICENSING SYSTEM

There are currently no bespoke planning rules, environmental regulation or licencing systems for the planning and operation of geothermal schemes. Instead, geothermal aspects are covered by existing regulation: Planning of geothermal energy schemes is determined by local planning authorities (LPA) and dealt with under the rules for mining and quarrying. Environmental regulations applied to deep geothermal systems are based around licensing of water abstraction and environmental permitting for discharging water to the environment determined by the environmental regulator. According to government guidance [34], conventional hydrothermal schemes require (i) Consent to Investigate a Groundwater Source (CIG), (ii) an abstraction licence and (iii) an environmental permit, whereas EGS systems will require (i) a CIG and (ii) an abstraction licence for operating the schemes. EGS systems typically operate in deep fracture systems that may not be classed as aquifers[9]. While, under the Water Resources Act 1991 (WR11), there is still a requirement for EGS systems to submit an 'Intent to Drill', requirements to obtain (i) a CIG; (ii) Abstraction Licence; or (iii) Groundwater Activity Permit are assessed on a case-by-case basis using a risk-based approach. In addition, a number of other statutory notices have to be observed relating to the Infrastructure Act 2015 [35] and Health and Safety regulations [36-38]. **There is currently no licensing or management of the actual use of the geothermal resource.**

Multi-agency regulation of geothermal schemes makes the approval process complicated and time-consuming. Streamlining the regulatory process would promote and facilitate wider uptake of this technology. A number of short term and longer-term measures are needed to improve the permitting and regulation processes, including

Short-term adjustments that streamline the regulatory process and enable the building of national expertise and guidance for geothermal energy. Central administration would provide a unified, consistent approach to the regulation and monitoring of geothermal schemes rather than delivering the management of the environmental permissions, the licencing process and definition of monitoring requirements through the environmental regulator's area offices and local planning authorities. In addition to ensuring consistency in the regulation, monitoring and licencing of these systems, this would also improve communication between industry and regulator, develop national expertise in the regulator and lead to swifter decisions.

Long-term changes in the definition of Geothermal Energy that recognise its status as a natural resource [39] for the purposes of establishing ownership and licensing. A **national licensing system** is required for (1) the protection and management of the geothermal resource and its long-term sustainability, (2) the protection of the geothermal user (licensee) from other external parties depleting or damaging the geothermal resource within their property (licence area) and (3) third party rights to consider if depletion of the resource (i.e. geothermal heat) extends beyond the bounds of the property. Large-scale investment in deep geothermal will not take place without a licensing system.

As part of this, a **sector-specific regulatory body** (or an office within an existing regulator- such as the Oil and Gas Authority) need to be established that administrates national licencing and regulations of geothermal operations and provides a single point of contact, support and advice to the geothermal industry.

Awareness must be drawn to the **learning from conventional and unconventional hydrocarbons, mining and other extractive industries** to ensure that all relevant controls are considered in the planning, regulation and licencing of geothermal systems, covering the entire life cycle of geothermal operations (planning – development – operation – decommissioning) and protecting all stakeholders and the environment.

---

[9] A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater

4.3 GEOTHERMAL TARGETS LINKED TO GOVERNMENT GOALS AND POLICY

There is a lack of awareness of the potential of deep geothermal energy in national and local government, housing developers, investment companies, the public etc. Geothermal energy often invokes images of steaming geysers within volcanic terrains. Medium temperature geothermal energy has a very low environmental or visual impact; an advantage for deployment, but an attribute that leads to a lack of awareness. Geothermal energy options are therefore often overlooked in favour of more visible renewable technologies or fossil fuel use.

To address these issues, it is recommended that the advancement of geothermal energy is supported through better **integration in government goals and policy** such as the existing Clean Growth Strategy or the proposed Green Heat Roadmap (called for by MPs and the former Minister for Climate Change Lord Duncan in 2019 [8, 9]). **A geothermal roadmap** could be laid out with quantifiable targets. An excellent example of such a roadmap is the Masterplan for Geothermal Energy in the Netherlands [29].

Geothermal energy goals will be most effective where these are aligned with and supported by other relevant policies and targets. An **alignment with district heating policy**, for example, could enhance recognition and encourage use of geothermal energy as an economically viable source of energy for district heating system, and promote co-development. Similarly, decarbonisation targets around heating could be supported by bold, **interventionist measures** that preclude fossil fuel use – which is currently still the cheapest option.

4.4 GOVERNMENT-SUPPORTED RESEARCH, DATA SHARING AND SKILLS TRANSITION

A base level understanding of the subsurface is required for commercial companies to invest in detailed, site-specific exploration. This has long been recognised in oil and gas exploration, which received wide-ranging support from the UK Government during the primary exploration stage. To progress the adaptation of geothermal technologies, **government-funded research for deep subsurface research and explorations as well as geothermal demonstrator development** is recommended. This would raise the base level knowledge of the subsurface and geothermal energy potential to a level that will reduce exploration risk and provide confidence for private investment.

Furthermore, all exploration data from subsurface geophysical investigations or exploratory deep drilling, whether collected for geothermal or other purposes, should become **open access data** in a short time scale. Such data delivered through web portals could rapidly increase early stage geothermal exploration to enable the sharing of best practice and a rapid increase in early stage geothermal development.

Geothermal drilling presents an opportunity for diversification of the UK's oil drilling and associated service industries. The UK already has cross-industry expertise, but it is important that **specialist participation and training in geothermal drilling is further promoted and supported**. A geothermal borehole can be very different to an oil and gas borehole, in terms of drilling strategies, casing design and well completion, although skills and equipment are transferable. Engaging a qualified and experienced geothermal drilling engineer is critical to the success of geothermal drilling and exploration. The two ERDF-funded projects in Cornwall are both drilled using oil industry rigs, crews and supplies, but with specialist geothermal drilling supervision. Improving UK technical capabilities in drilling and completing geothermal boreholes can help to avoid costly delays and poorly constructed projects.

References

1. Abesser, C., *Deep impact: Unlocking the potential of geothermal energy for affordable low-carbon heating in the UK* in *British Geological Survey Science Briefing Note*. 2020: https://www.bgs.ac.uk/about-bgs/our-work/science-briefing-papers/.

2. Gluyas, J., et al., *Keeping warm: a review of deep geothermal potential of the UK.* Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 2018. **232**(1): p. 115-126.

3. Busby, J. and R. Terrington, *Assessment of the resource base for engineered geothermal systems in Great Britain.* Geothermal Energy, 2017. **5**(1): p. 7.

4. BEIS, *Sub-national Electricity and Gas Consumption Regional and Local Authority, Great Britain, 2018-19* in *National Statistics*. 2019.

5. BMWi, *Erneuerbare Energien in Zahlen, Bundesministerium für Wirtschaft und Energie, https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/erneuerbare-energien-in-zahlen-2017.pdf, accessed 01/04/2020*. 2017.

6. BMWi, *Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland, Stand März 2020*. 2020, Bundesministerium für Wirtschaft und Energie, https://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html, accessed 01/04/2020.

7. BMWi. *Bruttobeschäftigung durch erneuerbare Energien 2000 bis 2017, https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihe-der-beschaeftigungszahlen-seit-2000.pdf?__blob=publicationFile&v=2, accessed 04/04/2020*. 2018.

8. Policy Connect, *Uncomfortable Home Truth - Why Britain urgently needs a low carbon heat strategy*. 2019: London. p. 71.

9. Policy Connect, *MPs call for green heat roadmap by 2020 & olympic-style delivery body to tackle UK's 27M 'uncomfortable home truths'*. 2019: https://www.policyconnect.org.uk/cc/news/mps-call-green-heat-roadmap-2020-olympic-style-delivery-body-tackle-uks-27m-%E2%80%98uncomfortable-home (accessed 24/04/2020).

10. Bell, M., et al., *Next steps for UK heat policy*. 2016, Committee on Climate Change. p. 103.

11. Policy Connect, *Uncomfortable Home Truth - Why Britain urgently needs a low carbon heat strategy*. 2019, Future Gas series: Part 3, 71p. https://www.policyconnect.org.uk/research/uncomfortable-home-truths-future-gas-series-part-3: London.

12. Rybach, L. *Legal and regulatory environment favourable for geothermal development investors*. in *Porceedings World geothermal Congress*. 2010. Bali, Indonesia, 25-30 Aoril 2010.

13. Bader, K. and C. Bauer. *Opportunities Geothermal Energy in Germany*. 2017 [cited 2018 30/08/2018]; Available from: http://www.nortonrosefulbright.com/knowledge/publications/147194/opportunities-geothermal-energy-in-germany.

14. Busby, J., *Geothermal energy in sedimentary basins in the UK.* Hydrogeology Journal, 2014. **22**(1): p. 129-141.

15. Boissavy, C., et al., *Geothermal Energy Use, Country Update for France*, in *European Geothermal Congress 2019, Den Haag, The Netherlands, 11-14 June 2019*. 2019.

16. Provoost, M., et al. *Geothermal Energy Use, Country Update for The Netherlands* in *European Geothermal Congress 2019*. 2019. Den Haag, The Netherlands, 11-14 June 2019.

17. Sanner, B. *Summary of EGC 2019 Country Update Reports on Geothermal Energy in Europe*. in *European Geothermal Congress 2019*. 2019. Den Haag, The Netherlands, 11-14 June 2019.

18. Busby, J. *Geothermal Prospects in the United Kingdom* in *Proceedings World Geothermal Congress 2010*. 2010. Bali, Indonesia, 25-29 April 2010

19. Edwards, B., et al., *Seismic monitoring and analysis of deep geothermal projects in St Gallen and Basel, Switzerland.* Geophysical Journal International, 2015. **201**(2): p. 1022-1039.

20. Majer, E.L., et al., *Induced seismicity associated with enhanced geothermal systems.* GEOTHERMICS, 2007. **36**: p. 185-222.

21. Jupe, A. and P. Ledingham, *Seismic Monitoring at the United Downs Deep Geothermal Power Project, Cornwall, UK*, in *Proceedings World Geothermal Congress 2020*. 2020: Reykjavik, Iceland, April 26 - May 2, 2020.

22. Ledingham, P., L. Cotton, and R. Law, *The United Downs Deep Geothermal Power Project*, in *PROCEEDINGS, 44th Workshop on Geothermal Reservoir Engineering*. 2019: Stanford University, Stanford, California, February 11-13, 2019.

23. Dumas, P., et al., *Risk Mitigation and Insurance Schemes Adapted to Geothermal Market Maturity: The Right Scheme for my Market.*, in *European Geothermal Congress 2019*. 2019: Den Haag, The Netherlands, 11-14 June 2019.

24. ADEME, *Marchés & emplois concourant à la transition énergétique et écologique – Synthèse générale- Situation 2014-2016 et perspectives à court terme*. 2019, Agence de l'Environnement at de la Maitrise de l'Energy.

25. ADEME, *Le Fonds Chaleur- Outil majeur de la transition énergétique - Bilan 2009-2017*. 2018. p. 20.

26. Weber, J., H. Born, and I. Moeck. *Geothermal Energy Use, Country Update for Germany 2016 - 2018*. in *European Geothermal Congress 2019*. 2019. Den Haag, The Netherlands, 11-14 June 2019

27. Hockenos, P., *Aiming for Climate Targets, Germany Taps Its Geothermal Potential*, in *Yale Environment 360*, Yale School of Forestry & Environmental Studies Editor. 2019.

28. Richter, A., *SWM complete drilling campaign pushing forward with three week test run at heat plant in Munich*, in *ThinkGeoenergy; https://www.thinkgeoenergy.com/swm-complete-drilling-campaign-pushing-forward-with-three-week-test-run-at-heat-plant-in-munich; accessed 17 March 2020*. 2020.

29. Platform Geothermie. *Master Plan Geothermal Energy in the Netherlands*. 2018 09 September 2019]; Available from: https://geothermie.nl/images/bestanden/Masterplan_Aardwarmte_in_Nederland_ENG.pdf.

30. Hirschberg, S., S. Wiemer, and P. Burgherr, eds. *Energy from the Earth - Deep Geothermal as a Resource for the Future?, TA-SWISS Study, TA/CD 62/2015*. 2015, vdf Hochschulverlag AG. 524.

31. Link, K., G. Siddiqi, and N. Lupi, *Geothermal Energy Use, Country Update for Switzerland*, in *European Geothermal Congress 2019, Den Haag, The Netherlands, 11-14 June 2019*. 2019.

32. Swiss Seismological Service, *Earthquake country Switzerland*, E.Z. Swiss Seismological Service, Editor. 2020.

33. IEA, *Energy Policies of IEA Countries: United Kingdom 2019 Review*. 2019, International Energy Agency, : Paris.

34. BEIS. *Deep geothermal energy regulation - How to comply with environmental permitting regulations to abstract deep geothermal energy.* 2014; Available from: https://www.gov.uk/guidance/deep-geothermal-energy-regulation.

35. *Infrastructure Act 2015*. 2015.

36. OIWR, *The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996*. 1996.

37. BSOR, *A guide to the Borehole Sites and Operations Regulations 1995. Guidance on Regulations* 1995.

38. CDM, *Construction (Design and Management) Regulations*. 2015.

39. Abesser, C., et al., *Who owns geothermal heat? .* BGS Science Briefing paper, http://nora.nerc.ac.uk/id/eprint/523369/1/whoOwnsGeothermalHeat.pdf, 2018.