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Geothermal Energy Use, Country Update for United Kingdom

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ABSTRACT

In the reporting period, 2020–2022, there has been a sustained resurgence of interest in all aspects of geothermal energy in the United Kingdom (UK), particularly in the provision of decarbonised heat. Currently, the main area of exploitation are shallow geothermal resources using GSHP (Ground Source Heat Pump) systems, but the exploitation of medium to deep geothermal resources continues to be slow.

Utilisation of shallow geothermal via GSHPs has accelerated (from a low base) due to the positive impact of the domestic and non-domestic versions of the Renewable Heat Incentive (RHI) scheme in Great Britain (GB). The domestic scheme closed to new applicants in March 2022 and has been replaced by the Boiler Upgrade Scheme (BUS) which currently favours Air Source Heat Pumps (ASHPs). The nondomestic scheme closed to new applicants in March 2021. Funding schemes for Decarbonisation of Public Sector buildings is also generating interest in various forms of geothermal energy to deliver low carbon heat. The Public Sector Decarbonisation Scheme (PSDS) remains the main funding route to install large GSHP on public buildings. Mine water energy is also of increasing interest and significant private mine water projects have been completed in the Northeast of England and others are in development.

The most significant developments in deep geothermal have been the completion of the drilling phases of the United Downs Deep Geothermal Project (UDDGP), and the first well of the Eden Geothermal Project (EGP), both in Cornwall. At United Downs, the production borehole UD-1 was completed to a drilled depth of 5275 m (vertical depth of 5057 m), and injection borehole UD-2 to a drilled depth of 2393 m (2214 m depth). At Eden the first borehole has been completed to 5277 m drilled (4871 m vertical depth)– making it the longest geothermal well drilled in the UK. Both deep geothermal projects have encountered permeable structures at depth in radiogenic granites and have undergone a period of well testing to provide information on temperature and permeability of target zones and to enable characterisation of the geothermal resource to understand how the wells will perform and their expected outputs.

The Natural Environment Research Council, through the British Geological Survey (BGS), has established a geothermal research site in Glasgow and is currently in the process of building a second site in Cheshire to investigate aspects of mine water geothermal and of shallow, borehole related geothermal energy delivery, respectively, as part a £31m project funded by the 2014 UK Government Plan for Growth of Science and Innovation. The sites are open to the research community and industry to investigate and innovate multiple aspects of geothermal energy.

1. INTRODUCTION

The exploitation of geothermal energy in the UK remains small and mainly restricted to the utilisation of ground source heat pumps supported by recent government policies. However, there is an increasing interest in the development of deep geothermal resources and the last years have seen the completion of drilling phases of the United Downs Deep Geothermal Project (UDDGP) and the Eden Geothermal Project (EGP) in Cornwall (SW England).

Mine water geothermal has also seen renewed interest with the development of new commercial projects and the completion of the UK Geoenergy Observatory (UKGEOS) in Glasgow, funded by NERC-UKRI and managed by the British Geological Survey.

The comprehensive work by the British Geological Survey (reported by Downing and Gray, 1986) is still the definitive reference to the geothermal prospects of the UK. For a background to material provided here, readers are referred to earlier UK Country Updates provided for the GRC International Symposia on Geothermal Energy (Garnish, 1985; Batchelor, 1990), the IGA World Geothermal Congresses (Batchelor, 1995; Batchelor et al., 2005, 2010, 2015, 2020) and the European Geothermal Congresses (Curtis et al., 2013, 2016, 2019). The most recent summaries are provided in the IEA Geothermal UK Country Report (Abesser and Jans-Singh, 2022) and the European Geothermal Congresses 2022 Country Update (Abesser et al., 2022).

Other recent publications of interest include policy briefings developed by the British Geological Survey (Abesser et al. 2018, 2020), a report developed by the Renewable Energy Association and ARUP, assessing the potential for UK deep geothermal resources to deliver decarbonisation (REA, 2021), as well as a mine energy white paper, commissioned by the North East Local Enterprise Partnership (NELEP, 2022). The Parliamentary Office for Science and Technology (POST) have produced a comprehensive briefing paper on geothermal energy for UK parliament (Abesser and Walker, 2022).

2. GEOTHERMAL RESOURCES

2.1 Shallow Geothermal Resources

The availability of different types of ground source heat pump (GSHP) systems (closed-loop; open-loop; hybrid; mine water systems) and the flexible design options mean that deployment of these systems is feasible almost anywhere in the UK (Figure 1).

One of the resources that is of increasing interest for geothermal exploitation using GSHPs is mine water from abandoned mines. It is estimated that around a quarter of the UK's population live above abandoned coal mines and large figures for the heat resource from abandoned coal mines in the UK have been quoted (e.g. Adams et al., 2019). The existence of disused mine workings beneath many areas across the UK (Farr et al, 2021) (Figure 1) and the coincidence of towns and cities, particularly areas of fuel poverty and brownfield sites, with the mine water resource offers significant opportunity to match demand and resource. Heat recovery from, and storage in, Britain's coal mines is still in its infancy, though there are operational schemes and more being constructed. A range of challenges still need to be addressed, including development of regulatory and licensing frameworks (Stephenson et al. 2019), high initial CAPEX costs (Townsend et al. 2020) and technical questions associated with understanding the hydrogeology and thermal behaviour of abandoned coal mine workings, sustainable low-temperature heat recovery and its impacts on the environment (Monaghan et al. 2022a,b).

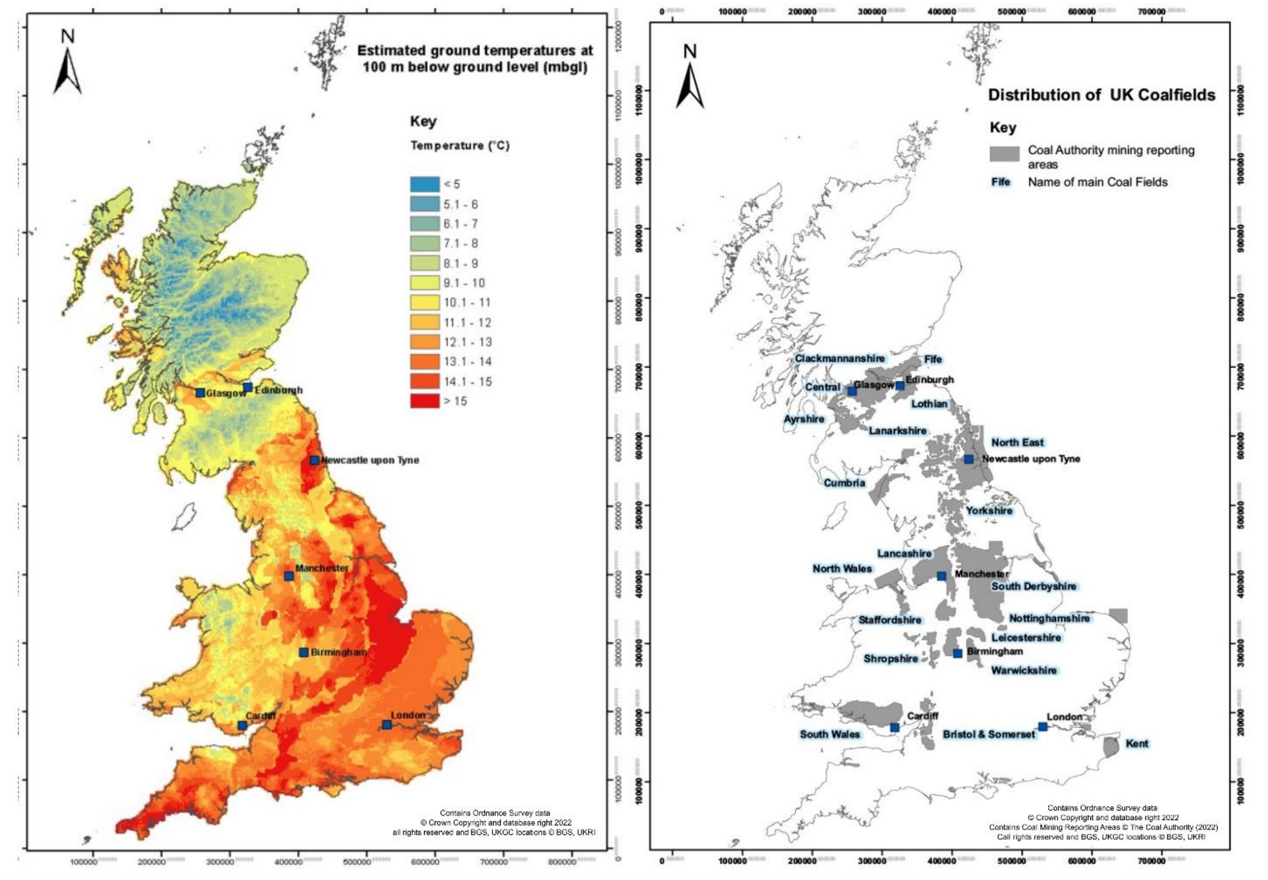

Figure 1: Estimated ground temperature at 100 metres below ground level (mbgl) (modified from Busby et al., 2011) (left) (Contains Ordnance Survey data © Crown Copyright and database right 2022, all rights reserved and BGS UKGC locations © UKRI 2022) and distribution of Coal Authority mining reporting areas in Great Britain (right) (Contains Ordnance Survey data © Crown Copyright and database right 2022, all rights reserved. Contains Coal Mining Reporting Areas © The Coal Authority, 2022 and BGS UKGC locations © UKRI, 2022)

2.2 Deep Geothermal Resources

The geological and tectonic setting of the UK precludes the evolution of high enthalpy resources close to the surface and historically only low to moderate temperature fluids have been accessed by drilling in deep sedimentary basins, in S England, NE England and in Northern Ireland (NI), and in some granitic intrusions, most notably in southwest England for EGC systems (Figure 2).

In the 1970s and 80s several research projects to assess the potential of geothermal resources took place, including a national program conducted by the British Geological Survey between 1977 and 1984 that still constitutes one of the key references for geothermal energy in the UK (Downing and Gray, 1986). As part of the research, between 1977 and 1979 four wells were drilled to investigate the Permo-Triassic sandstones in Larne (Northern Ireland), Cleethorpes (Lincolnshire), Marchwood and Southampton (Wessex). Both Wessex wells yielded good flow rates from the reservoir located at around 1700 m depth with temperatures around 75°C, and one of them, the Southampton one, was lately developed and connected to the district heating scheme in the city. The Larne well in

Northern Ireland found very low permeability, while the Cleethorpes well was drilled into a very permeable sequence of the Sherwood Sandstone at 1.1-1.5 km depth and found temperatures of 53°C.

A Hot Dry Rock (HDR) geothermal reservoir was developed and tested in three phases over a 15-year period in Rosemanowes (Cornwall) as part of the Camborne School of Mines 'Hot Dry Rock' R&D program funded by the Department of Energy (Batchelor, 1985; Parker, 1991; Richards et al., 1994). The tests conducted between 1985 and 1988 showed that the effective size of the subsurface heat exchanger , developed at depths of ~2 km in the Phase 2 of the programwas only a fraction of that required for a commercial development, also encountering several problems (temperature decrease, water loss) and, although a new well was drilled to about 2.6 km, the program was discontinued in 1991 (MacDonald et al., 1992). The more recent projects in Cornwall, including the United Downs Deep Geothermal Project, Eden Geothermal and other projects in planning are summarised in more detail later.

In the NE England, the drilling of the Eastgate and Newcastle boreholes (Manning et al., 2007; Younger et al., 2016) that targeted the buried Weardale Granite also suggested higher than anticipated temperature gradients and hence increased focus on the possible application of geothermal heat in that region. Although not utilized after drilling, the Newcastle borehole is being resurrected as part of the NetZero GeoRDIE project as a research facility (Brown et al., 2022).

Recent assessments of the potential of deep geothermal resources in the UK were published by Busby (2014) for sedimentary basins, by Busby and Terrington (2017) for EGS (Figure 2) and by Gluyas et al (2018).

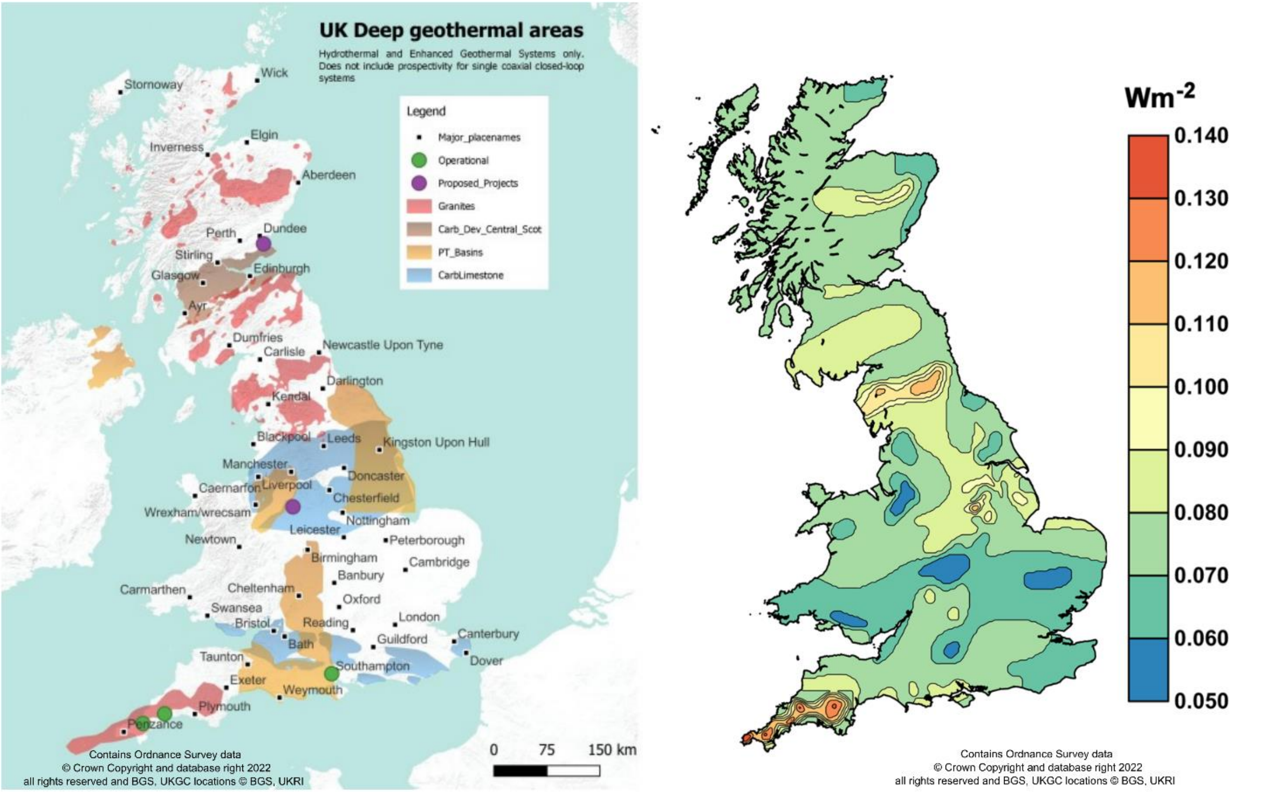

Figure 2: Distribution of deep geothermal resources in the UK (left) (Contains Ordnance Survey data © Crown Copyright and database right 2022, all rights reserved and BGS UKGC locations © UKRI 2022) and estimated heat flow (modified from Busby and Terrington (2017) (right) (Contains Ordnance Survey data © Crown Copyright and database right 2022, all rights reserved and BGS UKGC locations © UKRI 2022) .

Deep geothermal energy resources in the UK can be classified mainly in two groups: hydrothermal resources in deep sedimentary basins, and hot dry rock or EGS resources mainly from granites among which are of special interest those in Cornwall, the North of England and the North-East of Scotland (Figure 2). In addition, there is increased interest in repurposing oil and gas wells for geothermal energy production.

2.1.1 Sedimentary Basins

Sedimentary basins are dispersed across Great Britain and parts of Northern Ireland (Figure 2).

Favourable conditions have been identified in sedimentary units comprising Permo-Triassic sandstones (Busby, 2014) which occur in five principal basins across the UK, including Wessex and Worcester (South of England), Cheshire (Northwest of England), Eastern England, Larne and Lough Neagh (Northern Ireland).

Karstified and fractured Carboniferous Limestones are also a potential geothermal play. They provide the source of the thermal springs in the Taff Valley, Buxton, Bristol and Bath (Darling, 2019; Pharaoh et al., 2021; Jones, 2021). These manifestations of hot water in the UK have been known for centuries since Celtic times and exploited since Roman times. The springs from Bath, which temperatures range between 42 and 48°C can be considered as the only true hot springs (temperatures above 37°C), while the warm springs in Buxton and Marlock are considered warm springs at 28 and 20°C respectively (Gallois, 2007).

Another area of interest is the Midland Valley in the central part of Scotland, where various studies are assessing the geothermal potential of Devonian and Carboniferous deep sedimentary aquifers.

2.1.2 EGS/HDR Resources

Aside from sedimentary basins, granite batholites containing small quantities of radioactive elements constitute medium-enthalpy geothermal resources that could be used for the production of heat and power. Such granite batholites are found in Scotland, North of England and Cornwall (SW England). Naturally, the granites have very low intrinsic porosity and permeability, but some have been affected by geological faulting, such as those under development in Cornwall. The GWatt project explores the potential for deep EGS systems based on fracture networks in the UK granites, as was reported at WGC 2020 (Rochelle et al, 2020).

3. GEOTHERMAL UTILISATION

3.1 GSHPs

The background to GSHP activity in the UK is provided in earlier Country Update papers - e.g. for EGC 2022 (Abesser et al., 2022), WGC 2020 (Batchelor et al., 2020), and for IEA Geothermal (Abesser and Jans-Singh, 2022).

In early 2022, the UK was reported to have approximately 43,700 GSHPs and a total installed capacity of 787 MW_{th}, representing an annual production of 1,316 GW_{th}/yr. In recent years, there has been an increase of 4,000 installation per year and it is expected that the number of GSHP will be around 48,000 in 2023 with a total installed capacity of 903 MW_{th}.

During the reporting period, the Renewable Heat Incentive (RHI) for both domestic and non-domestic heating installations (solar, biomass and heat pumps) had a significant (positive) impact on the rate of GSHP installations. Following a decline since 2010, a review by the government department responsible for energy (initially DECC which later became BEIS) of the relative RHI tariffs for heat pumps compared to other technologies led to revised tariffs and a subsequent acceleration in GSHP installations since spring of 2017. Taking advantage of the revised tariff, several large multi-MW open loop WSHP installations have been installed either using rivers or existing water treatment facilities. The RHI scheme closed to new applicants in March 2022 for domestic installations and has been extended for a further 12 months for pre-approved non-domestic installations. The new Boiler Upgrade Scheme that has superseded the RHI provides grants of up to £6000 off the cost and installation of a ground source heat pump, including water source heat pumps (£5000 off the cost for air source heat pumps, ASHPs).

The UK Ground Source Heat Pump Association (www.gshpa.org.uk) has held technical seminars and has continued to develop technical standards. A new Drilling Standard for closed loop GSHPs has been developed with the MicroGeneration Certification Scheme (MCS) and the British Drilling Association. The UK GSHPA standards are now available on the CIBSE website (https://www.cibse.org/). To promote awareness of the significant carbon reduction potential of GSHPs in the UK, due to the rapid reduction in the carbon intensity of the UK electricity grid, the GSHPA supports an online app that provides real time, regionally based, CO2 emissions for various heating systems. This app has been adopted by the newly formed UK Heat Pump Federation at: https://www.hpf.org.uk/carbonwatch.

3.3 Mine Water Heat

There is an awakening of interest in the use of flooded abandoned coal and metal mines for geothermal purposes in different regions of the UK. Whilst a number of formerly active schemes have ceased (Shettleston, Lumphinnans, Crynant, Caphouse in Walls et al. 2021), there are three operational commercial schemes (two schemes by Lanchester Wines) and one heat network (Gateshead) in the final phases of testing as well as a number of potential heat networks under investigation. The Coal Authority, who manage the effects of past coal mining and own the majority of coal mining infrastructure in Great Britain, are developing the heat resource from several existing mine water treatment schemes, including the Dawdon mine water treatment scheme in North East England, which will supply heat to the 'Seaham Garden Village' development (Coal Authority, 2020) (see Abesser et al., 2022 for more detail). The Coal Authority have also been supporting Gateshead Council who are in the final stages of testing their 6MW mine water heat network, which will supply up to 1,250 new private homes, a care home, Gateshead International Stadium and other Council-owned buildings (https://www.gateshead.gov.uk/article/21170/From-the-industrial-revolution-to-a-green-revolution).

The first large scale mine water projects in the UK were commissioned by Lanchester Wines in Gateshead (Banks et al., 2022). This comprises of two schemes operating mine water source WSHPs of 2.6 MW and 1.4 MW thermal capacity, respectively, delivering 4300 MWh/year to two large wine storage warehouses. TownRock Energy have taken on the operations & maintenance (O&M) and optimisation / improvements to Lanchester Wines since 2021. The project is described in a IEA Geothermal Case Study: https://drive.google.com/file/d/1ZpJaXjIgzKHzLzNToWDrB_J85Qou2uFb/view.

Across Scotland there are a number of mine water projects at various stages of feasibility and development. Local councils, in particular, are keen to see adoption of mine water heating systems for district heating networks and urban building decarbonisation. TownRock Energy (TRE) completed a commercial exploratory drilling programme in Dollar, Clackmannanshire in December 2020, supported by researchers at the Universities of Glasgow and Strathclyde (Walls et al, 2022).

In South Wales, following feasibility studies and reports (Brabham et al., 2020), Bridgend Council have redirected their funding to other renewable projects and the proposed mine water heating scheme has not currently been developed.

In 2021, a mine energy white paper (NELEP, 2021) was published to make the case for mine energy in the UK. The document provides a series of recommendations, generated from literature review and stakeholder consultation to help ensure the development of the sector.

There remain a number of barriers to putting the old mine workings back to work in sustainable developments to provide heating, hot water and cooling. These include time taken for permitting from a number of different bodies, sustainability of the mine water resource and heat licensing, reduction in operational maintenance burden, mitigation of any environmental impacts (Walls et al., 2021) as well as resolving issues of surface and subsurface ownership and the potential claims of mineral owners, the latter being particularly relevant for metal mines.

The IEA Geothermal TCP has launched an international mine water expert group (https://iea-gia.org/areas-of-activity/geothermal-heating-and-cooling/mine-water-geothermal-energy-group/). The group aims to build global collaborations between industry, research and regulators in the field of mine water energy (heating, cooling and storage) to encourage enhanced deployment of the technology whilst reducing some of the biggest barriers to widespread deployment – cost and risk.

See also Section 5.3 for research infrastructure related to mine water heat & storage.

3.4 Medium / Low Enthalpy Hydrothermal Projects

The City of Southampton Energy Scheme (Smith, 2000) remains the only deep aquifer geothermal energy system in the UK. It is owned and operated by Cofely District Energy, now part of ENGIE. The scheme started in the 1980s when an aquifer in the Triassic Sandstone containing 76 °C fluid was identified at approximately 1,800 m depth in the Wessex Basin. Construction of a district-heating scheme commenced in 1987 and this has since evolved and expanded to become a combined heat and power scheme for 3,000 homes, 10 schools and numerous commercial buildings. While gas fired CHP now supplies most of the district energy scheme's low-carbon heat, it is reported that the geothermal well has saved 131,564 tonnes of CO2 emissions since start of operation (ENGIE 2022, pers. comm). The geothermal well was taken offline in 2020 to install a new borehole pump and is presently not in operation due to a technical problem with another component of the district heating and cooling network unrelated to the geothermal system (ENGIE 2022, pers. comm).

Another deep hydrothermal project in Stoke-on-Trent has achieved planning permission and is expected to progress into the drilling stage soon. The project will connect a doublet drilled into the Carboniferous limestone reservoir beneath Etruria Valley with a district heating network developed by Stoke-on Trent City Council. The deep geothermal solution will comprise two wells and it is predicted that hot water exceeding 95˚C could be located at an approximate depth of 3,800 m (http://gtenergy.net/projects/projects/etruria-valley-stoke-on-trent/).

3.5 EGS Projects

There are currently two significant EGS projects under development in the UK, both in Cornwall: the United Downs Deep Geothermal Project, and the Eden Geothermal Project. The evolution of these projects has been reported on in earlier EGC, WGC, and IEA Geothermal UK Country update papers.

3.4.1 United Downs Deep Geothermal Power project

The United Downs Deep Geothermal Power project (UDDGPP), led by Geothermal Engineering Ltd (GEL), is the first commercial project in the UK to develop deep geothermal for power generation. The project aims to utilize the natural permeability of the Porthtowan Fault, a deep Variscan NW-SE striking, steeply dipping, strike-slip fault zone in the Carnmenellis granite in Cornwall. Drilling of two deviated wells started in November 2018 and was completed in 2019. The wells intersect the fault at two different depths in order to create a closed loop circulation system vertically along the fault. The first well, UD-1, has a drilled length of 5275 m (5057 m total vertical depth), encountering temperatures of nearly 200 °C, and is the production well (Figure 3). The second well, UD-2, has a drilled length of 2393 m (2214 m total vertical depth) and will act as the injection well.

Limited hydrotesting of the wells took place in July 2021 on the basis of which a 5 MWe gross air-cooled binary power plant has been ordered. There is a restriction on power export of ~3 MWe due to local grid constraints. Installation of the power plant is expected to be complete in 2022. A contract for power supply has been signed with the green energy supplier Ecotricity Ltd. The project plans to supply 3 MW electricity to the grid and distribute 12 MW of heat to a range of potential users (including a new housing estate, a tropical rum distillery and a direct lithium extraction plant). GEL has announced plans to develop four more projects in Cornwall by 2026. One of these four sites has received local planning approval at the time of writing.

In addition, GEL is planning a trial of a lithium extraction plant at the United Downs geothermal site, which was reported to have significant lithium concentrations (averaging around 220 mg/L) in the produced geothermal fluids. The pilot plant will use Direct Lithium Extraction (DLE) technology to recover lithium from the geothermal water.

3.4.2 Eden Geothermal Project

The second, deep geothermal project is at the Eden project in Cornwall. It is situated on the St Austell granite. The project is being developed by Eden Geothermal Ltd., which has shareholders comprising Eden Project Ltd., EGS Energy Ltd. and BESTEC (UK) Ltd. The project has funding of £9.9m from the European Regional Development Fund, £1.4m from Cornwall Council and £5.5m from institutional investors. The project is targeting a deep Variscan NNW-SSE striking, steeply dipping, strike-slip fault zone known as the Great Cross Course in the St Austell granite in Cornwall. Drilling of the well (Figure 3) into the granite began in May 2021 and was completed in November 2021. The well, EG-1, has a vertical depth of 4871 m and its measured depth (actual drilled depth) is 5277 m, making it the longest geothermal well in the UK. High temperatures and early signs of potential permeability at depth have been recorded.

The initial phase of injection testing has now been completed. Further injection and production tests will be conducted at a later date following a period of further wireline logging. The results of the well testing will enable characterization of the geothermal resource to understand how the geothermal system will perform, and the expected outputs.

It is a requirement of the funding of this project that the first hole is initially used as a deep coaxial system to demonstrate its production capability. Preparations are underway to install the co-axial completion and associated pumps and pipework to deliver heat to the biomes (displacing gas fired boilers), greenhouses and other buildings at the adjacent Eden Project. The intention is to drill a second deep borehole in order to develop a doublet for ultimate power production. If this goes ahead, the coaxial installation will be decommissioned, and waste heat from the power plant will be used to supply the biomes instead.

Figure 3: HAS Innova drilling rig on Borehole UD1 at United Downs Cornwall, February 2019 (© Curtis et al., 2019) (left) and drilling at Eden Geothermal Limited site at the Eden Project in Cornwall (right) (© BGS/UKRI, 2022).

3.4.3 Deep Geothermal – Scotland and Northern Ireland

Deep Geothermal is still managing to elude Scotland, despite early government support (Gillespie et al., 2013) for feasibility studies to evaluate deep geothermal resources. Though some projects have made it to feasibility level they stalled for a variety of reasons (Townsend et al., 2020).

It is thought that the paleoclimatic effect of the last glaciation period has resulted in heat flow being significantly underestimated in Scotland (Gosnold, 2005; Westaway and Younger, 2013), and more recently published heat flow data for Scotland and resource estimates have been corrected for that effect (Busby et al., 2015; Busby and Terrington, 2017).

In Northern Ireland, whilst there are no commercial deep geothermal projects at the planning or feasibility stage, both the Energy Strategy Action Plan from DfE and the EU PEACEPLUS Programme make provision for progressing deep geothermal demonstration projects.

3.5 New Technologies

Recently the Scottish Government Low Carbon Infrastructure Transition Programme (LCITP) supported the development of the BODYHEAT Programme through a Green-Recovery from Covid-19 Pandemic. The BODYHEAT system harnesses thermal energy produced by dancers and stores it in shallow geothermal boreholes. The first pilot project is being built by TownRock Energy in SWG3 Events Venue, Glasgow.

The repurposing of abandoned hydrocarbon wells is an area of active research with a range of project being announced. For example, CeraPhi in collaboration with Petrofac have announced support for an offshore field study on the EnQuest Magnus platform in the North Sea (https://www.energyvoice.com/renewables-energy-transition/413793/geothermal-north-sea/).

3.6 Geothermal District Heating

District heating networks are not as common in the UK as in other European countries. However, there is an increasing recognition in the role these can play in reaching net zero targets. Consequently, government funding (such as the Green Heat Network Fund (GHNF); see more info in section 4 below) has been directed to these projects.

Among the developments, the use of common ground loop borehole arrays delivering to distributed heat pumps has gained significant traction in the social housing sector due to policy changes that allowed the use of deemed (nonmetered) estimates of heating consumption. This unlocked a combination of RHI (now closed) and other funding for these schemes and has allowed several City Councils to retrofit their apartment blocks or housing estates with these systems.

In South Wales, Rhondda Cynon Taf County Borough Council has announced the Taff's Well Thermal Spring Heat Network Project. The project will utilise Wales' only natural thermal spring, Taff's Well, as a source of low-carbon heat for the heating systems of the new school block and nearby pavilion.

4. POLICY AND REGULATION

4.1 General Trends and News

In this reporting period, the UK has moved beyond the driver of the EU 20/20/20 RES Directive and is formulating its own renewable energy and decarbonization plans (UKGOV, 2021a,b). Events in Ukraine have created a new focus for UK government on energy security. An UK energy strategy has been released (which mentions geothermal energy) to address the dual objectives of meeting CO2 reduction targets whilst achieving national energy security.

In April 2019, the UK Climate Change Committee (CCC) published their recommendations to UK Government for all new housing to be fitted with low / zero carbon heating systems from 2025. In the same year, the Chancellor of the Exchequer announced that new standards mandating the end of fossil fuel heating systems in new homes will be introduced from 2025. The Heat and Buildings Strategy published in October 2021 (UKGOV, 2021) sets the ambition to phase out the installation of new fossil fuel boilers from 2035. The strategy outlines a route to decarbonisation by "electrification of heat for buildings using hydronic (air-to-water or ground-to-water) heat pumps, heat networks and potentially switching the natural gas in the grid to low-carbon hydrogen", including a target of installing at least 600, 000 hydronic heat pumps per year by 2028. (Deep) geothermal energy has been recognised in the strategy as a low-carbon source for heat networks that government "will continue to monitor … (to) assess whether the technology provides a cost-effective option to help to decarbonise heat." Plans for achieving these targets and delivering the transition in the heating sector have yet to be published. At a local level, the Greater London Authority (GLA) has recently announced revised carbon performance requirements for new and redeveloped buildings within its region.

An inquiry into Geothermal Technologies was conducted by the Parliamentary Environmental Audit Committee (EAC 2022), focussing on deep geothermal and mine water heat. The committee found that "exploiting this resource can support Britain's energy security and transition to a net-zero society, as well as create jobs and drive investment across the country." It expressed disappointment in the "lack of formal recognition of the potential for geothermal in Government energy and decarbonisation strategies, and [in] the lack of explicit targets …., [which] prevents the industry from growing."

The most significant policy driver for geothermal during this reporting period has been the final years of the RHI. Enabling legislation was passed in 2008 to allow for feed-in tariffs (FITs) for both small scale electricity generation and for renewable heat. The latter is the Renewable Heat Incentive (RHI) scheme which applies to biomass, solar thermal, and heat pump technologies. After four years of evolution and development, the RHI for domestic and non-domestic installations has been operating in this reporting period. The tariffs for biomass and borehole based GSHPs initially led to a disproportionate fraction of the non-domestic RHI being taken by biomass installations (>90%). This tariff imbalance was reviewed and addressed, resulting in a fall-off in the rate of biomass installs, and a significant increase in GSHP installs, particularly in larger installations in the non-domestic sector. During this reporting period the domestic scheme closed to new applicants in March 2022, but the non-domestic scheme has been extended by a year (for pre-registered non-domestic schemes only) to compensate for delays in completion caused by Covid-19.

A new scheme, the Boiler Upgrade Scheme (£450 million over three years), has been announced in the Government's Heat and Building Strategy for domestic and small non-domestic installations in England and Wales, starting in April 2022. The scheme offers capitals grants of £5000 for ASHPs and biomass boilers, and £6000 for GSHPs for schemes up to 45 kW, including shared ground loops for non-social housing projects. A maximum of 30,000 homes per year would be able to benefit from the scheme at the current level of funding, the same as current installation levels. Separate funding will be made available for social housing schemes.

The Electrification of Heat Demonstration Project (£14.6m) installed ca 750 innovative heat pump systems across a range of different housing types. The project will monitor these systems to demonstrate the feasibility of a large-scale roll-out of heat pumps. The system installation phase was completed in 2021, monitoring will be undertaken for two years, finishing in 2023. Early results indicate that heat pumps are suitable for all UK housing types.

4.2 England and Wales

A number of support schemes are available for heat networks. The Heat Network Delivery Unit (HNDU) provides support for local authorities in England and Wales for carrying out techno-economic feasibility studies and specialist consultancy work around provision of heat (including from geothermal sources) to heat networks. This fund was set up in 2013 and a total of £25.6m has been awarded to date.

In England and Wales, BEIS's Heat Network Investment Project (HNIP) invested £320m up to April 2022 to support the construction of heat networks and accelerate the growth of the market across England and Wales. Although now closed, this fund is referred to a number of times in this report as it provided the grants to the North East mine water geothermal schemes.

HNIP has been replaced by the £288m Green Heat Network Fund (GHNF) scheme in England, which started in March 2022. To assist in the transition between HNIP and GHNF, a £10 million transition scheme was launched in June 2021 (Green Heat Network Fund Transition Scheme) for networks with heat demands >2GWh/year (urban) or >100 connected dwellings (rural). These are more likely to be served by deep geothermal or mine energy sources instead of GSHPs. The Transition Scheme provided grant funding to support projects through the commercialisation phase of development so they would be ready to apply to the GHNF for construction funding when it opens.

GHNF is a capital grant fund that runs for three years from March 2022. The scheme supports all networks that meet its core eligibility criteria (which include metrics on technology carbon intensity and minimum heat demand supplied by the network) irrespective of technology. It covers commercialization and construction costs including geological surveys and exploratory investigations, Environmental Impact Assessment, contract negotiations for Energy Supply Arrangements as well as costs for accessing the heat source, low-carbon generation, primary heat network distribution and the upgrading of infrastructure in secondary distribution, respectively.

Legislation for deep geothermal development has been slow to catch up with the renewed level of interest in the sector. There is no licensing scheme for deep geothermal development in the UK. Geothermal power continued to be eligible to compete in the Contracts for Difference (CfD) under Pot 2 (less established technologies). CfD is a mechanism by which the government buys power from renewable technologies with 15-year contracts. They are "won" by developers of eligible technologies through a competitive auction. No geothermal projects have so far been successful.

4.3 Scotland

In Scotland, several additional funding streams are available for geothermal energy technologies, including the Low Carbon Infrastructure Transition Programme (LCIPT) and the Community and Renewable Energy Scheme (CARES). Under the Scotland Act, heat policy, energy efficiency and building standards are devolved. In October 2021, Scottish Government published its "Heat in Buildings Strategy", including a commitment to make available at least £1.8 billion for heat and energy efficiency projects across Scotland, £200 million of capital funding to support decarbonisation of social housing and £200 million to support the Scottish public sector estate to improve and reduce energy use and install zero emissions heating systems. The Heat Networks (Scotland) Act 2021 sets ambitious targets for the amount of heat to be supplied by heat networks - 2.6 Terawatt hours (TWh) by 2027 and 6 TWh by 2030. This was followed by the Heat Network Delivery Plan (published on 31 March 2022) that sets out how wider policy will contribute to increasing heat networks in Scotland.

4.4 Northern Ireland

The governance of energy in NI is almost entirely a devolved policy matter, but there are existing UK-wide agreements and legislation that influence energy policy in NI. The Department for the Economy (DfE) leads on energy policy and in December 2021 published the Northern Ireland Executive's Energy Strategy - the Path to Net Zero Energy. The strategy and accompanying action plan set out plans to develop opportunities for heat networks and assess potential solutions to decarbonise existing heat networks. As part of this DfE will take forward heat network trials and demonstrators, using a range of energy sources including geothermal energy as outlined in Point 16 of the Energy Strategy Action Plan 2022.

To support the Energy Strategy, DfE set up a new Geothermal Advisory Committee (GAC) for Northern Ireland, chaired by the Geological Survey of Northern Ireland (GSNI). The GAC was established in July (2021) and brings together a group of experts from industry, academia, public sector and professional organisations based in UK and Ireland. This group will provide independent advice to DfE aimed at informing, supporting and developing public policy on geothermal energy for NI.

In Northern Ireland, interest in geothermal energy has seen a notable rise over the past few years. Following on from a successful international conference in December 2020 organised by GSNI and the Centre for Sustainability, Equality and Climate Action (SECA) at Queen's University Belfast (QUB), a series of monthly webinars have been organised by GSNI, QUB, Geothermal Association of Ireland (GAI) and Geological Survey Ireland (GSI) through 2021 and 2022. The GSNI produced a summary report on geothermal energy potential (Raine and Reay, 2021) and Queen's University Belfast produced two strategic reports commissioned by the Department for Economy (see Section 6.2).

The cross-border EU PEACEPLUS Programme 2021– 2027 comprises €1.1bn funding to support peace and prosperity across Northern Ireland and the border counties of Ireland, building upon the work of the previous PEACE and INTERREG Programmes. Theme 5.5 of the draft programme has EUR €20m allocated for a geothermal energy demonstration programme under Theme 5 and Investment Area 5.5 which aims to promote energy efficiency and reduce greenhouse gas emissions.

At the time of writing, feasibility studies for two geothermal projects, one deep hydrothermal project and one shallow GSHP project, are being tendered for by the Northern Ireland Department for Economy (DfE). The studies are expected to start in early 2023.

5. RESEARCH AND INNOVATION

5.1 Research Projects

UK geothermal research is starting to broaden out, with an increasing number of funding calls supporting geothermal research. Overall, funding for geothermal research remains sparse with much research undertaken within / led by the Higher Education sector. A number of new projects have started in the last years, some of them outlined below.

A second call for an £14.6 NERC/EPSRC Programme to Decarbonise Heating and Cooling was issued in 2020. Eleven projects were funded under this call, including three geothermal projects (GEMS, SaFE Ground and ATESHAC; for more details see Abesser et al., 2022).

A 2022 call from Natural Environment Research Council (NERC) Highlight Topic F: Smart subsurface assessment and monitoring of urban geothermal resources, was recently awarded to the project SmartRES, led by Imperial College London. Imperial is also leading the project ATESHAC - Aquifer thermal energy storage for decarbonisation of heating and cooling: Overcoming technical, economic and societal barriers to UK deployment https://www.imperial.ac.uk/earthscience/research/research-groups/ateshac/

Another project led by Imperial and funded by NERC aims to understand and mitigate the "induced seismicity" that might be caused by injecting fluids into rocks when developing multiple green energy technologies, such as geothermal energy, carbon sequestration, and subsurface hydrogen storage. https://www.imperial.ac.uk/earth-science/research/seisgreen/

The £8m UK Unconventional Hydrocarbons (UKUH) research programme (funded by NERC and ESRC) made £400K funding available to fund a series of projects that address new research themes, which have emerged as the result of the changes to the shale gas landscape in the UK (more details of the projects funded are in Abesser et al., 2022)

In Northern Ireland, funding announced for an innovative new partnership between academia and industry will harness Northern Ireland's natural geothermal resources, thermal energy that comes from the sub-surface of the earth to encourage the most efficient use of energy by industrial users such as data centres. It is funded through Invest NI's Competence Centre Programme and the Centre for Advanced Sustainable Energy (CASE). Collaboration among a number of NI organisations (QUB, UU, GSNI, iCRAG, DIAS, GSI, NUIG) aim to build and develop geothermal datasets and to improve subsurface monitoring and imaging for geothermal.

5.2 International Collaborations

Collaboration of UK partners (Durham University, BGS) with the INTERREG NW Europe DGE-ROLLOUT project and publication of two new papers on the Carboniferous Limestone Geothermal Resource as part of a Special Publication in the Journal of the German Geological Society - Zeitschrift der Deutschen Gesellschaft für Geo-wissenschaften (Narayan et al., 2021; Pharaoh et al., 2021).

The British Geological Survey Anglia Ruskin University and Geothermal Engineering Ltd. will take part in the European Project PUSH-IT, led by TU-Delft. This Horizon Europe grant aims to demonstrate and develop large scale seasonal heat storage using three different Aquifer, Borehole and Mine Thermal Energy Storage (ATES, BTES, MTES) technologies. One of the MTES sites will be located in United Downs (Cornwall).

5.3 Research Infrastructure

The UK Geoenergy Observatories (UKGEOS) are part of a £31m project funded by the 2014 UK Government Plan for Growth of Science and Innovation to deliver essential new data from underground that can help to understand how geothermal energy and other solutions can reduce carbon emissions. It comprises two sites.

The UKGEOS site in Glasgow will enable the international science community to study the low temperature mine water geothermal environment at shallow depth. The infrastructure comprises 12 wells drilled into an abandoned mine system and equipped with high resolution monitoring technology, as well as a sealed, open loop between 2 abstraction, 2 re-injection boreholes operating at 3-12 L/s, 3 heat exchangers and a heat pump/chiller of c. 200 kW to simulate a heat user or thermal storage. The site opened for use in 2022. Commissioning and operation include detailed site characterisation, extensive environmental monitoring and delivery of knowledge and open data through the UKGEOS website (https://www.ukgeos.ac.uk/glasgow-observatory).

The Coal Authority is also developing a 'Living Lab' which will comprise of a series of monitoring boreholes in proximity to an active mine water heat network, providing information that will help to better understand the wider interactions of mine heat schemes and in turn drive evidenced based licencing decisions.

A second site, UKGEOS Cheshire, is currently being built and will include infrastructure for research on GSHP systems, thermal storage in the Triassic Sherwood Sandstone and investigation of environmental impacts. The first boreholes have been drilled in 2022. The Cheshire Observatory will be equipped with a range of subsurface technologies that include borehole heat exchangers for heating and cooling, advanced sensors for 3D imaging of subsurface processes in real time and equipment for multilevel groundwater monitoring and hydraulic control.

In Cardiff, an affiliated research site, the Cardiff Urban Geo-Observatory is investigating shallow geothermal heat recovery and storage. The project aims to improve the understanding of the way groundwater and heat moves around in a complex geological environment changed by industrialisation and urban growth.

For additional information and access to available published data the reader is referred to https://www.ukgeos.ac.uk.

6. MEETINGS AND PUBLICATIONS

6.1 Meetings

The level of interest in all things geothermal in the UK is reflected in recent symposia/meetings held on the subject and a number of generic papers on the subject.

2021 Mine Water Geothermal Energy Symposium: Mine Water Heating and Cooling – A 21st Century Resource for Decarbonisation (virtual), organised by the BGS, BEIS and IEA Geothermal, 12 -13 April 2021: https://iea-gia.org/workshop-presentations/2021mine-water-geothermal-energy-symposium/.

2022 Mine Water Geothermal Energy Symposium, organised by the BGS, Coal Authority and IEA Geothermal, 16-17 March 2022 (virtual): https://iea-gia.org/workshop-presentations/2022mine-water-geothermal-energy-symposium/. During the symposium, the new IEA Geothermal Mine Water Group was announced. Anyone interested in joining can contact the group directly at: MineWaterThermal_IEA@bgs.ac.uk.

2023 Mine Water Geothermal Energy Symposium: Mine Water Heating and Cooling – A 21st Century Resource for Decarbonisation (virtual), organised by the BGS, BEIS and IEA Geothermal takes place 19 -20 April 2023: https://iea-gia.org/call-for-presenters-mine-water-energy/

A Parliamentary Debate on Opportunities for geothermal energy extraction in the UK took place in the House of Commons on 15th September 2021. (Hinson and Sutherland, 2021)

The principal UK geothermal energy conference was the 8th London Geothermal Symposium held on 17th November 2021 at the Geological Society: https://www.geolsoc.org.uk/11-EG-Geothermal and the 9th London Geothermal Symposium that in 2022, which, for the first time, run over two days, the 14 and 15th November 2022 https://www.geolsoc.org.uk/expired/EG-9th-UK-Geothermal-Symposium

Build Back Better: Geothermal Energy for Norther Ireland virtual conference (virtual) 11th December 2020: Conference-Agenda-Building-Back-Better-A-futurefor-Geothermal-Energy-in-Northern-Ireland.pdf (qub.ac.uk)

The first online SPE Aberdeen Geothermal Seminar 2022 https://www.spe-aberdeen.org/wp-content/uploads/2022/01/Geothermal-Conference-Programme_1.1.pdf. A new SPE Aberdeen Geothermal Seminar 2023 has been announced https://www.spe-aberdeen.org/wp-content/uploads/2022/07/SPE-Geothermal-Programme-Flyer_0.3.pdf

The UK GSHPA continues to hold its Annual AGM and Seminar/Exhibition. The most recent one was held on 22nd October 2021 at Skipton, Yorkshire and the 2023 conference will take place in September 2023 in Hull https://www.eventbrite.co.uk/e/gshpa-annual-conference-2023-tickets-417906869697.

The UK section of WING (Women in Geothermal) has been formed and has been actively promoting a series of online webinars.

6.2 Publications

In April 2022, the UK Parliamentary Office for Science and Technology (POST) published a briefing paper (POST brief) on Geothermal Energy (Abesser and Walker, 2022).

In Northern Ireland, three reports were commissioned by the Department for the Economy were published, developed by Queen's University Belfast

Building the Geothermal Energy Sector in Northern Ireland https://www.qub.ac.uk/schools/QueensManagementSchool/FileStore/Filetoupload,1518743,en.pdf

Defining the Vision for Geothermal Energy in Northern Ireland https://www.qub.ac.uk/schools/QueensManagementSchool/FileStore/Filetoupload,1518742,en.pdf

And Arup And the British Geological Survey:

Research into the geothermal energy sector in Northern Ireland

https://www.economy-ni.gov.uk/sites/default/files/publications/economy/research-into-the-geothermal-energy-sector-in-northern-ireland.pdf

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