Chapter 3

Where Is the Heat? Exploring the United Kingdom's Subsurface Geology

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The UK's diverse subsurface geology offers resources that—if harnessed effectively—could make a significant contribution to decarbonising energy across the region.

Despite the United Kingdom's varied geology that offers a diverse portfolio of geothermal opportunities, geothermal use across the wider UK remains limited compared with other countries because of issues such as gaps in data, regulatory uncertainty, and high risks in developing projects. This chapter seeks to identify data gaps by assessing the potential for geothermal energy across the United Kingdom and highlighting where and what additional data would be beneficial.

The United Kingdom's potential is suited to a range of different applications and scales. Shallow geothermal systems and aquifer thermal energy storage (ATES) could readily be deployed as solutions for urban decarbonisation, particularly where shallow aquifers are accessible and demand for heating and cooling is high. Deep sedimentary basins represent some of the largest medium-temperature heat resources in the United Kingdom, supporting district heating, industrial applications, and cooling for data centers. High heat-producing granites offer potential for electricity generation (powering data centres in some locations) and other benefits such as critical mineral recovery. In addition, using minewater for geothermal provides a unique pathway to repurpose existing subsurface infrastructure for low-cost heating. While the potential for geothermal is specific to local geology, across the United Kingdom, Project InnerSpace estimates that there are approximately 25 gigawatts of total technical potential for electricity, down to 5 kilometres. Additionally, we estimate there are approximately 3,900 gigawatts of total technical potential for heating and cooling down to 3.5 kilometres. The various geology and technologies are detailed in this chapter, and **Table 3.1** and **Figure 3.1** outline the diversity of options for geothermal development across the United Kingdom and what UK geographies are best suited for their deployment.

The United Kingdom has sufficient geological and geothermal information to identify areas of high potential and to distinguish between different geothermal resource types. However, limitations in subsurface measurements—particularly at depth—constrain the accuracy of resource modelling. Reservoir properties such as permeability and fracture connectivity remain incompletely characterised, and the majority of available seismic data derive from surveys acquired for petroleum exploration, which could benefit from reprocessing to provide improvements for geothermal applications. More targeted acquisition and reprocessing of geophysical data, combined with direct subsurface measurements, would significantly improve resource assessment.

While this chapter highlights the principal areas of opportunity, advancing beyond conceptual classification requires additional data. Priority actions include new seismic acquisition and reprocessing, pilot drilling to provide direct data on temperature and flow potential, and the adoption of standardised geothermal reporting protocols to ensure consistency and comparability across projects. Broader regulatory and financial reforms needed to unlock investment are addressed in Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," and Chapter 9, "Minding the Gap: Financing Solutions to Advance Geothermal in the United Kingdom." Collectively, improved data and a supportive policy framework will be essential for moving UK geothermal resources from conceptual appraisal to bankable, deployable projects.

DISTRIBUTION OF KEY GEOLOGICAL SETTINGS RELEVANT TO UK GEOTHERMAL POTENTIAL

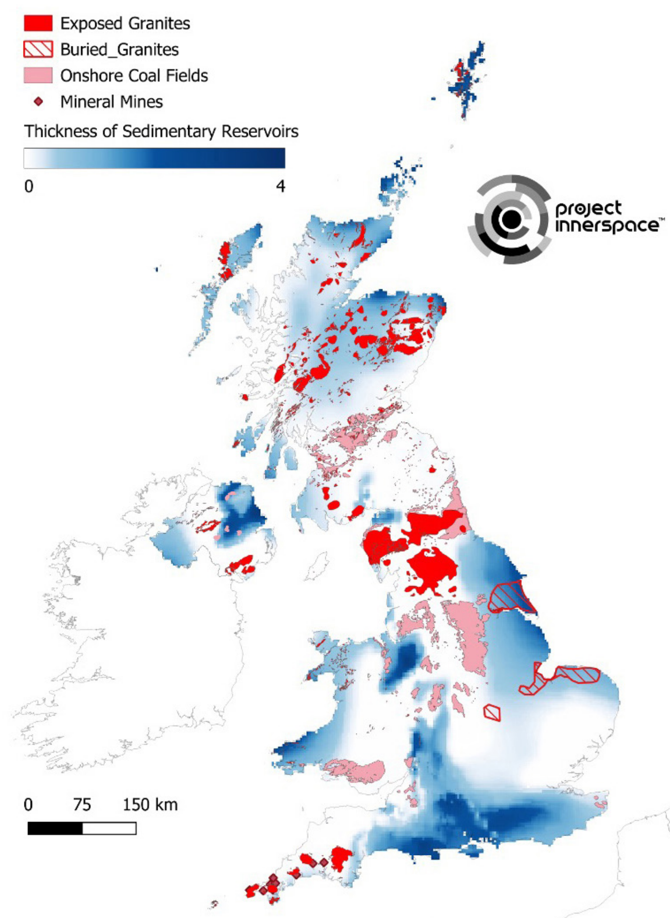

Figure 3.1: Distribution of key geological settings relevant to UK geothermal potential, showing the extent and depth of sedimentary reservoirs, the locations of exposed granites and buried granites, and areas of historic or active mining. In the southwest, the red granite areas are the most likely option for power generation, while the sedimentary aquifers have potential for heating and cooling, complemented by the areas where former mines could be used for heating and cooling.Sedimentary reservoir depths range from 0.1 kilometres (light blue) to more than 2.0 kilometres (dark blue), highlighting regions with potential for aquifer thermal energy storage and direct-use geothermal heating. Projection: OSGB36/British National Grid. Map created by Project InnerSpace. Data sources: Holdt, S., Slay, R. & White, N. (2025). *Global sediment thickness* (in preparation). Project InnerSpace; ArcGIS Hub. (2025). Mineral mines. *UNESCO WHC sites dossiers elements core points*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). *Documentation on excess heat potentials of industrial sites including open data file with selected potentials* (Version 2). Zenodo; British Geological Survey. (2020). *Coal resources for new technologies dataset*; British Geological Survey. (n.d.). *BGS Geology 625K*; Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *Evidence report supporting the Deep Geothermal Energy White Paper: The case for deep geothermal energy—unlocking investment at scale in the UK*. British Geological Survey.

DATA

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Available Data

Much of our current understanding of the subsurface is based on the more than 2,000 wells drilled over the past 106 years, mainly in the United Kingdom's onshore petroleum provinces. As a result, our knowledge of the onshore deep geology remains poor compared with that of offshore, where more than 10,000 wells have been drilled since 1965[1] and the seismic quality remains poor, dominated by sparse 2D lines.

Despite this lack of knowledge, there are still a wealth of public, academic, and commercial sources for subsurface data that provide essential information on the United Kingdom's geothermal resources. The British Geological Survey (BGS) and the Geological Survey of Northern Ireland (GSNI) are the primary custodians of national subsurface data sets, which are typically hosted as part of the National Geological Repository or the National Geoscience Data Centre. Data held in these repositories include borehole records, bottom-hole temperature logs, heat flow data, and thermal conductivity measurements, and the data are governed by a wide range of access requirements, with only some data sets available and accessible. Many of these data sets were initially acquired by the petroleum and coal industries, but they also are relevant to geothermal exploration and development. In 2024, BGS released the first digital version of the *UK Geothermal Catalogue*, which comprised more than 11,800 geothermal data points from 743 sites, including temperature, thermal conductivity, and heat flow measurements.[2] Despite the availability of such information, our knowledge of deep thermal gradient data is limited, as approximately

GEOTHERMAL TECHNOLOGIES AND BEST-SUITED REGIONS

Geothermal Technology	Best-Suited Regions	Applications
Shallow geothermal (ground source heat pumps)	Nationwide potential; urban areas with shallow aquifers	Heating and cooling via ground source heat pumps; urban decarbonisation
Aquifer thermal energy storage (ATES)	London, Southampton, Cheshire, Manchester (Chalk and Sherwood Sandstone aquifers)	Seasonal heating and cooling storage; large-scale urban networks
Minewater geothermal	Former coalfields: Northeast England, Yorkshire, South Wales, Midlands, Cornwall	District heating and cooling using flooded mines; repurposing legacy coalfields
Granite-hosted systems	Cornwall (Cornubian Batholith), Weardale	High-temperature heat, power generation, critical mineral recovery (e.g., lithium)
Deep sedimentary basins	Wessex Basin, Cheshire Basin, East Yorkshire–Lincolnshire, parts of Scotland, Northern Ireland (Larne and Lough Neagh basins)	District heating, industrial heat, hybrid power-heat systems

Table 3.1: The types of geothermal heating and cooling and power generation available in the United Kingdom and where current geological data (as identified in this chapter) show where they can be best deployed. Source: the authors.

93% of the recorded temperatures are from depths shallower than 2 kilometres.[3]

Geophysical data are held by both the BGS and the UK Onshore Geophysical Library (UKOGL; **Table 3.2**). The BGS holds records of gravity and magnetic and seismic data, whereas the UKOGL principally maintains an indexed repository of seismic reflection data and well records. These data are free to academic users and available for a modest fee to commercial entities. Other relevant data sets are held by the North Sea Transition Authority (NSTA), the Mining Remediation Authority, the Environment Agency (EA), Natural Resources Wales (NRW), and the Scottish Environment Protection Agency (SEPA). Subsurface data relevant for geothermal exploration for Northern Ireland are managed by GSNI, which has a dedicated geothermal sub-portal within its broader data catalogue.[4] At present, the sub-portal contains only the geothermal webinar series, but data that are applicable for geothermal exploration (e.g., well data, logs, LAS files, seismic) will be made available though this catalogue in the future.[5] The Geoenergy NI data will likewise be made available though the department's page on the OpenDataNI website in October 2025.[6]

Commercial projects are also emerging as important sources of geothermal data. Companies such as Geothermal Engineering Ltd (GEL), Cornish Lithium, and Star Energy have acquired new geophysical, borehole, and temperature data through exploration and development activities. For example, the United Downs project by GEL provided new thermal and geochemical data from wells drilled to depths exceeding 5 kilometres.[7] Several councils—including Durham, Gateshead, South Tyneside, and a community project at Swaffham Prior in Cambridgeshire—have been active developers of geothermal energy, overseeing both the drilling of new wells and the acquisition of new data for both minewater and shallow geothermal. Although some of this information remains commercially sensitive, developers increasingly collaborate with researchers and public bodies to publish aggregated or interpreted data sets. Consultancies involved in

EXAMPLE DATA SETS IN THE UK

Key Data Set Type	Custodian(s)
Borehole data (logs and core)	BGS, GSNI, NGR
Heat flow, temperature, and thermal conductivity data	BGS, GSNI
Aquifer designations and properties	BGS, EA, GNSI
Seismic reflection data (onshore)	UKOGL, BGS
Non-seismic geophysics	BGS, GNSI
Onshore oil and gas wells	North Sea Transition Authority, UKOGL, BGS
Coal mining data (including hydrogeological data)	Mining Remediation Authority
Water quality and abstraction data	EA
Heat networks and heat demand	Department for Energy Security & Net Zero

Table 3.2: The example data types shown frequently underpin web apps or web map tools that enable users to interact with the data sets without the need to download them. Examples of these tools include the BGS Open-loop GSHP Screening Tool, the BGS UK Geothermal Platform, and the Environment Agency Water Quality Explorer. BGS = British Geological Survey; EA = Environment Agency; GSNI = Geological Survey of Northern Ireland; NGR = National Geological Repository; UKOGL = UK Onshore Geophysical Library.

geothermal feasibility studies and drilling support may also be involved in the collection and management of proprietary data sets during project services; in some cases, this may enable access to and use of the data in future activities.

Some industry–academic partnerships yield hybrid data models, where private drilling results are shared with universities under non-disclosure agreements or published in conference proceedings. Moreover, data acquired during licensing, permitting, or regulatory compliance stages (for example, Environmental Impact Assessments) may be stored with local planning authorities.

Despite the increasing availability of open-access data on which early-stage evaluations can be based, considerable data gaps continue to exist, such as in built-up urban areas with high heating demand. Similarly, while ongoing efforts such as the UK Geothermal Platform aim to unify data sources, standardise quality, and expand accessibility to support new development, those efforts remain incomplete. For the United Kingdom to unlock the full potential of geothermal energy, dedicated new data acquisition is required.

MINEWATER GEOTHERMAL ENERGY IN THE UNITED KINGDOM

Charlotte Adams, David Banks, Helen Doran, Gioia Falcone, Jon Gluyas, and Mark Ireland

Minewater geothermal is an important opportunity that is discussed in more detail in Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors." However, given that this chapter aims to present a cohesive picture of all subsurface potential in the United Kingdom, some of the important minewater points are included here as well.

Roughly one-quarter of the UK population is located above abandoned coalfields, representing a significant untapped heating resource. Estimates suggest these areas could deliver as much as 2.2 gigawatt hours of thermal energy, enough to supply around 6 million homes along with more than 300,000 commercial and office buildings.

UK ONSHORE COALFIELDS, MINERAL MINES, AND DISTRICT HEATING DEMAND

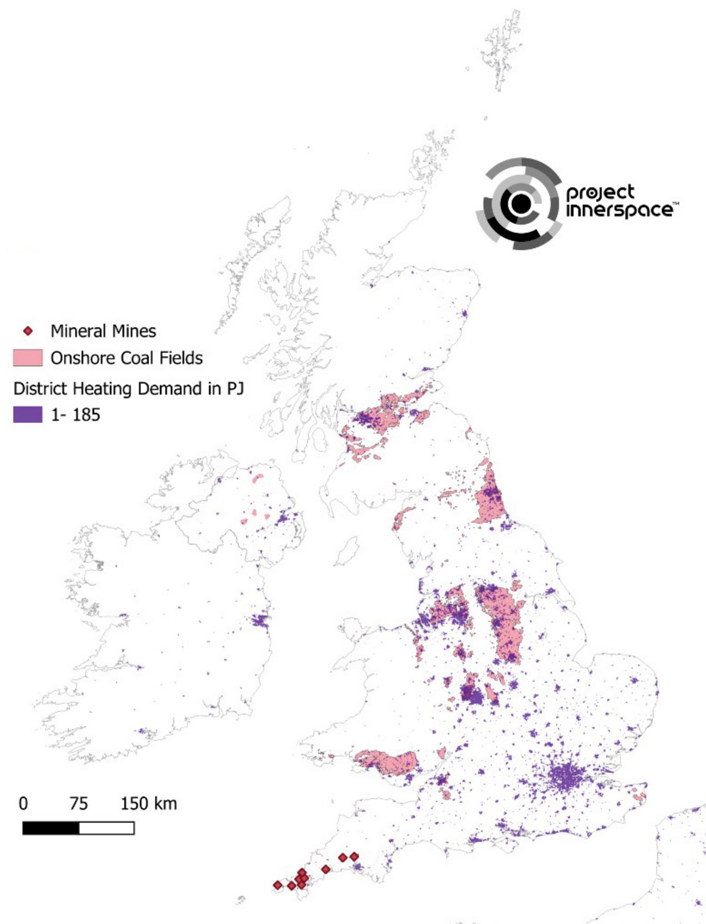


Figure 3.2: Distribution of onshore coalfields, mineral mines, and district heating demand across the United Kingdom. Areas shaded in pink indicate known onshore coalfields, while red diamonds mark the locations of active or historical mineral mines. Purple dots show spatial variation in district heating demand (1–185 petajoules), highlighting significant clusters of potential heat users in urban and industrial regions. This spatial overlap informs the assessment of minewater geothermal and co-located geothermal heating opportunities. Sources: ArcGIS Hub. (2025). *UNESCO WHC sites dossiers elements core points*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). *Documentation on excess heat potentials of industrial sites including open data file with selected potentials* (Version 2). Zenodo; British Geological Survey. (n.d.). *Coal resources for new technologies* [Data set].

As illustrated in **Figure 3.2**, the areas with the greatest minewater energy potential are concentrated in the South Wales Coalfield, Central Scotland (notably Glasgow and Lanarkshire), and north-east England, including counties such as Durham and Northumberland. Additional opportunities exist across the East and West Midlands, Lancashire, and Kent. In Northern Ireland, disused mining districts like East Tyrone (Dungannon–Coalisland) and Ballycastle also show promise for minewater heating, though resources there are more limited and localised. See Chapter 4 for more detail on minewater, including a case study on Gateshead.

SEDIMENTARY BASINS

Helen Doran, Gioia Falcone, Jon Gluyas, Mark Ireland, and Matthew Jackson

The United Kingdom hosts a diverse set of onshore sedimentary basins formed through multiple tectonic phases throughout geological time. These basins—characterised by thick accumulations of Mesozoic, Permian, and older strata—offer some of the country's most promising geothermal targets due to their favourable combinations of depth, porosity, permeability, temperature, and proximity to high-heat-demand populated areas.

Target Aquifers and Regional Focus

Several principal and numerous secondary bedrock aquifers that are geographically widespread can be found in the United Kingdom (**Figure 3.3**).[8,9] At shallow depths, and particularly relevant for ATES, principal aquifers have high porosity (typically of order 0.2–0.4 porosity units) and permeability (typically of order 10^{-14}–10^{-10} m^2, or 1 mD–10 D; see **Table 3.3**), providing a high level of groundwater storage and transmission and supporting water supply on a strategic scale.[10]

Secondary aquifers are porous and permeable rock layers capable of supporting water supply at a local rather than strategic scale or lower-permeability layers that may store and yield limited amounts of groundwater due to localised features such as fissures or thin permeable horizons and weathering. Superficial aquifers—which comprise loose, unconsolidated deposits such as sand and gravel—are also present in some locations.

The most important UK aquifers with potential for ATES and other shallow and deep, open-loop geothermal technologies are the Chalk, the Lower Greensand, the Oolites, the Magnesian Limestone, the Late-Permian to Triassic sandstones of the Sherwood Sandstone Group, and the Carboniferous Limestone.[11] Secondary aquifers include Carboniferous and Devonian sandstones.[12]

The Chalk is the major aquifer of southern and eastern England, present in the south-east of Yorkshire southwards across the Humber and into Lincolnshire. It extends east and south of the Wash across central southern England from north Norfolk, through the Thames Basin, and along the Kent coast, down to the Isle of Wight and into Dorset towards Portland Bill. The Chalk is also the major aquifer for London, where it is harnessed in 55 open-loop geothermal systems, including several ATES installations.[13,14,15,16]

The Sherwood Sandstone Group is also a key aquifer. The Sherwood aquifer runs through a series of deep basins throughout the United Kingdom, including Carlisle, eastern England from Yorkshire to the Wash, the Fylde coast in north-west England, the Cheshire Basin, Shropshire, Worcestershire, and southern England from Hampshire to Dorset. It also acts as the primary aquifer for Manchester, Birmingham, and Nottingham. In Northern Ireland, the Sherwood aquifer also runs beneath Belfast and Lisburn and crosses Scotland to the west and south-west.[17]

In Scotland, Carboniferous and Devonian sandstones create secondary aquifers in parts of the Central Belt that could be used for ATES, while mining of the Carboniferous Coal Measures in the Central Belt could provide a resource for MTES. Devonian sandstones also extend to the north-east of Scotland and into the Orkney Islands.

SEDIMENTARY THICKNESS OF THE UK

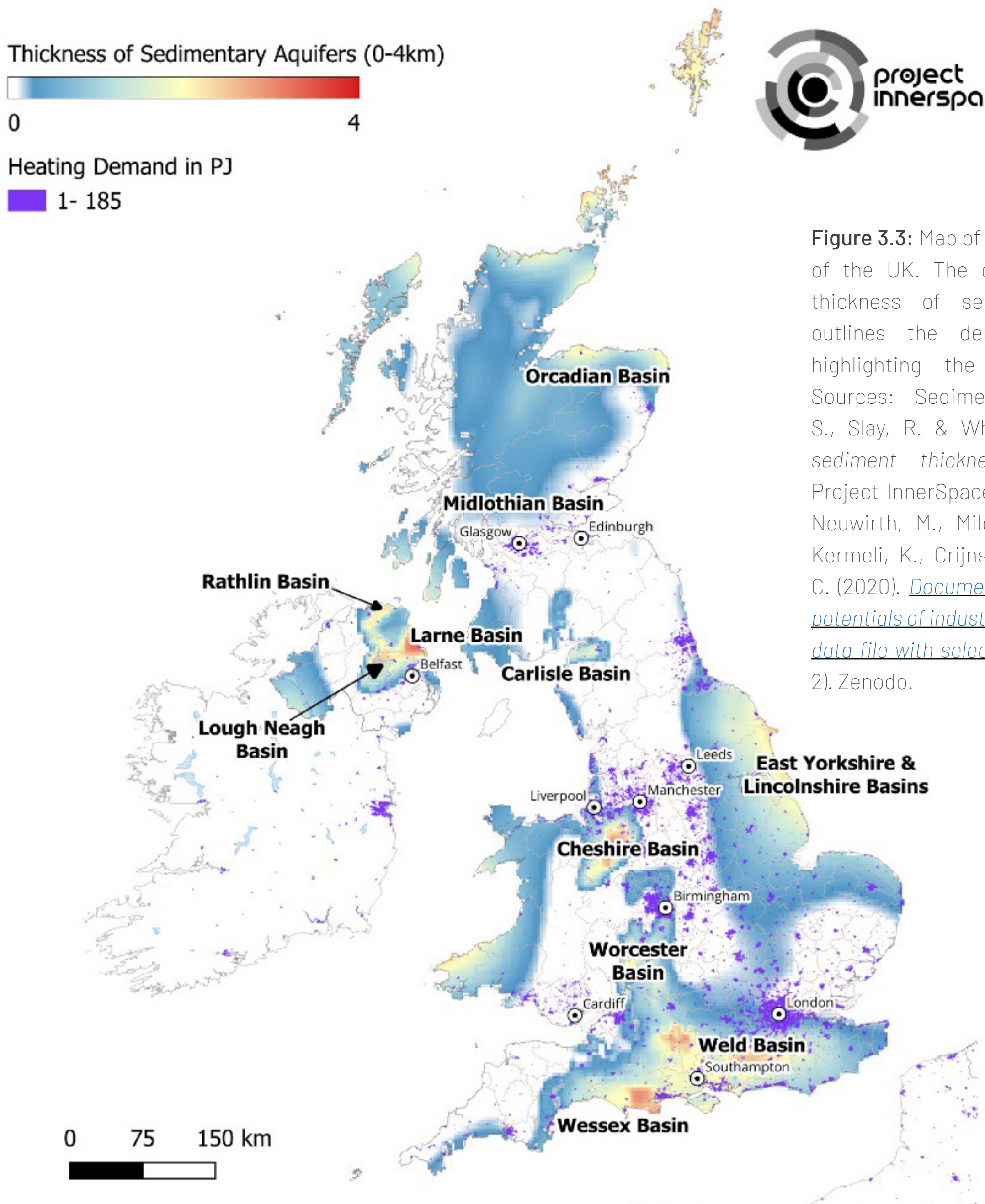


Figure 3.3: Map of sedimentary thickness of the UK. The colours represent the thickness of sediments, the purple outlines the demand in petajoules, highlighting the population centres. Sources: Sediment thickness: Holdt, S., Slay, R. & White, N. (2025). *Global sediment thickness* (in preparation). Project InnerSpace; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). [Documentation on excess heat potentials of industrial sites including open data file with selected potentials] (Version 2). Zenodo.

Shallow Aquifer Properties and Suitability

Most sedimentary geothermal projects (and ATES) target sands and sandstones with high intergranular porosity and permeability that accommodates most of the groundwater storage and flow.[18,19] The Chalk in the United Kingdom is a dual-porosity aquifer. Groundwater flow occurs primarily through fractures and intervals of karst. Solid (unfractured) Chalk rock has high intergranular porosity but very low permeability, so it allows high groundwater storage but little flow (**Table 3.3**).[20,21,22,23] In London, the Chalk is typically confined by mudstones and siltstones of the London Clay formation that acts as an aquitard; locally, the Chalk may be directly overlain by the Thanet Sands and the Woolwich and Reading Beds.[24] Flow in the Chalk in

London typically occurs primarily within the upper few metres within intervals of karst, evident as large voids and fissures in borehole geophysical logs.

The Sherwood Sandstone Group is mostly made up of sandstones and pebbly sandstones with minor amounts of conglomerate at its base and interbedded mudstone and siltstone. It typically behaves as a single aquifer with high but variable intergranular porosity and permeability.[25,26] Fractures may be present, particularly at shallow depth (within the upper few tens of metres), which can host significant localized flow. Mudstone, siltstone intervals, and dykes and sills (In Northern Ireland) can act as local barriers to flow with varying lateral extent. Where confined, the Sherwood Sandstone Group is overlain by mudstones of the Mercia Mudstone Group.

Activity Across Deep Sedimentary Basins

Geothermal energy development in the UK's sedimentary basins is advancing through a range of feasibility studies, test drilling, and early-stage demonstration projects. More details on the activity in shallow applications such as ATES can be found in Chapter 4.

Geothermal exploration in the United Kingdom has increasingly focused on deep sedimentary reservoirs, so the remaining portion of this section deals with deep geothermal activity. Deeper geothermal is particularly focused on the Sherwood Sandstone Group due to its widespread distribution and potential good-quality reservoirs in some locations (see **Appendix A**). In the Cheshire Basin, a doublet system in Stoke-on-Trent was proposed to supply 10 megawatts thermal of heat from 3,800 metres deep (although the status of the project is uncertain at the time of the writing of this chapter), while proposals in Manchester and Crewe are exploring district heating using boreholes targeting temperatures above 90°C. The Cheshire Observatory provides a dedicated research platform to study shallow reservoir behaviour (~100 metres) and support future deployment. In the Humber Basin, developments include Third Energy's proposed reuse of existing boreholes in Ryedale, deep reservoir proposals at Scunthorpe General Hospital, and a proposed closed-loop borehole to 1,821 metres at Newcastle Helix. Historic exploration at Cleethorpes and ongoing feasibility work at Bishop Auckland further reflect regional interest.

PROPERTIES OF THE UK'S TWO MOST IMPORTANT AQUIFERS

Property	Values	
	Chalk	Sherwood Sandstone (Matrix Dominated)
Porosity (porosity units [pu] on a scale of 0–1)	0.05–0.2 (karst dominated) $1x10^{-6}$–0.01 (fracture dominated) 0.25–0.45 (matrix dominated)	0.15–0.35
Permeability (m^2)	$1x10^{-10}$–$5x10^{-9}$ (Karst dominated) $1x10^{-11}$–$5x10^{-11}$ (Fracture dominated) $5x10^{-17}$–$3.5x10^{-14}$ (Matrix dominated)	$1x10^{-14}$–$5x10^{-12}$
Wet thermal conductivity ($W\ m^{-1}\ K^{-1}$)	1.8–3 (Matrix dominated)	2–4.5
Dry density ($kg\ m^{-3}$)	1,400–2,000	2,000–2,700
Dry specific heat capacity ($J\ kg^{-1}$)	900–950	700–840

Table 3.3: Summary properties of the UK's two most important aquifers over the depth range 0–300 metres suitable for LT-ATES. The full source list can be found after the conclusion to this chapter.

Detailed work has been undertaken on the East Midlands Shelf using data from producing oil and gas fields and tested reservoirs in Nottinghamshire, Lincolnshire, and adjacent areas.[27,28] Much of this study was on Upper Carboniferous sandstones, but a small number of fields produced oil from karstified and vuggy Lower Carboniferous limestone and dolomites, and these tested limestones provided the initial work on the Lower Carboniferous limestones conducted by Narayan and colleagues.[29] Lower Carboniferous limestones are known to be highly active reservoirs beneath the Rhaetian-age lower reservoir in the Humbly Grove gas storage site.[30] Extensive ongoing work at the University of Manchester is mapping the distribution of the Lower Carboniferous limestone and its flow properties, including the orientation and flow potential of the fractures (in collaboration with the University of Leeds).[31,32,33]

Hirst et al. subsequently examined the Cheshire Basin,[34] where only a small number of wells have been drilled, but they were able to integrate data from the adjacent East Irish Sea Basin and especially the Liverpool Bay area, which has a long history of petroleum exploration and production. A more recent study by Johnstone reinterpreted the seismic and well data using established exploration workflows to evaluate the geothermal potential of the area.[35]

In the Wessex Basin, the Southampton District Heating Scheme—the UK's longest-running geothermal system—previously supplied heat from a 76°C reservoir at around 1,800 metres deep and is undergoing review for refurbishment. Other feasibility studies are ongoing at Eastbourne, Salisbury, and Southampton hospitals. Thermal springs at Bath (46°C), Buxton (20°C), and Matlock Bath (27°C) continue to support spa operations, while a low-temperature spring at Taff's Well is being considered for school heating. In York, the university has recently received funding through the Public Sector Decarbonisation Scheme, which will enable it to drill into deeply buried Lower Carboniferous limestones and target heat production.[36] (See Chapter 4 for more details on all of these topics.)

In Northern Ireland, deep boreholes in the Larne Basin at Larne (2,873 metres) and Kilroot (868 metres) have recorded temperatures up to 91°C, and a demonstrator system is underway at the Stormont Estate, where five boreholes have been drilled for low-carbon heat supply. A separate demonstrator is planned at Greenmount (CAFRE) to provide heat to an agricultural campus following a geophysical survey of the area.

Scotland has seen feasibility studies for geothermal heating near Guardbridge, Edinburgh, and Heriot-Watt University, with target depths of between 1.5 kilometres and 2 kilometres and estimated capacities of between 1.3 and 3.2 megawatts thermal. In the Orcadian Basin, a malting facility is exploring 2.22 megawatts thermal of potential from Devonian sandstones at about 3 kilometres deep. These developments collectively signal a growing, geographically diverse effort to tap the United Kingdom's low- to medium-enthalpy geothermal resources for district and institutional heating. **Table 3.4** provides a summary of activity in the sedimentary reservoirs and additional examples as outlined in a report by Abesser and colleagues and added to through personal communications with a range of players in the UK ecosystem.[37]

A SELECTION OF UK SEDIMENTARY AQUIFER GEOTHERMAL PROJECTS AND PROSPECTS

Location / Project	Location	Basin	Status	Description
Stoke Deep Geothermal Project	Stoke-on-Trent	Cheshire	Proposed	Doublet to be drilled to a maximum depth of 3,800 m to exploit permeable fractures at an anticipated water temperature of 95°C. The heat will supply a district heat network in the Etruria Valley.
North Manchester General Hospital	Manchester	Cheshire	Proposed	Feasibility study
Cheshire Basin	Cheshire	Cheshire	Proposed	Two phases. Not enough depth to the Sherwood Sandstone Group across the area of interest. Phase 2 focused on leisure centres.
Oxford Road DHN	Manchester	Cheshire	Proposed	Proposal to drill a deep (3.5 km) doublet into the Carboniferous Limestone to provide heat to a district network.
Manchester Metropolitan University, Crewe Campus	Crewe	Cheshire	Proposed	Proposal to drill a 2 km deep single borehole heat exchanger to heat the university campus.
Cheshire Basin	Cheshire	Cheshire	Observatory	
Newcastle Helix (Newcastle Science Central)	Newcastle upon Tyne	Solway Basin	No current activity	Development of a deep closed-loop research borehole using existing borehole (Newcastle Science Central borehole) drilled in 2011 into the Fell Sandstones to a depth of 1,821 m.
Scunthorpe General Hospital	Scunthorpe	East Yorkshire & Lincolnshire Basins	Under development	Sherwood Sandstone Group, first well drilled to depth >500 m.
Third Energy	Kirby Misperton, Ryedale	East Yorkshire & Lincolnshire Basins	Proposed	Geothermal energy centre powered by several existing boreholes for new distillery complex and nearby gas-heating and community heating.
Third Energy (CeraPhi)	NY Moors	East Yorkshire & Lincolnshire Basins	Proposed	Heating of leisure/tourism facilities such as eco-lodges, botanical gardens, and bike hubs.
Third Energy (CeraPhi)	Great Habton/ Little Barugh, Ryedale	East Yorkshire & Lincolnshire Basins	Proposed	Community heating project using four existing boreholes within a km of each rural settlement.
Third Energy (CeraPhi)	Pickering, Ryedale	East Yorkshire & Lincolnshire Basins	Proposed	Geothermal energy centre powered by two existing boreholes for new leisure and school facilities.
The Auckland Project	Bishop Auckland	East Yorkshire & Lincolnshire Basins	Proposed	Feasibility study ongoing.
Cleethorpes No. 1	Cleethorpes, South Humberside	East Yorkshire & Lincolnshire Basins	Exploratory borehole	Drilled in 1984. Depth 2092 m. Bottom hole temperature 69°C. Aquifer found at range 1093 m–1490 m with temperature 44°C–55°C.

A SELECTION OF UK SEDIMENTARY AQUIFER GEOTHERMAL PROJECTS AND PROSPECTS

Location / Project	Location	Basin	Status	Description
Stormont	Stormont Estate, Belfast	Lagan Valley	Drilling and testing of five boreholes, four of which will be hydrogeology boreholes around 250 metres deep, and one borehole will be cored to 500 metres depth. A series of tests and analyses including down-hole geophysics will then be carried out on the boreholes to identify the optimum numbers and depths of boreholes required to deliver low carbon and renewable heat to the Stormont Estate.	Exploratory geothermal drilling and testing on the grounds of Stormont Estate as part of the Department for the Economy's £3 million GeoEnergy NI project. Examining shallow geothermal potential and its possible future application to provide sustainable low carbon, renewable heating and cooling systems for a number of pre-identified buildings on the Estate.
Larne No. 2	Larne, Co. Antrim, Northern Ireland	Larne Basin	Exploratory borehole	Completed in July 1981. Depth 2873 m; main aquifer at 960 m–1247 m. Bottom hole temp 91°C, aquifer ~40°C.
Kilroot GT-01	Co. Antrim, Northern Ireland	Larne Basin	Exploratory borehole	Drilled in 2009 to a depth of 868 m. Fully cored with complete Sherwood Sandstone Group section.
Agricultural College (CAFRE)	Greenmount, Antrim, Northern Ireland	Lough Neagh	Demonstrator	Feasibility study and site investigations to identify a site and plan for a deep test borehole. Commissioned by the NI Department for the Economy as part of the geothermal demonstrator project.
Ballymacilroy No. 1	Co. Antrim, Northern Ireland	Rathlin Basin	Exploratory borehole	Initially drilled in search of coal. Found hot water in Sherwood Sandstone Group. Geological and hydrogeological studies done.
Guardbridge Integrated HSA and Biomass Heat Network	Guardbridge, St Andrews	Orcadian	Proposed	This feasibility study (2016) investigates whether a geothermal district heating system, which accesses hot sedimentary aquifer potential underlying a brownfield site at Guardbridge in northeast Fife. Scottish Government Geothermal Energy Challenge Fund.
Southampton Geothermal Heating Company Ltd. (SGHC)	Southampton	Wessex	Operational for more than three decades, SGHC is working with Star Energy to explore new opportunities for the district heating network	A borehole from the early 1980s brought into production in 1987 connected to a city centre district heating scheme. It exploited the Sherwood Sandstone (depth interval of 1725 m–1749 m). The brine was extracted at a temperature of 76°C. The well was reported to be offline due to a technical problem with another component of the district heating and cooling network unrelated to the geothermal system and is not in operation.
Southampton General Hospital	Southampton	Wessex	Proposed	Feasibility study ongoing
Eastbourne District General Hospital	Eastbourne	Wessex	Proposed	Feasibility study ongoing

A SELECTION OF UK SEDIMENTARY AQUIFER GEOTHERMAL PROJECTS AND PROSPECTS

Location / Project	Location	Basin	Status	Description
Salisbury District Hospital	Salisbury	Wessex	Proposed	Feasibility study ongoing
Marchwood No. 1	Marchwood	Wessex	Exploratory borehole	Drilled in 1980 to a depth of 2609 m. Bottom hole temperature of 88°C. Main aquifer at 1672 m–1686 m; temperature of the aquifer 74°C.
New Bath Hotel & Spa	Matlock Bath	Worcester Graben	Operational	Outdoor lido fed from natural hot spring waters (27°C) from the Carboniferous Limestone.
Thermae Spa	Bath	Worcester Graben	Operational	Utilisation of the natural hot spring waters (46°C) from the Carboniferous Limestone in a modern-day spa.
Taffs Well Thermal Spring	Taffs Well, S. Wales	Worcester Graben	Proposed	Taffs Well spring flows at 5 l/s at 21°C. Planning is accepted for development of an open loop scheme which discharges into the river to heat a local primary school. BGS Wales raised awareness, with plans being taken forward by NewVision Energy Wales and RCT Council.
North of Scotland Malting Plant	Speyside	Orcadian Basin	Proposed	Assessment of geothermal energy potential of the Devonian sandstones extending ~3 km below a whisky distiller's malting facility in the north of Scotland.
Outskirts of Edinburgh	Edinburgh	Midlothian Basin	Proposed	A major development plan includes new commercial and residential properties on the western periphery of Edinburgh with renewed minewater heating and ongoing potential and the hot sedimentary aquifer heating potential beneath the existing and proposed development area.
Heriot-Watt University Campus	Heriot-Watt University	Midlothian Basin	Proposed	The study was carried out within the context of the university's low-carbon heat strategy. This study looked at the benefits of installing a geothermal heat system utilising a hot sedimentary aquifer. Target of up to 300 m thickness located approximately 1500 m–2000 m below the site.
University of York DeepGeothermal Project	University of York	Basin	Pre-drill	Phase 1 of 3 years with heat produced for campus buildings. It is envisaged that the project will be located on freehold land on York's Campus East, placing this project of UK significance on a university campus. It will be a catalyst for potential future research projects by creating a "living lab" on campus.

Table 3.4: Summary of sedimentary aquifer geothermal projects and prospects in the United Kingdom. Source: Compiled from multiple program reports and websites; Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *Evidence report supporting the deep geothermal energy white paper*: The case for deep geothermal energy–Unlocking investment at scale in the UK. British Geological Survey; personal communications with Helen Doran, Mark Ireland, Jon Glyes, and Gioia Falcone.

Subsurface Development Challenges and Data Needs Across Deep Sedimentary Basins

While the UK's sedimentary basins present significant geothermal potential, their development faces a common set of geological, technical, and operational challenges that must be addressed to unlock scalable deployment.

Subsurface Characterisation

1. Deep borehole data remain limited in most basins, particularly below between 2 kilometres and 3 kilometres. Only around 150 boreholes extend deeper than 2,000 metres true vertical depth, and just 13 are deeper than 3,000 metres.[38] Modern exploration drilling is needed to constrain reservoir properties such as porosity, permeability, and temperature at depth.

2. Seismic data are often poor-quality, legacy 2D data and in need of reprocessing prior to reinterpretation. Geophysical well data are often poor-quality scanned paper copies and require digitisation and re-interpretation to construct consistent and up-to-date 2D and 3D geological models for identifying lateral reservoir continuity, fault compartmentalisation, and optimal drilling locations. There are few deep boreholes onshore with drill cores from target horizons, and appraisal of potential targets should consider the collection of new seismic and borehole geophysical data and of drill cores to determine rock physical properties.

Reservoir Testing and Flow Performance

1. Most basins lack deep flow testing and long-term production trials, which are critical to validating sustainable flow rates, transmissivity, and thermal drawdown behaviour. In particular, the potential for deep reservoir targets to sustain flow along fractures is a key uncertainty.

2. Site-specific doublet testing and pilot systems are required to de-risk larger developments and inform well spacing, pumping design, and reinjection strategies.

Hydrochemistry and Scaling

1. There are legacy measurements for deep-water chemistry from the *Geothermal Catalogue*, as well as some limited data in research publications and individual well reports. There are approximately 500 measurements for water chemistry from deep intervals. While early projects (such as Southampton) highlight development risks from iron, sulphate, chloride, and salinity—which may lead to scaling, corrosion, or reinjection incompatibility—these are considered mostly manageable with adequate characterisation.

2. Comprehensive geochemical profiling should be undertaken during exploration and appraisal activities to ensure treatment planning.

Infrastructure and Integration

1. While many target basins lie near urban heat demand (for example, Crewe, Lincoln, Belfast), deployment requires district heat planning, anchor loads, and infrastructure coordination with local authorities and energy providers.

2. Integration with hybrid systems (such as seasonal storage including underground thermal energy storage, heat pumps) will enhance efficiency and resilience, especially for low- to mid-temperature resources.

Technical and Economic Constraints

1. Capital investment remains a barrier, particularly for deep wells and pilot projects in underexplored basins.

2. Standardised techno-economic models, resource classification, and heat network incentives are needed to stimulate private–public sector collaboration.

3. Drilling through basalt (for instance, in Northern Ireland) increases cost and complexity but offers insulation advantages.

Subsurface Actions Required

1. Establish a portfolio of high-potential opportunities that are based on an agreed-upon UK-wide geothermal resource classification.

2. Coordinate data acquisition and drilling across the United Kingdom such that work programmes can leverage cost benefits from cost-sharing models while still providing required data to individual projects.

3. Identify the optimum locations for first-of-a-kind (FOAK) projects in high-potential basins such as Crewe, Southampton, Lincoln, Lisburn, and Larne to build operational evidence and public confidence.

4. Promote policy tools that support heat zoning, de-risking capital investment, and long-term offtake contracts to enable project bankability.

The UK's deep sedimentary basins offer a strategic geothermal opportunity to decarbonise heat at scale, exploiting reservoir systems, especially within the Sherwood Sandstone Group. Coordinated exploration, FOAK projects, and infrastructure alignment are now required to transition these basins from theoretical resources to operational reality.

HEAT MAPPING OF THE TRIASSIC SANDSTONE RESERVOIR ACROSS THE UK

Volumetric Heat-in-Place Model Methodology

To assess the geothermal resource potential of the UK's Triassic Sherwood Sandstone Group, we applied a volumetric heat-in-place (HiP; heat-initially-in-place [HIiP] is used in some maps in this chapter) model based on a detailed, high-resolution lithospheric thermal framework. The model integrates structural, thermal, and petrophysical data to estimate the distribution of subsurface heat available for a range of geothermal applications, from domestic and industrial heating to ATES. The model combines multiple data sets—including basin-specific depth maps, porosity and compaction trends, measured borehole temperatures, and geophysical inputs such as sediment and crustal thickness—to create the UK Lithosphere Thermal Model.[39] By linking temperature-depth relationships with variations in rock properties, the model refines resource estimates across the Sherwood reservoir system. **Appendix A** provides a detailed description of the methodology, data sets, and assumptions.

> ***An analysis of Triassic reservoirs beneath NHS facilities reveals substantial potential for subsurface heat to support low-carbon heating, cooling, and storage. Across the NHS estate, the total estimated heat-in-place in Triassic reservoirs is substantial.***

Volumetric Heat-in-Place Model Results

An analysis of Triassic reservoirs beneath NHS facilities reveals substantial potential for subsurface heat to support low-carbon heating, cooling, and storage. Across the NHS estate, the total estimated HiP in Triassic reservoirs is substantial. Summing the mean values for all sites shows approximately 8,600 petajoules of recoverable heat at 20°C or higher; 3,250 petajoules at 40°C or higher; 1,167 petajoules at 60°C or higher; and around 20 petajoules at 90°C and higher. These totals are based on mean HiP per facility and align with the distribution of sites: roughly 300 facilities above a 20°C reservoir, 130 above 40°C, 60 above 60°C, and 20 above 90°C.

When expressed as average continuous thermal output over a 30-year project life, these resources equate to approximately 2.45 gigawatts thermal (≥20°C), 0.93 gigawatts thermal (≥40°C), 0.33 gigawatts thermal (≥60 °C), and 0.0057 gigawatts thermal or ≈ 5.7 megawatts thermal (≥90°C). These conversions assume a 50% recovery factor, 0.9 capacity factor, 60% delivery efficiency, and 30-year plant lifetime, providing a realistic indication of the scale of continuous heat that could be supplied for direct-use applications across the NHS estate. While the NHS properties are used here as a case study, the findings are equally applicable to industrial facilities, district heating networks (at 60°C or above), data centre cooling, and other large energy users with consistent heating or cooling demand.

A key insight from this analysis is the critical role of robust subsurface data. To highlight this point, we applied a ±20% variation in the underlying thermal model to explore the impact of temperature uncertainty on estimated resource availability, generating maximum, average, and minimum scenarios (**Appendix A**). This approach highlights how differences in reservoir temperature can substantially influence calculated HiP values and, therefore, resource availability and project feasibility. This is also true for reservoir thickness and porosity, although these scenarios were not run in this calculation but will be part of a future effort.

At a 20°C cut-off (**Figure 3.4**), suitable geothermal resources in the Triassic are widespread, covering much of England and parts of Northern Ireland. Many NHS facilities—and, by extension, other large energy consumers—sit above reservoirs where heat could be exploited directly or through heat-pump-integrated heating and or cooling systems.

Raising the threshold to 40°C (**Figure 3.5**) focuses geothermal potential into a smaller number of high-value hotspots, suitable for direct-use heating and hybrid heat-power systems.

GEOTHERMAL RESOURCE POTENTIAL BENEATH NHS FACILITIES, ≥20°C

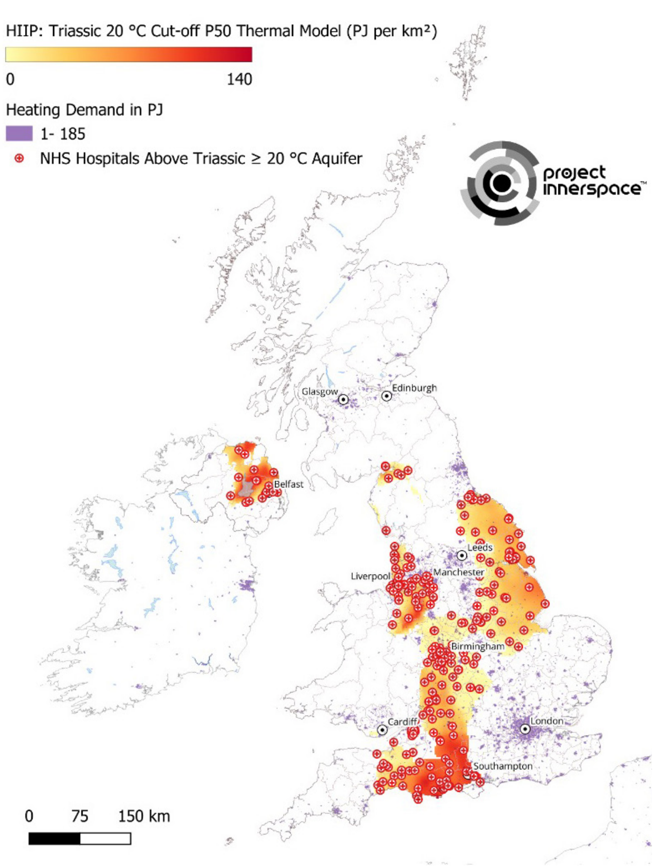


Figure 3.4: Geothermal resource potential in Triassic reservoirs beneath National Health Service (NHS) facilities ≥20°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). *Documentation on excess heat potentials of industrial sites including open data file with selected potentials* (Version 2). Zenodo. Created for Project InnerSpace.

GEOTHERMAL RESOURCE POTENTIAL BENEATH NHS FACILITIES, ≥40°C

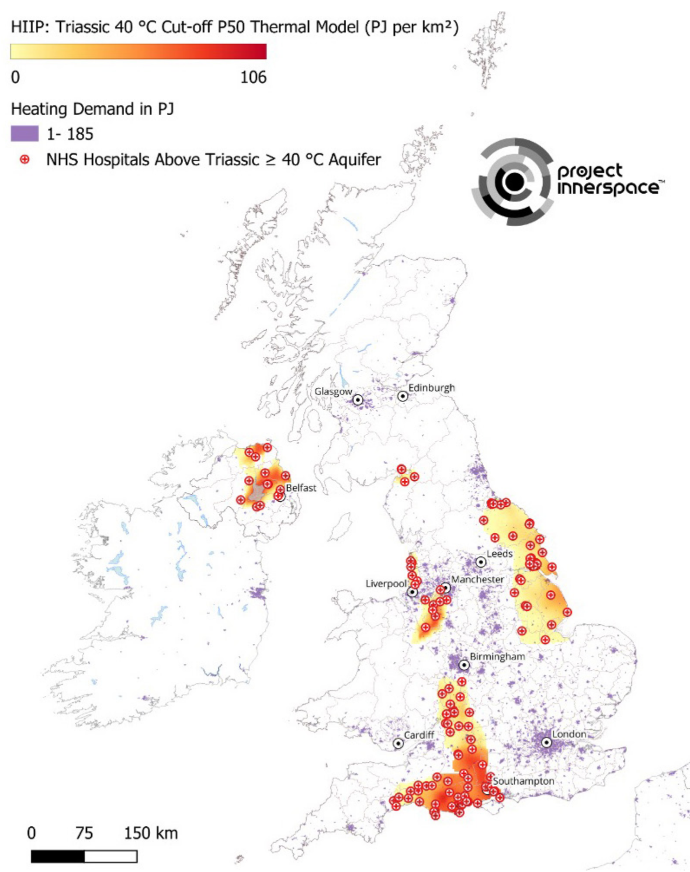


Figure 3.5: Geothermal resource potential in Triassic reservoirs beneath National Health Service (NHS) facilities ≥40°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). *Documentation on excess heat potentials of industrial sites including open data file with selected potentials* (Version 2). Zenodo. Created for Project InnerSpace.

Key regions include the following:

- **Southern England (Wessex Basin):** This region retains the highest HiP values and emerges as the primary deployment target.
- **Northwest England (Cheshire Basin):** This region offers significant but more localised potential.
- **East Yorkshire–Lincolnshire:** Moderate opportunities exist but often require ATES and heat pumps.
- **Northern Ireland (Larne and Lough Neagh basins):** This region offers targeted high-potential zones for pilot projects.

At a 60°C threshold (**Figure 3.6**), viable geothermal resources become scarce and highly localised, limited to a handful of strategic regions:

- **Southern England (Wessex Basin):** This region remains the standout target with the highest HiP values, suitable for direct-use heating and potential low-enthalpy power generation.
- **Northwest England (Cheshire Basin):** This region retains smaller but relevant hot spots.
- **Northern Ireland (Larne and Lough Neagh basins):** This region offers limited but distinct opportunities for demonstration projects.
- **East Yorkshire–Lincolnshire:** Resources above 60°C are minimal in this region, favouring ATES and heat-pump solutions instead.

At this elevated threshold, the ±20% variation in thermal modelling has the strongest impact, reducing or expanding viable zones substantially (**Appendix A**). Without robust, high-resolution temperature data, projects targeting high-temperature geothermal systems carry significant geological and financial risks.

Figure 3.7 maps the estimated HiP at a 90°C cut-off (P50 model) across the United Kingdom. The results highlight distinct high-potential zones in southern England (Wessex Basin) and parts of Northern Ireland (north-east of Lough Neagh in Antrim). The overlay of NHS hospital sites above these ≥90°C aquifers illustrates the most promising opportunity for integrating deep geothermal energy into public-sector decarbonisation strategies.

Uncertainty in subsurface temperature, reservoir properties, and aquifer characteristics has a major impact on estimated geothermal resource availability and project feasibility. Developing a comprehensive, high-quality subsurface data set—integrating data from existing wells, borehole logs, and geophysical surveys—and collecting new data are essential for improving resource estimates, reducing investment risk, and enabling efficient targeting of opportunities.

While the NHS is used here as a case study, the findings are broadly applicable to industrial clusters, district heating schemes, and data centres. Unlocking this potential will require investment in robust subsurface data; tiered deployment of geothermal technologies; and alignment of policy, funding, and infrastructure planning.

Modelling Future Production Scenarios for the Wessex Basin

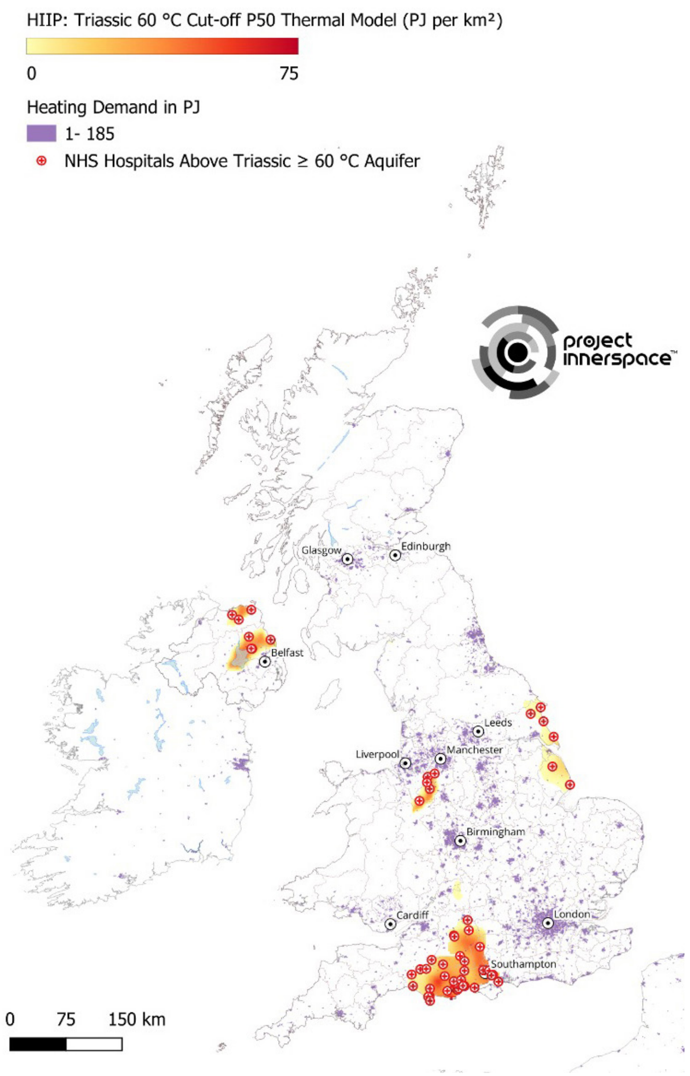
Methodology

To further assess the future potential for geothermal energy production in the Wessex Basin, we modelled the potential production across a number of locations (**Figure 3.8**). We used the Wessex Basin as a case study due to the relative abundance of existing subsurface data that constrains the geological model, the presence of previous geothermal exploration and development, and the extensive clusters or urban areas with high heat demand. We used a geothermal doublet modelling framework (a producer–injector pair) based on the methodology described by TNO,[40] which was further refined by Ireland et al.[41] The model provides indicative geothermal capacity and production estimates based on a basic geological depth prognosis for deep geothermal reservoirs and a producer–injector pair (often referred to as a doublet system).

To identify possible development locations on which to base our models, we started by assuming that developments for direct-use heat would require co-location with heating demand, based on the map of

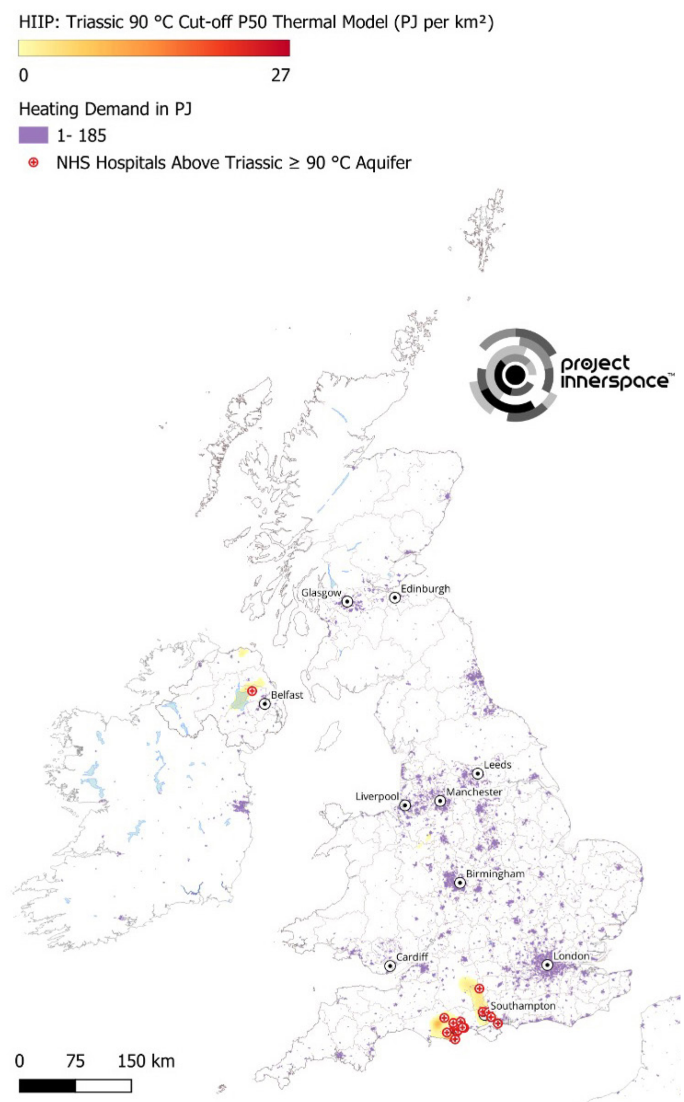
GEOTHERMAL RESOURCE POTENTIAL BENEATH NHS FACILITIES, ≥60°C

Figure 3.6: Geothermal resource potential in Triassic reservoirs beneath National Health Service (NHS) facilities ≥60°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). *Documentation on excess heat potentials of industrial sites including open data file with selected potentials* (Version 2). Zenodo. Created for Project InnerSpace.



GEOTHERMAL RESOURCE POTENTIAL BENEATH NHS FACILITIES, ≥90°C

Figure 3.7: Geothermal resource potential in Triassic reservoirs beneath National Health Service (NHS) facilities ≥90°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). *Documentation on excess heat potentials of industrial sites including open data file with selected potentials* (Version 2). Zenodo. Created for Project InnerSpace.



built-up urban areas provided by the Office for National Statistics.[42] We then used the centroid of each built-up area within the Wessex Basin and extracted the key geological properties from the geological model used for the HiP in the previous section and **Appendix A**. We considered only locations where the anticipated reservoir temperature is above 40°C. In doing so, we identified 111 built-up urban areas within the Wessex Basin (see the list of assumptions in **Appendix A**, in the section "Modelling Future Production Scenarios for the Wessex Basin"). Each location was subsequently used as the basis for a semi-analytical model of the potential geothermal energy production.

Across 111 different development locations, we estimated that the cumulative energy production could be greater than 1,000 gigawatt hours per year (assuming 60% full load hours).

The models assumed a single development of a producer-injector pair for the doublet system and did not examine the consequences of multiple developments. In each of the models, we also assumed a single producing reservoir interval. We do not examine the impact of operational strategies on short- or long-term production scenarios. As the model is probabilistic, each development concept we model consists of 1,000 different scenarios iterating the parameter distributions described in the model. Because the probabilistic approach simulates potential scenarios, we describe the results in terms of their percentile (P), where, for example, P90 is the probability that 90% of the modelled scenarios exceed a particular value. As a final consideration, we use a 60% full load hours (5,076 hours) across a calendar year to estimate the annual geothermal energy that could be produced at each locality. (Engineering assumptions and full details of the model parameterisation can be found in **Appendix A**, in the section "Modelling Future Production Scenarios for the Wessex Basin.")

GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS, ≥20°C

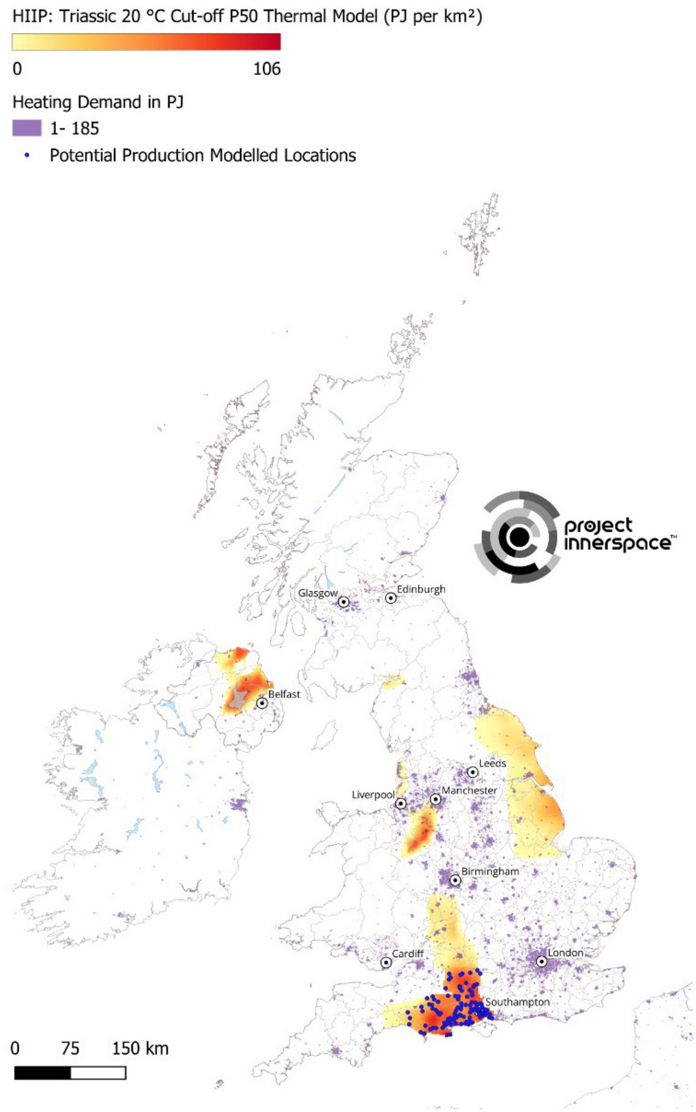


Figure 3.8: Geothermal resource potential in Triassic reservoirs ≥20°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & Rutten, C. (2020). Documentation on excess heat potentials of industrial sites including open data file with selected potentials (Version 2). Zenodo. Created for Project InnerSpace.

Results

Across 111 different development locations, we estimated that the cumulative energy production could be greater than 1,000 gigawatt hours per year (assuming 60% full load hours). The cumulative P50 geothermal capacity across all 111 modelled development locations ranged from 197 gigawatts (P90) to 253 gigawatts (P50) to 324 gigawatts (P10). To compare the results of the modelling to a known system, the modelled production

PROBABILITY DISTRIBUTION OF GEOTHERMAL CAPACITY OF CONCEPTUAL DEVELOPMENT WITHIN THE BOURNEMOUTH BUILT-UP AREA

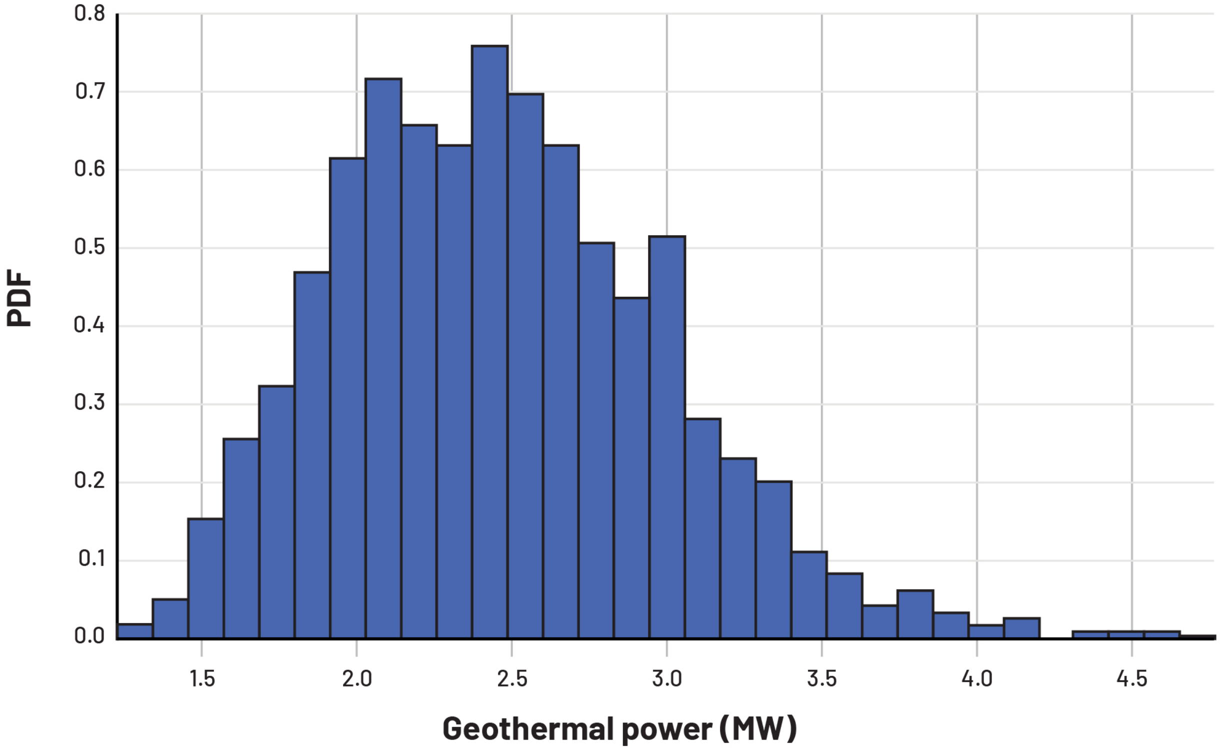


Figure 3.9: Probability distribution of geothermal capacity of conceptual development within the Bournemouth built-up area. Source: Ireland, M., Doran, H. & Falcone, G. (2025). *Geothermal energy potential of the Triassic Sandstone reservoirs in the Wessex Basin*. Project InnerSpace.

for a location in the city of Southampton 1.5 kilometres away from the previous deep geothermal development in the city predicts a capacity of 1.5 megawatts, which is comparable to the reported production (see the Southampton case study in Chapter 4 for more details).[43] Bournemouth is an example of the scale of resources that could be accessible. As of April 2025, Bournemouth has four locations listed within the Department for Energy Security and Net Zero Heat Networks Planning Database.[44] In the built-up area of Bournemouth, the Triassic Sherwood Sandstone is predicted to be at 1,681 metres depth with a reservoir temperature of 73°C. The model indicates a P50 geothermal capacity of 2.27 megawatts thermal and a potential energy production of 11.93 gigawatt hours per annum. This is broadly equivalent to meeting the annual space and water heating demand of around 1,000 typical UK homes, based on average gas consumption of 11,500 kilowatt hours per household per year.[45] The system would avoid approximately 2.4 kilotonnes of carbon dioxide equivalent (ktCO_2e) per year (range: 2.37–2.73 ktCO_2e depending on boiler efficiency), relative to gas heating using the 2025 UK government greenhouse gas conversion factors for natural gas at 0.18307 kgCO_2e per kilowatt hour.[46]

Across the 111 sites, the modelled results for P50 power capacity range from 0.09 megawatts (Langton Matravers) to 12.0 megawatts (Kintbury). At Langton Matravers, despite the reservoir temperature predicted to be greater than 80°C, the permeability is predicted to be less than 10 millidarcy, hence limiting the flow potential. At Kintbury, despite the modest depth (1,064 metres) and temperature (46°C), the predicted permeabilities of 600 millidarcy lead to higher flow rates. This emphasises the need for dedicated exploration drilling to further characterise the opportunities. The P10 scenarios indicate that the potential upside resource across the Wessex Basin is significant. Individual modelled locations may have geothermal capacities of up to 21 megawatts in these cases.

Project-Specific Potential

The Wessex Basin modelling results provide indicative estimates of potential geothermal capacities and highlight the variability between locations, driven by local differences in depth, temperature, and permeability. However, these results should not be viewed as development-ready resource assessments. They represent conceptual opportunities rather than bankable projects, and significant uncertainties remain around subsurface properties, regulatory constraints, and commercial viability. This further indicates the need for targeted exploration and appraisal to move from basin-wide modelling estimates to project-specific evaluations. Using examples such as Bournemouth and Southampton, we explore how more detailed subsurface data, updated geological models, and site-specific assessments are required to bridge the gap between theoretical geothermal potential and deployable heat projects.

As outlined by Conti and Falcone,[47] early basin, regional, and country-wide assessments tend to start as a high-level, top-down approach, with averaging of key parameters across considerably vast geographical areas and taking a coarse resolution approach (for example, before considerations of ignoring land accessibility, socio-economic and environmental aspects, and end-users' demand). There are global examples,[48] as well as country-specific examples, such as the Netherlands (ThermoGIS). In general, with increased geographic focus, more rigorous approaches to assessing potential can be applied, subject to suitable data. The HiP assessment summarised in an earlier section provides aggregated HiP quantities estimated for the Wessex Basin that can be considered indicative of the broad potential, with it being too early to determine the environmental-socio-economic viability (categorised as E3.3 under the United Nations Framework Classification). Where these HiP data are linked to specific locations, they can be used as indicative of a potentially prospective project; however, the use of location-specific modelling of a potential doublet system within built-up urban areas provides a valuable additional step, enabling the potential to be considered (such as in relation to specific heat network location). The modelled results include an estimation of uncertainty and a range of outcomes, with the cumulative P50 geothermal energy across 111 locations being 2,374 gigawatt hours. These prospective project locations are still limited by not using all available subsurface data. There is a lack of consolidated and accessible subsurface interpretations based on legacy on which to build new predictions of reservoir and production performance. Many potential deep geothermal reservoirs have a wide range of matrix permeabilities. To date, there has been limited work to assess the potential deliverability of the reservoirs and the associated production risks, such as early cold-water breakthrough during reinjection. Exploration and appraisal activities should prioritise understanding permeability at multiple scales. Despite this uncertainty, the previous development at Southampton and the existence of direct evidence of reservoir quality and temperatures across the basin provide confirmation of key properties but would require further data acquisition to refine estimates. See **Appendix B** for details on classification.

The following actions would need to be carried out to progress towards a systematic assessment of the geothermal opportunities within the basin:

- Interpret available subsurface data from the bottom up to create a current and consistent geological model, including a comprehensive assessment of geological risks and uncertainties.
- Overlay land accessibility constraints, including regulatory and environmental limitations.
- Define notional projects (such as doublets or triplets) and estimate corresponding heat recovery.
- Apply realistic project boundaries to avoid double-booking of the same subsurface area.
- Integrate heat demand data (for instance, similar to the Scottish government's approach[49]) to assess heat supply opportunities compared with demand.
- Incorporate broader environmental and engagement aspects, including preliminary consultation with local authorities and communities.

This modelling exercise in the Wessex Basin demonstrates that geothermal energy could deliver more than 1,000 gigawatt hours of low-carbon heat annually across 111 urban areas, with site-specific opportunities ranging from modest community-scale schemes to larger projects capable of meeting thousands of homes' heating demand. The results confirm that the United Kingdom's subsurface can provide reliable, decarbonised heat where demand is concentrated, and they also highlight variability in reservoir properties that will require targeted exploration to unlock. The next steps are clear: Move beyond desk-based modelling into exploration drilling and test wells to validate the most promising sites; integrate geothermal into heat network planning in places such as Bournemouth and Southampton where demand and geology align; and establish a framework to prioritise urban clusters with the strongest resource-demand match. With these actions, the Wessex Basin can become a proving ground for scaling geothermal heat nationally, cutting emissions, and reducing reliance on gas.

FUTURE DATA REQUIREMENTS FOR DEEP SEDIMENTARY BASINS

While recent years have seen increased momentum in UK geothermal development, realising the full potential of geothermal heat and power will require addressing critical subsurface data gaps and overcoming non-technical limitations such as regulations and licensing. This section outlines the future directions for geothermal energy development in the United Kingdom, with a particular focus on the data and knowledge required to de-risk geothermal resources. Despite progress, the United Kingdom's geothermal potential remains constrained by limited subsurface data quality and quantity. Several critical limitations are widely recognised:

- **Sparse deep temperature and reservoir data in onshore sedimentary basins:** While shallow data (less than 2 kilometres) are relatively abundant, few deep wells penetrate to depths sufficient for assessing geothermal potential (more than 2–3 kilometres), which limits the ability to define reservoir conditions in key basins such as Cheshire, Wessex, Lough Neagh, and East Yorkshire–Lincolnshire.[50,51,52]

- **Inconsistent and incomplete data reporting:** Historical well logs including reservoir and temperature data vary widely in quality. Many are scanned paper copies and not truly digital, with inconsistent metadata, missing temperature corrections, and limited standardisation across reporting formats.[53]

- **Limited data for several areas:** Limited data on thermal conductivity, volumetric heat capacity, and radiogenic heat production are available.

- **Limited reservoir-scale permeability data:** Few permeability measurements are available from target geothermal formations, particularly in low-permeability units such as the Carboniferous limestones. Where data exist, they are often derived from oil and gas drilling reports rather than purpose-driven geothermal testing.

- **Limited flow test data:** Field-scale pump and injection tests are rare, and production data from deep geothermal wells are extremely limited. Without these tests, realistic assessments of sustainable flow rates and reservoir performance remain speculative, further discouraging investment.

- **Geophysical data:** While there are existing 2D and 3D seismic reflection data across onshore areas, these frequently are not located in areas of heat demand.[54] Across numerous areas of continental Europe, seismic data acquisition is used to define the subsurface structure and reservoir architecture ahead of drilling and development.

A critical opportunity for reducing uncertainty and targeting productive geothermal reservoirs can be found in integrated exploration data acquisition plans. In several UK sedimentary basins—notably the Cheshire, East Midlands, and Wessex basins—academic researchers and private sector collaborators have used existing 2D and 3D seismic data sets tied to legacy hydrocarbon and research wells to create geological models for key reservoir targets such as the Sherwood Sandstone Group, the Carboniferous limestones, and Permian sandstones.[55] These models provide an essential framework for understanding the geometry, thickness, and structural controls of potential geothermal reservoirs. While the BGS has historically produced regional geological models[56]

and aquifer depth models,[57] these were not developed with the aim of geothermal exploration. The application of established geothermal exploration workflows (for example, dedicated seismic acquisition and interpretation) for geothermal assessment remains limited in the United Kingdom. Most seismic-derived models to date have been developed for petroleum exploration and are only partially integrated into geothermal workflows. Improved integration of seismic data and borehole information for geothermal purposes—particularly through reprocessed legacy seismic lines and targeted new surveys—could enhance confidence in resource estimates and better inform well targeting. Generating higher-resolution models of reservoir units will be essential for evaluating reservoir performance. To move from conceptual estimates to bankable projects, we recommend the following near-term actions to close critical data gaps, standardise reporting, and coordinate exploration (with policy detailed in Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential"):

- **Expand deep exploration drilling:** Pilot wells in strategic sedimentary basins with integrated geophysical, temperature, rock and core sampling, and hydraulic testing should be prioritised to improve confidence in reservoir conditions.
- **Reconcile data collection and reporting:** National guidance should be issued to ensure that temperature, permeability, and flow measurements collected in future projects are consistent and accessible and that those from past projects are collated into a modern format that maximises their use.
- **Coordinate a national data acquisition programme to incentivise commercial developers:** A government-supported programme could provide a scalable and cost-effective mechanism for seismic data acquisition across multiple areas of the UK and the integration of legacy seismic data.[58] An alternative to central government support could be for multiple regional and local government agencies to collaborate. This approach could adopt the oil and gas sector's multi-client acquisition model, in which seismic surveys covering multiple areas of interest are acquired by a seismic acquisition company.[59]

By taking these steps, the United Kingdom can create a subsurface knowledge base comparable to leading countries and position geothermal as a credible component of its heat transition. Closing the data gap is foundational to this vision.

GRANITE-HOSTED GEOTHERMAL ENERGY IN THE UNITED KINGDOM

Jon Gluyas, Peter Ledingham, and Gioia Falcone

Harnessing the heat from granitic systems has been a long-term goal of the industry in the United Kingdom because of the potential for power generation, particularly in the Cornish Granites. However, in addition to providing a significant opportunity, harnessing the heat from these systems also presents technical challenges

Geological Context and Target Areas

Granite-hosted geothermal systems harness the high natural heat production found in radiogenic granitic rocks, particularly where natural, deep fracture systems provide pathways for fluid circulation. These systems are suitable for both deep-heat-only applications and systems aimed at electricity generation. In the UK, key target areas include the Cornubian Batholith in south-west England (covering parts of Cornwall and Devon), the Weardale Granite in County Durham, buried granites of Eastern England, the Mourne Granites in Northern Ireland, and various Caledonian granites in Scotland, such as those found near Aberdeen and in the Cairngorms (**Figure 3.10**).

These granites are enriched with heat-producing radiogenic elements such as uranium, thorium, and potassium, and they can generate heat at rates higher than the national average, particularly in the Cornwall granites. Predicted temperatures at a depth of 5 kilometres[60] largely exceed 200°C (Bodmin and Carnmenellis), 185°C (Dartmoor), 206°C (Land's End), and 221°C (St. Austell).

Of these, the most studied area is the Cornubian Batholith, a vast granitic intrusion in south-west England and extending offshore into the western approaches. Turan et al.[61] report that the batholith has significant heat stored of 8,988 exajoules (P50) (exajoule = 10^{18} joules), corresponding to 366 exajoules recoverable and a technical potential of 556 gigawatts thermal and 31 gigawatts electrical—equivalent to between about 65% and 70% of the UK's peak winter electricity demand.[62]

MAJOR GRANITE BODIES ACROSS THE UK

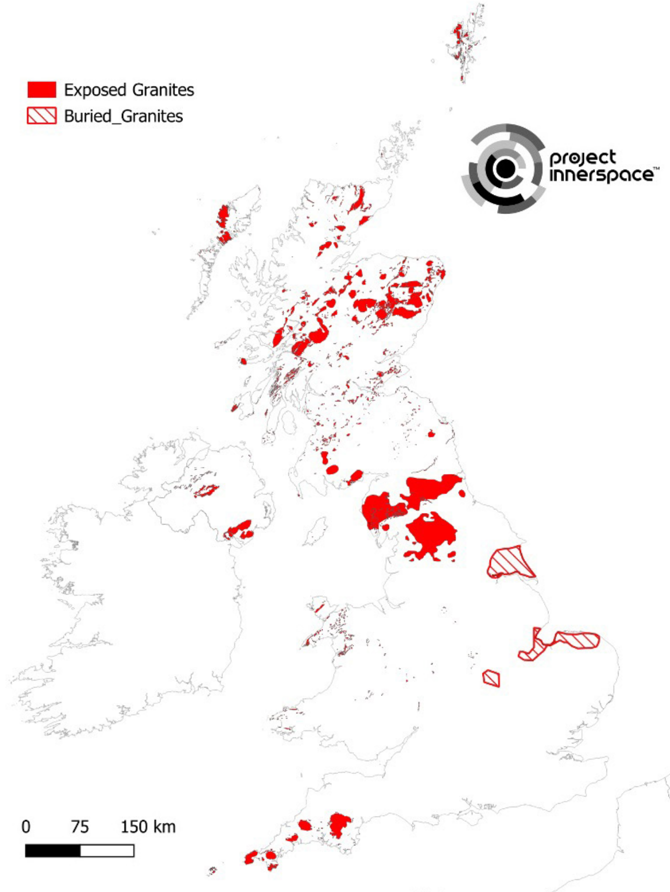


Figure 3.10: Distribution of granitic intrusions across the UK. Granites shown include key geothermal targets such as the Cornubian Batholith, Weardale Granite, Mourne Mountains, and Caledonian granites of Scotland. Source: Map produced by Project InnerSpace. Exposed and Buried Granites from BGS (625k_V5_Geology_UK_EPSG27700); Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *Evidence report supporting the deep geothermal energy white paper:* The Case for Deep Geothermal Energy-Unlocking investment at scale in the UK. British Geological Survey.

Turan et al. report that the batholith has significant heat stored of 8,988 exajoules (P50) (exajoule = 10^{18} joules), corresponding to 366 exajoules recoverable and a technical potential of 556 gigawatts thermal and 31 gigawatts electrical—equivalent to between about 65% and 70% of the UK's peak winter electricity demand.

In the north-east of England, the Weardale Granite in County Durham was the first geothermal granite target in the United Kingdom. It was first explored through the Rookhope well in 1961 (**Figure 3.11**) and later appraised by the Eastgate and Eastgate 2 geothermal boreholes in 2004, which recorded a temperature of 46°C at a depth of only 995 metres.[63,64] This indicates a notably high geothermal gradient by UK standards. With further drilling to depths of around 1.5 kilometres to 2.5 kilometres, the resource could supply district heating to local towns.

In Northern Ireland, the Mourne Mountains are underlain by a granite batholith with confirmed radiothermal properties.[65] The resource remains unproven, and further exploratory work is needed to assess feasibility and commercial viability.

Scotland's granite-hosted geothermal prospects are focused on three areas: the Cairngorm Mountains, underlain by the Cairngorm Granite; the new Aberdeen Exhibition and Conference Centre area near Aberdeen Airport, underlain by the Aberdeen Granite; and Hill of Banchory, associated with the Hill of Fare pluton. These locations highlight Scotland's major granite bodies with potential for deep heat extraction, with Banchory additionally benefiting from a nearby district heat network that could act as an immediate offtaker.

The Caledonian Granites in Scotland and Northern Ireland will be the focus of THERMOCAL (THERMOphysical properties of CALedonian rock materials to de-risk geothermal development). See **Table 3.5** for a list of geothermal activities in the UK granites.

UK'S FIRST GEOTHERMAL EXPLORATION WELL

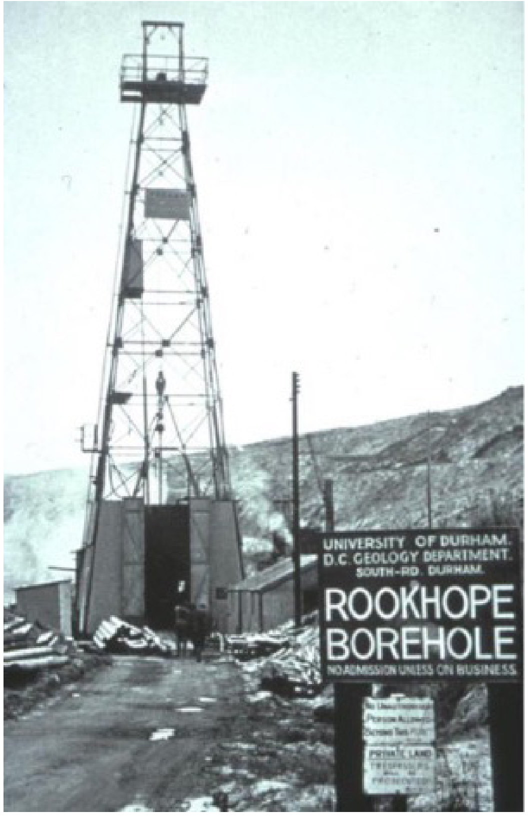


Figure 3.11: The UK's first geothermal exploration well. The well was drilled in 1961 in Rookhope in Weardale, County Durham. It proved the presence of hot granite, which until the well was drilled has been a speculative intrusion. Source: Photograph supplied by Durham University.

ACTIVITIES IN UK GRANITES

Location/Project	Status	Type of Geothermal System	Description
Eden Geothermal Energy Project	Operational	Engineered geothermal system	Operational since June 2023 to provide heat for the Eden Biomes and nursery facilities. In the second phase, a second well may be drilled, with a power plant constructed for combined heat and power to supply the biomes, greenhouses, and other associated facilities.
Langarth Garden Village near Truro in Cornwall	Stalled	District heating	The Department of Energy Security and Net Zero awarded £22 million in funding to the planned geothermal heating project at Langarth Garden Village near Truro in Cornwall. After a Treveth-led feasibility study, it was deemed uneconomical and unfeasible to transport heat to the development.
Jubilee Pool, Penzance Cornwall	Operational	Open-loop GSHP	The pool consists of a partitioned sub-section of a seawater pool that is heated with an open-loop GSHP supplied from a 400 m deep borehole at an inlet temperature of 25°C. The original idea was to keep the geothermal pool at 35°C and therefore extend the opening hours through the winter; however, sustaining that heat in the winter months has been reported to be a challenge (personal communication with Jubilee Pool).
United Downs Deep Geothermal Power Project, Redruth, Cornwall	In development	Engineered geothermal system	This 3 MWe gross capacity Organic Rankine Cycle power plant currently commissioning (August 2025), demonstration-scale geothermal lithium extraction plant is in development.
Penhallow Deep Geothermal Power Project, Cornwall	Planned	Engineered geothermal system (granite)	Permission granted in 2022. Similar in construction to United Downs (4,500 m depth abstraction and 3,000 m depth reinjection).
Manhay Deep Geothermal Power Project, Helston, Cornwall	Planned	Engineered geothermal system (granite)	Permission granted in 2023. Similar in construction to United Downs (4,500 m depth abstraction and 3,000 m depth reinjection).
Rosemanowes Quarry RH11, RH12, RH15, Penryn, Cornwall	Exploratory boreholes	Granite	Avalon Borehole Test Facility. UK Hot Dry Rock Geothermal Energy Research site. First deep geothermal project (1977–1997). Three boreholes to depths of 2566 m.
Silent Valley GT-02, Mourne Mountains, C.Down, NI	Exploratory borehole	Mourne Mountains Complex (granite)	Drilled in 2009 to 601 m depth. Part of GSNI geothermal project funded by Innovation Fund. Fully cored and logged.
Cairngorm Mts, Scotland	Proposed	Cairngorm Granite	Feasibility study to be completed in 2023
New Aberdeen Exhibition Conference Centre, Aberdeen, Scotland	Proposed	Aberdeen Granite	Feasibility study (2016) for a deep geothermal single well (DGSW) on the site of the new AECC near Aberdeen Airport. Scottish Government Geothermal Energy Challenge Fund.
Hill of Banchory, Scotland	Proposed	Hill of Fare Pluton (granite)	Potential for a deep geothermal heat project at Hill of Banchory, believed to have a good geothermal potential. The heat network, situated on the north side of town, offers a ready-made heat customer. Scottish Government Geothermal Energy Challenge Fund.
Eastgate No. 1 and No. 2, County Durham, Weardale Granite	Exploratory boreholes	Fractured Weardale Granite	Eastgate No. 1 (2004): bottom hole 46°C, main aquifer at 411 m (27°C). Eastgate No. 2: 420 m depth to evaluate fractures in granite.
Rookhope Borehole, County Durham, Weardale Granite	Exploratory boreholes	Fractured Weardale Granite	The Weardale Granite was discovered in 1961 during drilling at Rookhope, following the work of Bott and Masson-Smith. Their geophysical survey identified gravity and magnetic anomalies in the Northern Pennines, leading them to hypothesise the presence of an unexposed granite body. This hypothesis was confirmed when granite was encountered in the Rookhope borehole—later formally named the Weardale Granite. The top of the granite was found to be eroded, suggesting that the pluton had once been exposed at the Earth's surface.A temperature of 40°C was recorded at a depth of 808 m, which was significantly higher than anticipated, indicating elevated heat flow.
Woodland Borehole, County Durham, Weardale Granite	Exploratory boreholes	Fractured Weardale Granite	The Woodland Borehole, drilled in 1962 just south of the newly discovered granite body at Rockhope 1. The Woodland Borehole reached a depth of 499 m and recorded a temperature of 29.3°C, further confirming the anomalously high regional heat flow.
The Auckland Project, Bishop Aukland, County Durham, Weardale Granite	Proposed	Fractured Weardale Granite	The Auckland Project is progressing with fund raising to enable a deep, 5 km well to be drilled into the Weardale Granite for power and heat generation (Community Energy England, undated).
Durham Deep Geothermal, Durham & Gateshead	Proposed	Weardale Granite	Durham and Gateshead councils joint feasibility study

Table 3.5: Activities in the UK granites. Source: Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *Evidence report supporting the deep geothermal energy white paper:* The case for deep geothermal energy—unlocking investment at scale in the UK. British Geological Survey (Appendix 1 Table); personal communications with Thomas Olver from GEL Energy, Jon Gluyas, and Peter Ledingham.

CASE STUDY: UNITED DOWNS DEEP GEOTHERMAL POWER PROJECT, CORNWALL, UNITED KINGDOM

The United Downs Deep Geothermal Power (UDDGP) project represents a landmark attempt to harness deep, high-heat granitic resources for electricity and heat generation in the United Kingdom. As the country's first geothermal power project, it provides valuable insights into both the opportunities and challenges of exploiting thermally anomalous granites. While United Downs has demonstrated exceptional temperatures and significant lithium potential, its progress has been slower and more technically complex than anticipated, with uncertainties remaining around long-term productivity, cost-effectiveness, and scalability. This case study highlights key lessons from the project and considers their implications for the future development of granite-hosted geothermal resources in the UK.

UDDGP is located near Redruth, Cornwall, and operated by Geothermal Engineering Ltd (GEL), targeting the thermally anomalous Cornubian Batholith, a large radiogenic granite body (**Figure 3.12**). The site is close to the Porthtowan Fault Zone, a steeply dipping, NE-SW-oriented structure that enhances fracture permeability within the granite.[66] Predicted temperatures at a depth of 5 kilometres largely exceed 200°C.[67]

The project comprises two deviated wells drilled between 2018 and 2019:

- **Production well (UD-1):** This well reaches a measured depth (MD) of 5,275 metres, with a true vertical depth of approximately 5,057 metres. The well intersects the Porthtowan Fault Zone between 4.3 kilometres and 5.1 kilometres, where significant fractures were encountered.[68] Bottom-hole temperatures recorded in UD-1 exceeded 180°C, confirming modelled predictions.[69,70]

- **Injection well (UD-2):** This well was drilled to a depth of 2,393 metres MD. It is cased and designed for reinjection of cooled brine into lower-permeability zones of the granite.[71]

Testing began in late 2020 and continued through 2021, with a focus on injecting with the purpose of understanding the fractures. Initial results highlighted permeability within the natural, unstimulated fractures adjacent to the open-hole section of the production well and temperatures of 180°C at 5,275 metres MD, aligning with modelled estimations.[72] Microseismic monitoring confirmed effective stress transfer within the target fault zone while remaining within acceptable limits for induced seismicity (< local magnitude scale 2.0). Analysis of well pressure changes and migration of microseismic events suggest that the low-pressure stimulation successfully improved the hydraulic

SCHEMATIC DIAGRAM OF THE GEOTHERMAL DOUBLET DESIGN AT UNITED DOWNS

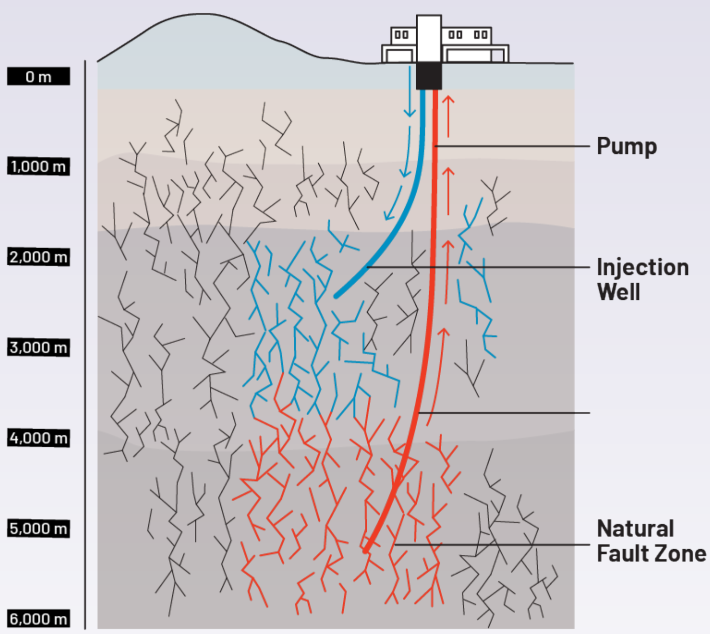


Figure 3.12: Schematic diagram of the geothermal doublet design at United Downs. The production well was drilled to a measured depth of 5,275 m and the injection to a measured depth of 2,393 m. Source: Olver, T., & Law, R. (2025). The United Downs Geothermal Power Plant, Cornwall, UK: Combining the generation of geothermal electricity and heat, with the extraction of critical raw materials. In *Proceedings of the 50th Workshop on Geothermal Reservoir Engineering (SGP-TR-229)*. Stanford, CA, United States.

conditions of the reservoir, with gradual expansion of fractures above and below the open hole, across an area greater than 50,900,000 cubic metres.[73] The planned energy conversion system is a multi-megawatt electrical Organic Rankine Cycle power plant. The plant will generate between 1 megawatt and 3 megawatts of electricity and 15 megawatts of heat.[74]

The Cornubian granites are prospective for not only heat but also critical raw materials, particularly lithium, which can occur in geothermal brines circulating through fractured zones. Recent work on fracture trends and structural controls in the batholith (at Cligga Head) highlights how geological features that enhance fluid circulation for geothermal heat production may also improve access to lithium-bearing zones.[75] This presents an important co-benefit: Geothermal projects in Cornwall have the potential to deliver both renewable heat and power and a secure domestic supply of lithium for battery technologies. Building on this opportunity, focused exploration and pilot extraction projects have been launched at United Downs.

Recent geochemical analysis has confirmed brine lithium concentrations of greater than 300 parts per million, among the highest reported in European geothermal fluids.[76] The lithium extraction project at United Downs is being developed alongside the geothermal power plant. Olver and Law describe three phases.[77] Phases 1 and 2 involved the following:

- A pilot study of ion exchange direct lithium extraction (DLE) using geothermal brine from initial testing of the production well.
- A technical and economic feasibility study for a demonstration-scale lithium plant, partly funded by the UK Department for Business and Trade's Automotive Transformation Fund (Feasibility Study Round 3).
- Testing of multiple DLE technologies to identify viable options.
- Engagement with a potential offtaker.

Phase 3, currently underway, involves the design and construction of a 100 tpa demonstration-scale DLE plant, also partly funded through the Automotive Transformation Fund under the Scale Up Readiness Validation (SuRV) scheme.

The long journey from initial concept in 2009 to power plant construction at United Downs (from 2021[78]) should also be highlighted, with first production yet to be achieved at the time this report was written. Unless project timelines are significantly reduced, this slow pace will act as an ongoing obstacle to further geothermal power deployment in the United Kingdom. Beyond United Downs, GEL has gained planning permission for two further sites in Cornwall—Manhay and Penhallow (**Table 3.5**)—which sit ready for drilling and development.

GEOLOGICAL AND EXPLORATION RISK

Research into hot dry rock (HDR) and enhanced geothermal systems (EGS) has aimed to create or improve permeability in otherwise impermeable rocks. At United Downs and Eden Geothermal in Cornwall, EGS concepts were tested using naturally fractured fault zones at around 5 kilometres depth. Success depends on accurately locating these permeable structures and achieving sufficient fluid flow; permeability remains a greater challenge than temperature. Both projects sought to show that NW–SE "cross-courses" could host commercial reservoirs but have not yet done so. Each used lower flow rates and lower-pressure "soft stimulation" to enhance permeability and implemented seismic hazard assessments, monitoring, and proactive public engagement. (See Chapter 7, "Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices," for more.)

Next-Generation Geothermal Technologies

Recent advances in drilling, well completion (processes ahead of flow testing), and reservoir stimulation technology to improve transmissivity in US geothermal projects have potentially significant implications for the future of geothermal in the United Kingdom.

Drilling deep wells into hard granite is capital-intensive, with well pairs typically costing between £9 million and £20 million. Fervo Energy, a leading EGS developer in the United States, has reported dramatic improvements[79] in drilling performance in hard crystalline rocks, including sustained rates of penetration averaging between 70 feet and 75 feet (21.34 metres and 22.86 metres) per hour in hard granite and the ability to reach vertical depths of more than 15,000 feet(approximately 4.6 kilometres) in as little as 16 to 21 days—a reduction of up to 79% compared with prior benchmarks.[80,81,82]

The potential for reduced drilling time and costs increases the depth limit of geothermal resources in the United Kingdom by making them more affordable, potentially bringing more areas of the country into the resource base.

Researchers at the U.S. Department of Energy's Frontier Observatory for Research in Geothermal Energy (FORGE) and Fervo have also applied completion and stimulation technologies developed for the oil and gas industry to the treatment of pairs of long-reach geothermal wells to develop commercial-scale heat exchange volumes, with reported power outputs of up to 10 megawatts per pair of wells. The successful application of such techniques could be a game-changer for power generation potential in the UK granites.

Granitic Geothermal Resource

As emphasised in earlier sections, the ability to reliably classify the geothermal energy that could be commercialised is important to investors, decision-makers, and stakeholders. Resource classification is a key element in the characterisation, assessment, and development of energy resources, including geothermal energy.[83] Stakeholders within government, industry, and the general public need consistent terminology when assessing geothermal resource quality, feasibility of development, and potential impacts. As an example, **Table 3.6** provides a best estimate of the resource classification for the United Downs project described in the earlier case study using the United Nations Framework Classification (UNFC).

Based on the current status of the project, it would fall under the E1.2 UNFC category. Capital funds have been committed and implementation of the development

UNITED DOWNS GEOTHERMAL PLANT DETAILS

Milestone	Years	Status
Exploration drilling	2018-2020	Completed
Flow testing	2020-2021	Completed
Power Purchase Agreement	2021 (10 years)	Yes
Contract for difference	2023 (15 years)	Yes (AR5)
Plant construction	2024-present	Ongoing
First production	2025 (anticipated)	Not achieved yet
Power production	n/a	2 Mwe (anticipated)*
Heat production	n/a	10 Mwth (anticipated)*
Funding	n/a	Yes (public and private)

Table 3.6: Key details of United Downs Deep Geothermal Power project. All information is assumed correct at the time of writing. * = Figures reported are operator best estimates. Source: Compiled by Gioia Falcone for this report.

is underway, which places the project under F1.2 (**Appendix B**). Hence, assuming a capacity factor of 90%, a project lifetime of 10 years (the shortest between the validity of the Power Purchase Agreement and the Contract for Difference), and that the reference point where quantities are estimated is the power plant, the G categorisation would be as follows:

***Electricity*: G1 + G2** (best estimate): 0.57 PJe (2 MWe x 7,884 hrs/year x 10 years)

***Heat*: G1 + G2** (best estimate): 2.84 PJth (10 MWth x 7,884 hrs/year x 10 years)

Note that for heat, it is assumed that there will be thermal energy demand for 12 months per year (for instance, beyond space heating in the winter months). Otherwise, the saleable or usable quantity would have to be reduced. Additionally, it is not currently known (based on information available in the public domain) if a heat purchase agreement is also already in place; it is therefore assumed that an agreement will likely be in place within a reasonable time frame (maximum of 5 years from the date of evaluation).

Although the project operator's long-term aim is to achieve commercial co-production of lithium at the site, a demonstration-scale lithium extraction plant is in development; once complete, it will be utilised for further testing before any potential future scale-up.[84] It is therefore assumed that the project is currently regarded as economically viable, even without the extra revenue stream from a sale of co-produced lithium.

CONCLUSION

This chapter provides a comprehensive assessment of the United Kingdom's subsurface geothermal resource potential to date, drawing on historic data, new modelling, and current demonstrator projects to establish an integrated framework for understanding opportunities and challenges across different geological settings. The UK's complex and diverse geology offers a broad portfolio of geothermal resources that, if harnessed effectively, could make a significant contribution to the decarbonisation of heat, cooling, and power.

The assessment highlights two key opportunity areas:

- **Deep sedimentary basins:** Provide some of the largest volumetric geothermal resources, particularly within the Triassic Sherwood Sandstone Group and Carboniferous limestones. Modelling of the Wessex Basin identified 111 urban centres suitable for conceptual doublet developments, with a cumulative P50 production potential of more than 2,000 gigawatt hours per year. However, significant uncertainties in reservoir properties and temperature distributions remain. High-potential areas include the southern and north-western parts of England, Wessex Basin, Cheshire Basin, East Yorkshire–Lincolnshire, Northern Ireland, Larne, and Lough Neagh basins.

- **High-heat granites:** Offers opportunities for high-temperature geothermal energy and critical mineral co-production. At the United Downs Deep Geothermal Power project, temperatures of higher than 180°C have been confirmed at 5 kilometres depth, alongside more than 300 parts per million lithium concentrations. Despite promising results, high capital costs (£20 million–£30 million per project) and slow development timelines remain challenges.

Across all geological settings, a common theme emerges: While the scale of the opportunity is significant, the United Kingdom lacks the data resolution, regulatory frameworks, and risk-sharing mechanisms required to move from conceptual resource estimates to bankable, project-ready developments. The new national-scale modelling presented in this chapter demonstrates that relatively small changes in assumed subsurface conditions—such as a ±20% variation in temperature estimates—can dramatically shift the distribution and viability of geothermal resources. This highlights the urgent need for the following:

- A dedicated national strategy supported by clear policy frameworks, public-private partnerships, and investment incentives

- Targeted exploration drilling in priority basins to obtain direct measurements of temperature, permeability, and flow rates

- Reprocessed and newly acquired seismic data optimised for geothermal reservoir characterisation

- Standardised reporting and data-sharing frameworks to enable integration of public, academic, and commercial data sets

- Scaling up of demonstration projects to de-risk investment and validate long-term performance

Northern Ireland is highlighted as a leading example of how proactive policy support and integration of geothermal into regional energy strategies can accelerate deployment. Lessons from Northern Ireland's approach—including early feasibility studies, demand-led planning, and policy alignment—offer a model for the rest of the United Kingdom.

In conclusion, the UK possesses the geological diversity and resource potential to make geothermal energy a strategic pillar of the net-zero transition. By combining improved subsurface data, targeted investment, and coordinated policy support, the UK can unlock a sustainable, secure, and low-carbon source of heat, cooling, and power while enabling co-benefits such as critical mineral recovery and thermal energy storage. This chapter provides the evidence base and roadmap for achieving that vision, positioning geothermal energy as a key enabler of a resilient, decarbonised energy system.

TABLE 3.3 SOURCES

Data compiled from Atkinson, T. C., & Smith, D. I. (1974). Rapid groundwater flow in fissures in the Chalk: An example from South Hampshire. *Quarterly Journal of Engineering Geology, 7*, 197–205; Price, M. (1987). Fluid flow in the Chalk of England. *Geological Society of London Special Publications, 34*(1),141–156; Bloomfield, J. P., Brewerton, L. J., & Allen, D. J. (1995). (1995). Regional trends in matrix porosity and dry density of the Chalk of England. *Quarterly Journal of Engineering Geology and Hydrogeology, 28*, S131–S142; Allen, D., Brewerton, L., Coleby, L., Gibbs, B., Lewis, M., MacDonald, A., Wagstaff, S., & Williams, A. (1997). *The physical properties of major aquifers in England and Wales*. British Geological Survey; Worthington, S. R. H. (1999). A comprehensive strategy for understanding flow in carbonate aquifers. *Karst Waters Institute Special Publication, 5*, 30–37; Law, R., Nicholson, D., & Mayo, K. (2007). Aquifer thermal energy storage in the fractured London Chalk: A thermal injection/withdrawal test and its interpretation. In *Proceedings of the 32nd Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States; Butler, A. P., Mathias, S. A., Gallagher, A. J., Peach, D. W., & Williams, A. T. (2009). Analysis of flow processes in fractured chalk under pumped and ambient conditions (UK). *Hydrogeology Journal, 17*(8),1849–1858; Busby, J. (2018). A modelling study of the variation of thermal conductivity of the English Chalk. *Quarterly Journal of Engineering Geology, 51*, 413–423; Boon, D., Farr, G., & Hough, E. (2021). Thermal properties of Triassic Sherwood (Bunter) Sandstone Group and Mercia Mudstone Group (Keuper Marl) lithologies. In *2nd Geoscience & Engineering in Energy Transition Conference, 2021* (pp. 1–5). European Association of Geoscientists & Engineers; Worthington, S. R. H., & Foley, A. E. (2021). Advances in conceptualizing transport in Chalk aquifers. *Geological Society of London Special Publication, 517*, 75–91; Department of Earth Science and Engineering. (n.d.). *Project: SMARTRES*. Imperial College London.

APPENDIX A: HEAT-IN-PLACE (HIP)

The heat-in-place (HiP) method utilises calculations from Pocasangre and Fujimitsu.[85] It breaks the total heat into two components: heat from the rock and heat from the fluid within the rock.

Input Data

Source Maps and References

The maps used to create a top Triassic depth map across Great Britain were based on the following information:

- Estimated temperature at mid-depth of the Sherwood Sandstone Group (East Yorkshire and Lincolnshire Basin)[86,87]
- Estimated temperature at base of Sherwood Sandstone Group (Wessex Basin)[88,89]
- Estimated temperature at base of Permo-Triassic sequence (Worcester Basin)[90,91]
- Depth map of top Sherwood Sandstone Group with indicative temperature estimates (Northern Ireland)[92]

Depth Conversion Workflow

- **Georeferencing:** Temperature contour maps were georeferenced in QGIS using the UK national grid spatial reference system.
- **Digitisation:** Contours were manually digitised as vector polylines to generate geospatial temperature data layers.
- **Surface temperature:** Surface temperature was determined based on global maps of soil temperature (**Figure 3.A.1**). The original map provides an estimate of the average soil temperature at depths between 5 centimetres and 15 centimetres at a resolution of 30 arc seconds globally.[93]
- **Depth conversion:** The subsurface temperatures were calculated using basin-specific geothermal gradients (GTG) per basin,[94] using the following equation: $T = T\_surface + (GTG \times \text{depth in kilometres})$.

DEPTH TO TOP OF TRIASSIC SANDSTONE GROUP ACROSS THE UK

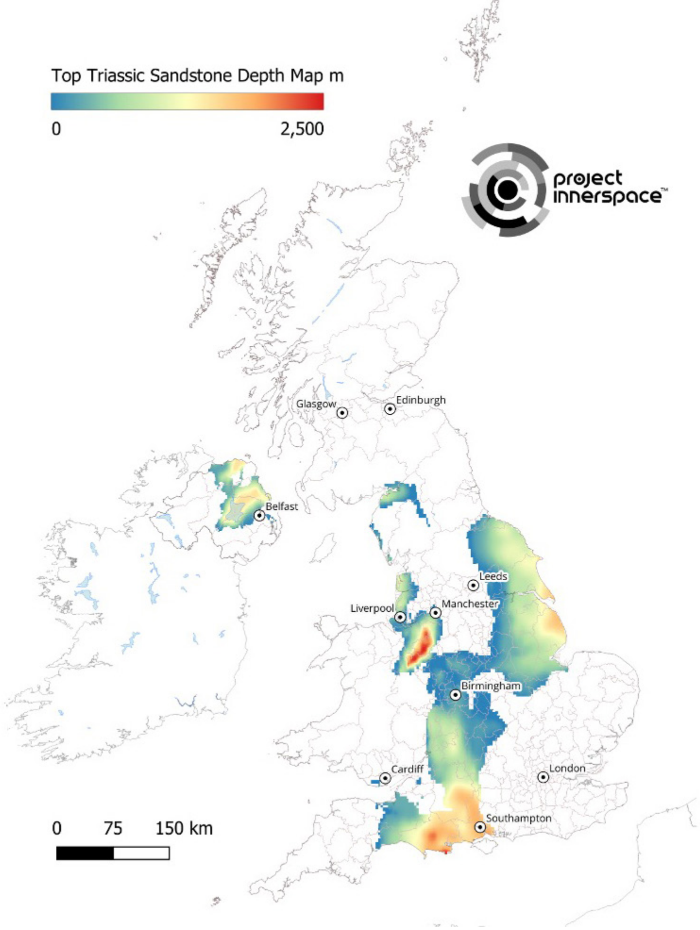


Figure 3.A.1: Depth to Top of the Triassic Sandstone Group across the UK. This map shows the estimated depth (in metres) to the top of the Sherwood Sandstone Group, one of the principal geothermal aquifers in the UK. Depths range from surface outcrop to more than 2,500 m (dark red). Sources: Data compiled by Helen Doran for Project InnerSpace using public domain sources: Rollin, K. E., Kirby, G. A., Rowley, W. J., & Buckley, D. K. (1995). *Atlas of geothermal resources in Europe: UK revision*. British Geological Survey; Hurter, S., & Haenel, R. (Eds.). (2002). *Atlas of geothermal resources in Europe*. European Commission; Raine, R., Reay, D., Wilson, P., & Millar, R. (2020). *The Sherwood Sandstone Group as a potential geothermal aquifer across Northern Ireland* [Poster presentation]. Irish Geological Research Meeting (IGRM) 2020.

Thermal Model

The total heat flux or heat budget available in a sedimentary basin is controlled by the heat flux from the mantle and the upper crust to the base of the sedimentary section.

The UK lithosphere thermal model includes the refined grids of sediment thickness, crustal thickness, and depth to the Moho (see Project InnerSpace's GeoMap for maps). These grids are used as inputs for DeepPlot, a basin modelling tool within the ZetaWare software suite Genesis,[95] which calculates the depth to the 1,330°C isotherm and models heat distribution across lithospheric layers.

To accurately model transient effects in heat flow, the thickness of the entire lithosphere must be considered. Genesis allows users to set a temperature boundary at the lithosphere's base and adjust heat flow by modifying lithospheric parameters. The model anchors to a mean annual surface temperature based on the surface temperature grid, with the base of the lithosphere defined at the 1,330°C isotherm.

The models generated a temperature-depth profile, which can be compared with the corrected measured temperatures from the borehole data. Across the United Kingdom, there is a strong correlation with the modelled lithospheric heat flow and borehole observations. Therefore, we interpret the observed lateral variations in geothermal gradients to be attributed to changes in lithospheric thickness, with higher thermal gradients occurring in areas of thinner lithosphere (Rathlin Basin). This indicates that the wells do not reveal any discrepancies between the lithospheric heat flow model and the expected conductive heat transfer. The alignment between lateral variations in the geothermal gradient and lithosphere thickness enhances confidence in the lithosphere model's reliability. Once this confidence is established, predictions can extend beyond the borehole locations, facilitating the generation of depth surface predictions across the area of interest and enabling the model to transition from a 1D to a 2D framework.

Temperature Depth Map of the Triassic Sandstone Across the UK

A temperature-depth map for the Triassic Sandstone was created using the UK Lithosphere Thermal Model described.

This method utilised a polynomial temperature-depth curve, derived as a best-fit curve from existing temperature data to predict temperature values across depths. This curve was extrapolated to 5 kilometres to cover the full depth of interest within the study area.

The map creation involved adjusting for surface temperature variations across grid cells, using a grid of present-day surface temperature to anchor the temperature-depth curve spatially. The thermal scalar map created from the Lithosphere Model was used to adjust each grid cell's temperature by factoring in variations of surface temperature and sediment thickness. This approach allowed for a spatially modified temperature-depth relationship, creating

MODELLED TEMPERATURE DISTRIBUTION AT TOP OF THE TRIASSIC SANDSTONE GROUP ACROSS THE UK

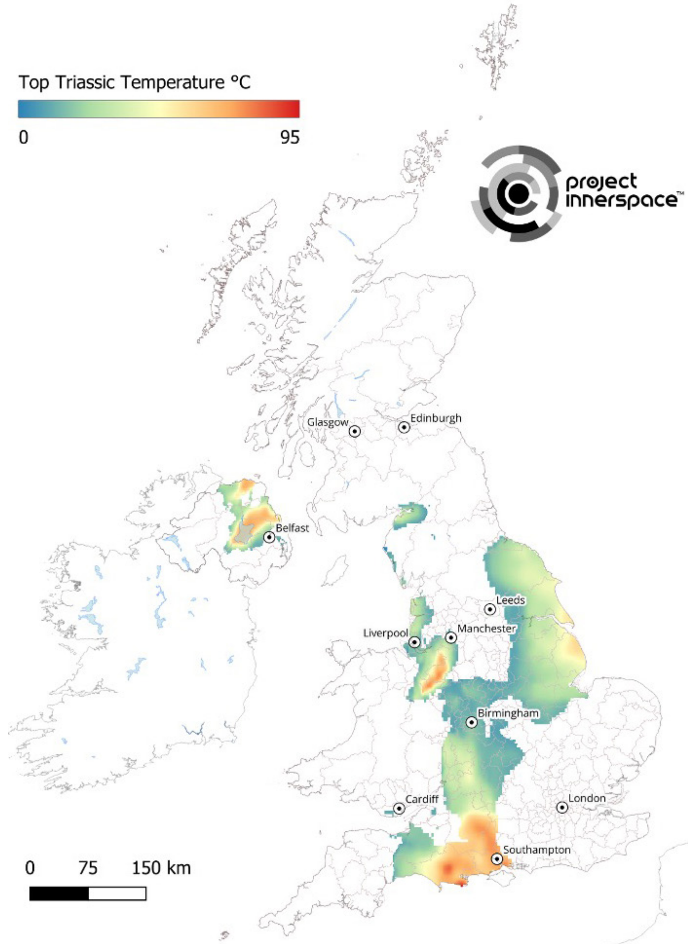


Figure 3.A.2: This map displays the modelled temperature distribution at the top of the Triassic Sandstone Group across the UK, with values ranging from 0°C (blue) to 95°C (red). Source: Temperatures were calculated using Doran, H., & Matt, V. (2025). *Global lithosphere thermal model*. Project InnerSpace.

accurate projections for geothermal gradients across the Triassic reservoir.

Porosity Variations of the Triassic Sandstone Across the UK

To estimate the porosities of the Triassic sandstone reservoir, a porosity vs. depth curve (compaction curve) has been used based on English et al.[96]

Porosity within the onshore Triassic Sherwood Sandstone Group (SSG) in Great Britain and Northern Ireland typically ranges from 10% to 30%, with most effective porosity values falling between 15% and 25%. In Northern Ireland, recent well log and core data confirm porosities generally between 15% and 25%, particularly within the Lough Neagh and Larne basins. In onshore Great Britain, formations such as the Wilmslow and Chester Formations in the Cheshire Basin commonly exhibit porosities in the range of 15% to 20%, while the Otterton Sandstone Formation in the Wessex Basin shows slightly higher values of 14% to 26%. These porosity values are strongly influenced by burial depth, diagenetic cementation (primarily quartz and carbonates), and sedimentary texture, with better-sorted and coarser-grained intervals retaining higher porosity.[97]

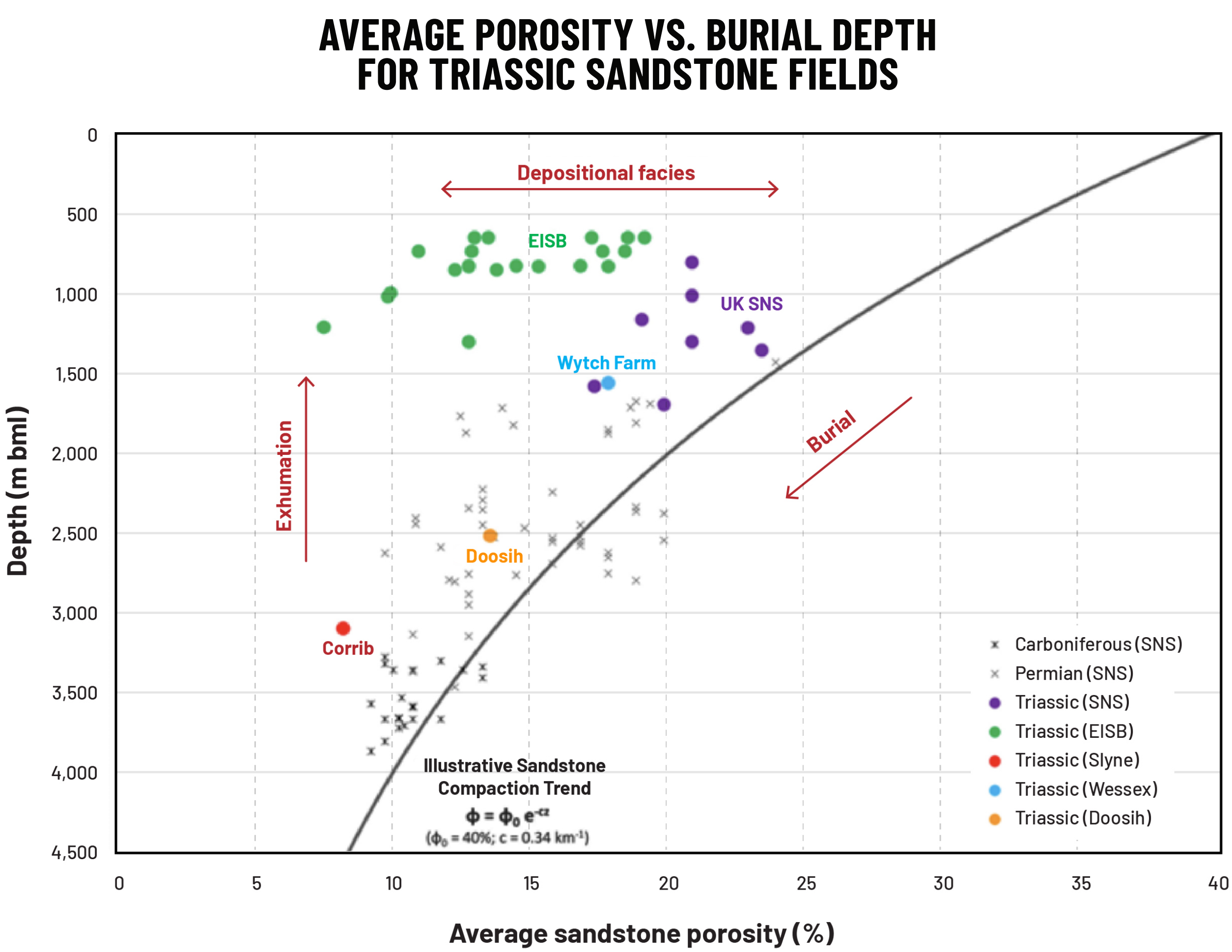


Figure 3.A.3: Average porosity vs burial depth for Triassic sandstone fields in UK and Ireland. Source: English, K. L., English, J. M., Moscardini, R., Haughton, P. D. W., Raine, R. J., & Cooper, M. (2024). Review of Triassic Sherwood Sandstone Group reservoirs of Ireland and Great Britain and their future role in geoenergy applications. *Geoenergy, 2*(1).

Methodology

Initial HiP (PJ)

The total thermal energy (Q_T), stored in the reservoir is given by the sum of the thermal energy in the rock matrix (Q_R) and the thermal energy in the pore fluid (water; Q_W) within the reservoir: $Q_T = Q_R + Q_W$

QR can be calculated using the following equation: $Q_R = A \cdot h \cdot \rho_R \cdot C_R \cdot (1-\phi) \cdot (T_r - T_{cutoff})$.

- A = reservoir area (m^2)
- h = average reservoir thickness (m)
- ρ_R = rock matrix density (kg/m^3)
- C_R = specific heat capacity of rock at reservoir conditions (kJ/kg•°C)
- ϕ = reservoir porosity (fraction)
- T_r = subsurface temperature (°C)
- T_{cutoff} = application-specific temperature threshold (°C)

The thermal energy in pore fluid (Q_W) is given by the following equation: $Q_W = A \cdot h \cdot \rho_w \cdot Cw \cdot \phi \cdot (T_r - T_{cutoff})$.

- ρ_W = pore fluid density (kg/m^3)
- C_W = specific heat capacity of the pore fluid at reservoir conditions (kJ/kg•°C)

For the purposes of this calculation, the fluid and rock density and heat capacity were set using the following values:

- Pore fluid density = 1030 kg/m^3
- Rock matrix density = 2800 kg/m^3
- Specific heat capacity of the pore fluid at reservoir conditions = 4.18 kJ/kg•°C
- Specific heat capacity of the rock at reservoir conditions = 0.79 kJ/kg•°C

Heat-density maps are generated using the Trinity T3 basin modelling toolkit (ZetaWare Inc. Geothermal Calculator)[98] requiring the following inputs:

- Formation depth of SSG
- Isopach map based on available well data
- Porosity maps for the formation utilising a porosity-depth compaction curve
- Surface temperature
- Geothermal gradient map created from Project InnerSpace proprietary thermal model

AVERAGE POROSITY OF THE TRIASSIC SANDSTONE GROUP ACROSS THE UK

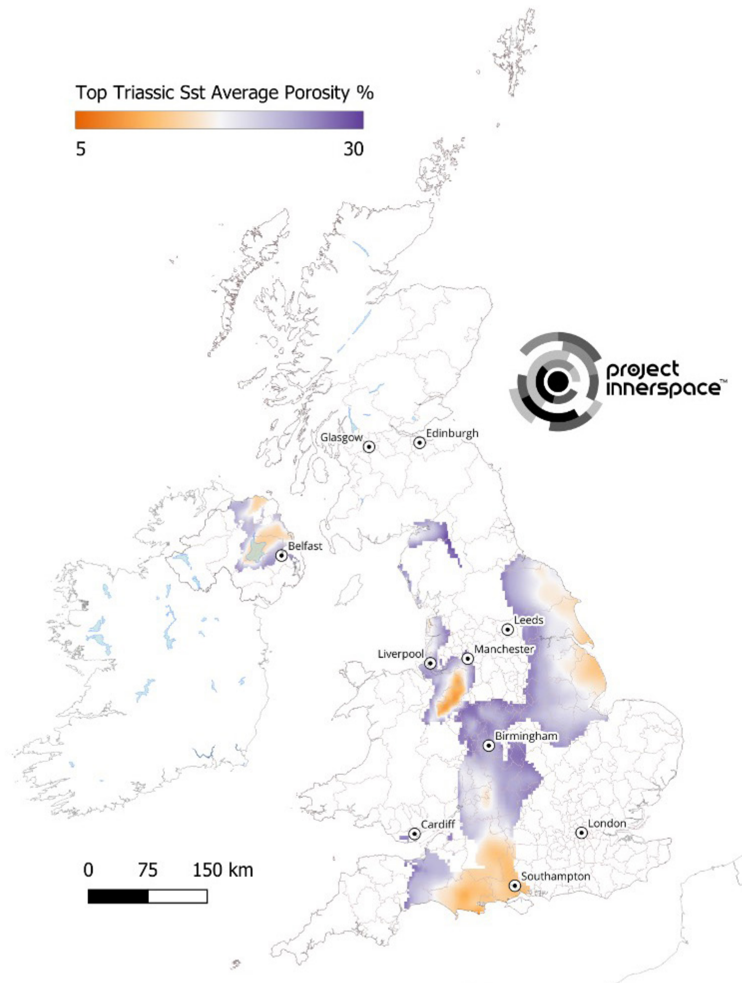


Figure 3.A.4: This map illustrates spatial variation in average porosity across the Triassic Sandstone, with values ranging from 5% (orange) to 30% (purple). Source: English, K. L., English, J. M., Moscardini, R., Haughton, P. D. W., Raine, R. J., & Cooper, M. (2024). Review of Triassic Sherwood Sandstone Group reservoirs of Ireland and Great Britain and their future role in geoenergy applications. *Geoenergy*, *2*(1).

Geothermal utilisation scenarios assessed include low-temperature domestic and industrial heat (thresholds of 20°C, 40°C, 60°C, and 90°C). Regions below these thresholds are excluded to maintain economic relevance.

Together, these equations provide the total potential heat stored in the reservoir (Q_T) in units of PJ/km^2. Next, we provide a working example per km^2, given the following parameters:

- Cutoff temperature (T cutoff) = 40°C
- Porosity = 10%
- Reservoir thickness = 100 m
- Water density = 1,030 kg/m^3
- Water heat capacity = 4.18 kJ/kg·K
- Rock density = 2,800 kg/m^3
- Rock heat capacity = 0.79 kJ/kg·K
- Depth = 2900 m
- Geothermal gradient (GTG) = 32°C/km
- Surface temperature = 10°C

Calculations

Average reservoir temperature (T_res) = T_surface + (GTG × depth in km) = 10 + (32 × 2.9) = 102.8°C

Temperature difference (ΔT) = T_res - T_cutoff = 102.8 - 40 = 62.8°C

Reservoir Volume (per km^2)

Area = 1 km^2 = 1,000,000 m^2

Thickness = 100 m

Volume = 1,000,000 × 100 = 100,000,000 m^3

Water and Rock Volumes

Porosity = 10%

Water volume = 100,000,000 × 0.10 = 10,000,000 m^3

Rock volume = 100,000,000 × 0.90 = 90,000,000 m^3

Mass of water and rock

Water mass = 10,000,000 × 1030 = 1.03×10^{10} kg

Rock mass = 90,000,000 × 2800 = 2.52×10^{11} kg

Thermal Energy Calculation: Convert Heat Capacities

Water: 4.18 kJ/kg·K = 4180 J/kg·K

Rock: 0.79 kJ/kg·K = 790 J/kg·K

ΔT = 62.8 K

Water Energy

Q_water = $1.03 \times 10^{10} \times 4180 \times 62.8 \approx 2.7 \times 10^{15}$ J

Rock Energy

Q_rock = $2.52 \times 10^{11} \times 790 \times 62.8 \approx 1.25 \times 10^{16}$ J

GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥20°C USING MAX THERMAL MODEL

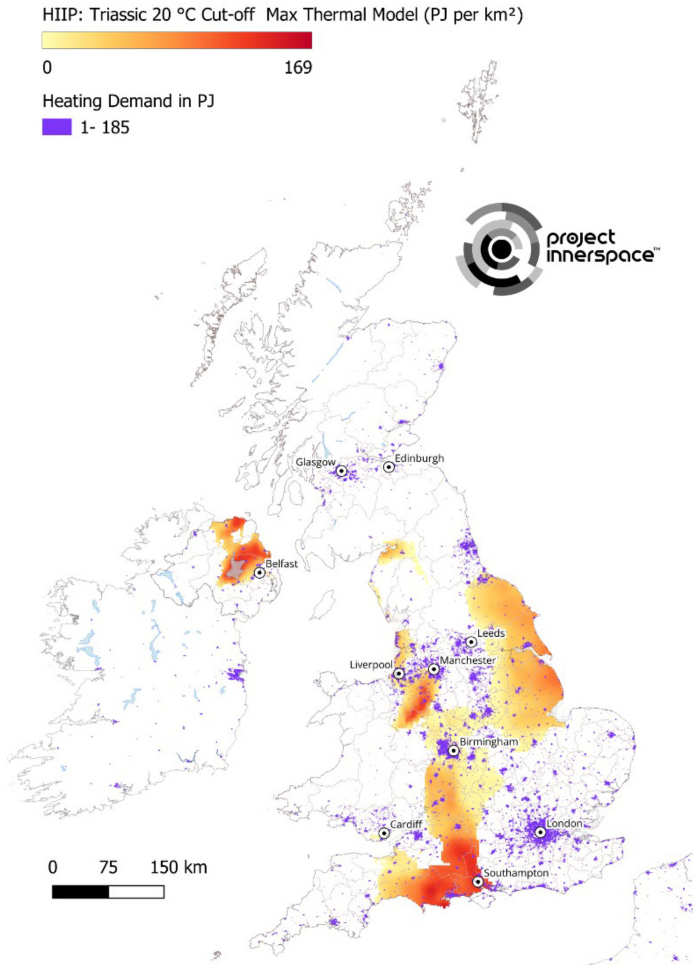


Figure 3.A.5: Geothermal resource potential in Triassic reservoirs ≥20°C using the Max thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.

Total Thermal Energy

Q_total = Q_water + Q_rock = $2.7 \times 10^{15} + 1.25 \times 10^{16} = 1.52 \times 10^{16}$ J

Convert to Petajoules (PJ)

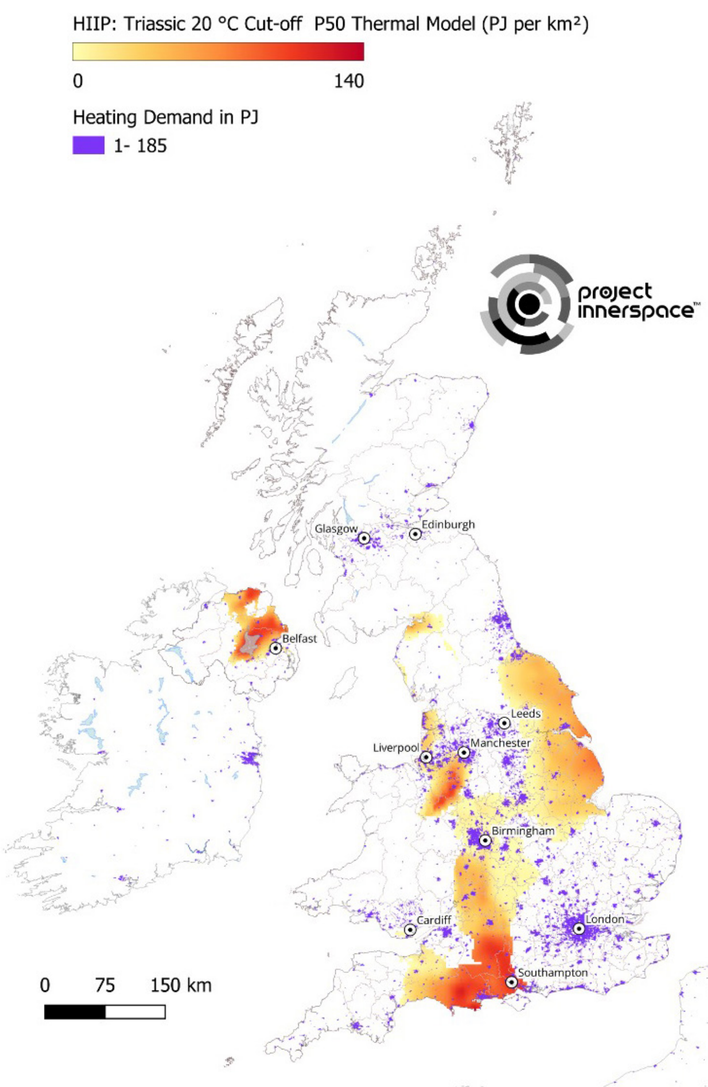
1 PJ = 10^{15} J

Q_total ≈ 15.2 PJ/km^2

Final answer: Heat-in-place ≈ 15.2 PJ/km^2

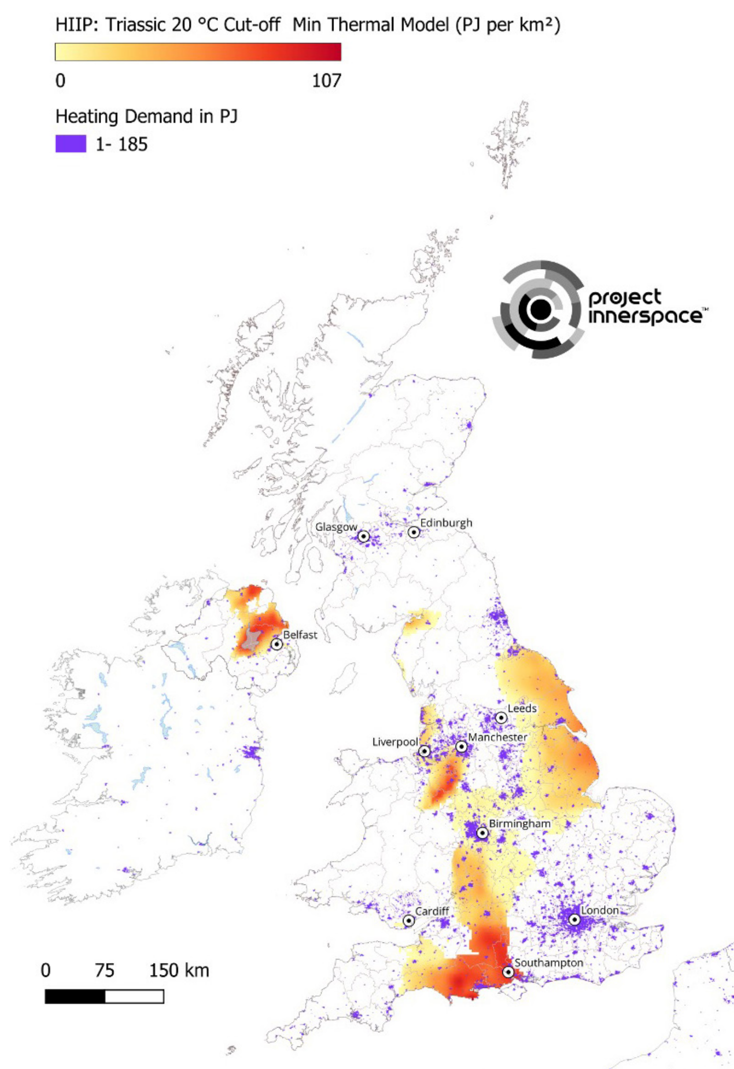
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥20°C USING P50 THERMAL MODEL

Figure 3.A.6: Geothermal resource potential in Triassic reservoirs ≥20°C using the P50 thermal model. The maps show HiP estimates in PJ/km². Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



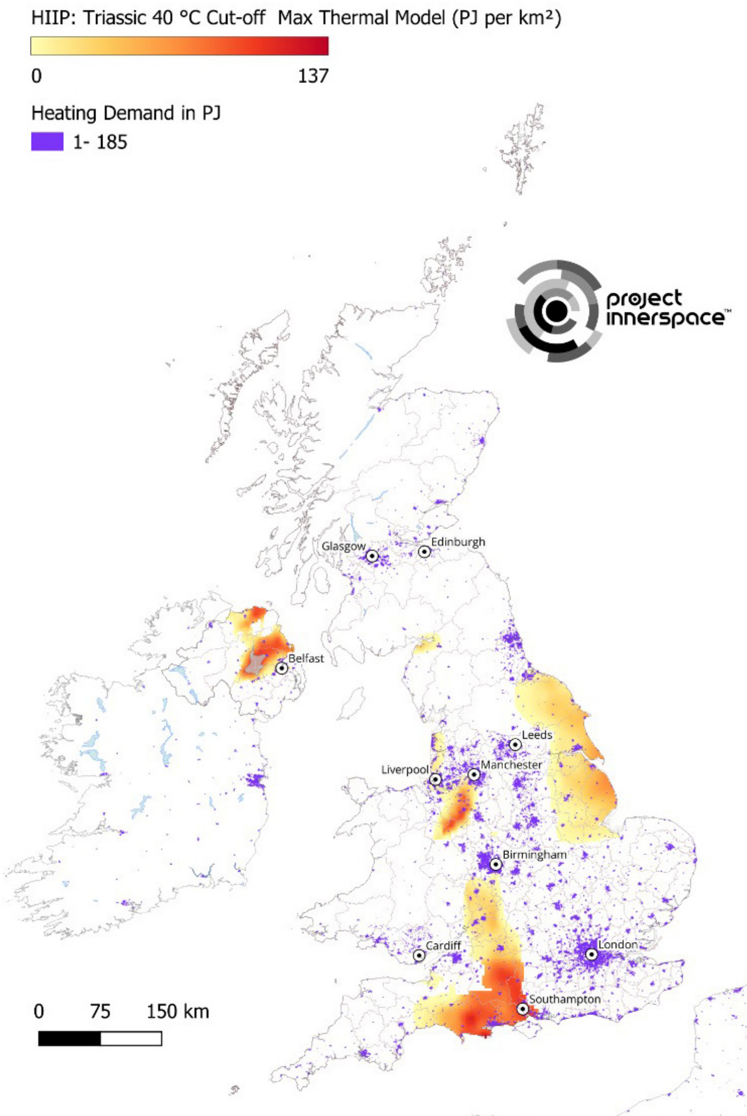
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥20°C USING MIN THERMAL MODEL

Figure 3.A.7: Geothermal resource potential in Triassic reservoirs ≥20°C using the Min thermal model. The maps show HiP estimates in PJ/km². Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



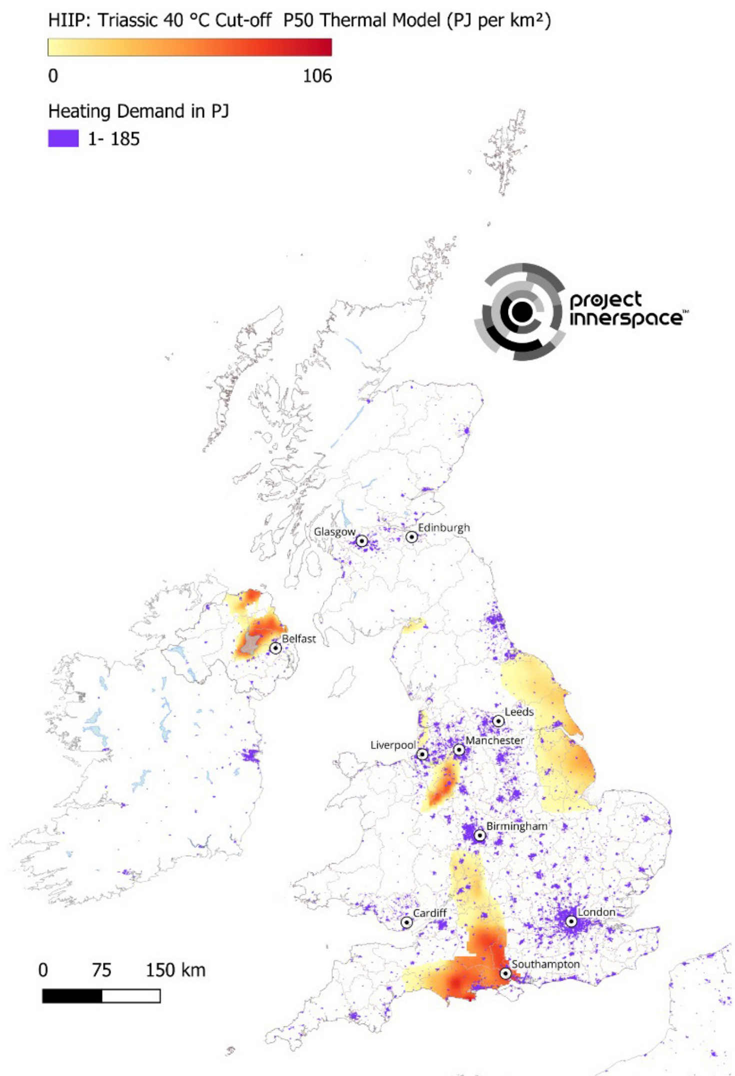
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥40°C USING MAX THERMAL MODEL

Figure 3.A.8: Geothermal resource potential in Triassic reservoirs ≥40°C using the Max thermal model. The maps show HiP estimates in PJ/km². Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



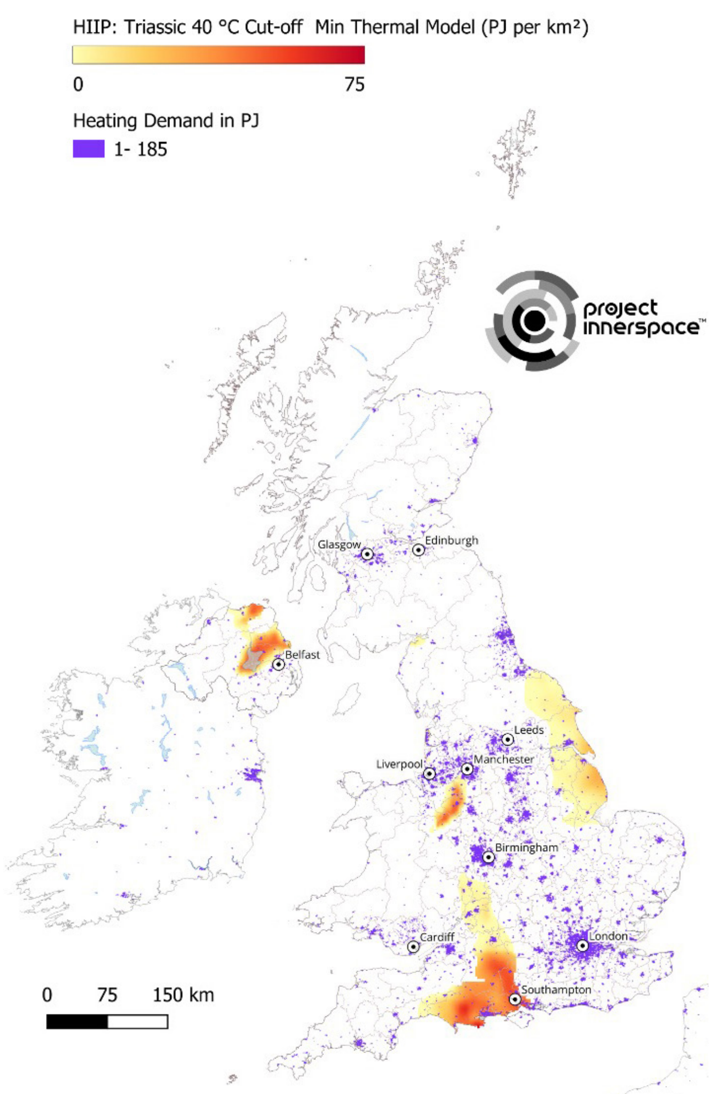
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥40°C USING P50 THERMAL MODEL

Figure 3.A.9: Geothermal resource potential in Triassic reservoirs ≥40°C using the P50 thermal model. The maps show HiP estimates in PJ/km². Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



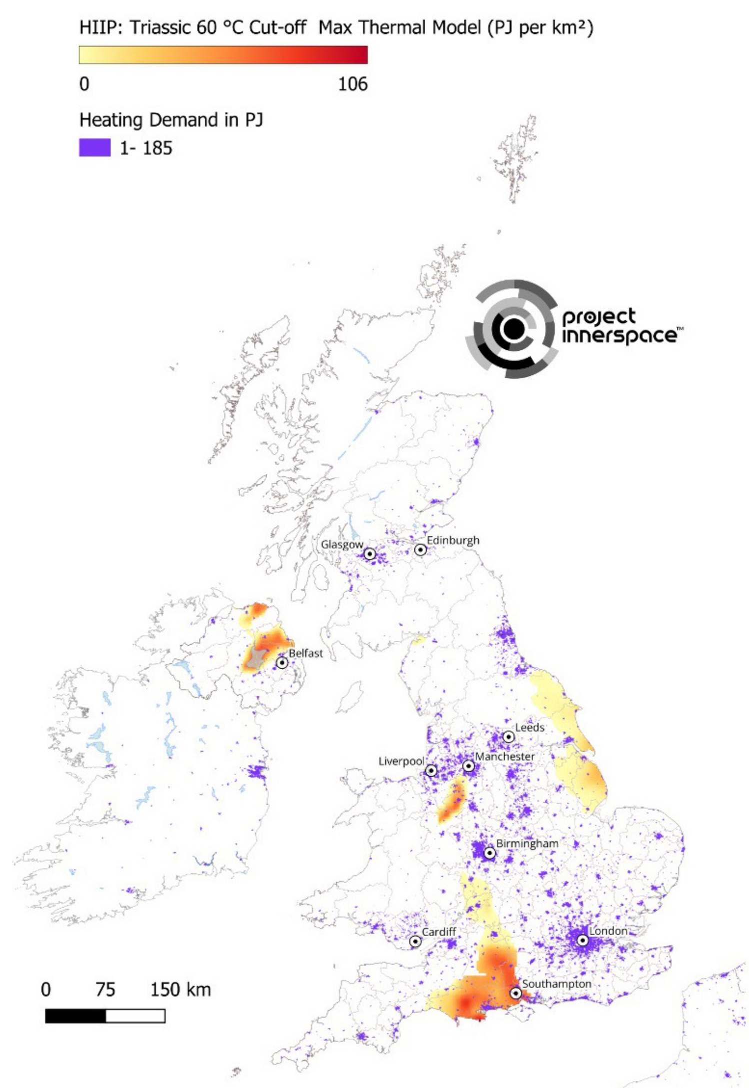
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥40°C USING MIN THERMAL MODEL

Figure 3.A.10: Geothermal resource potential in Triassic reservoirs ≥40°C using the Min thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



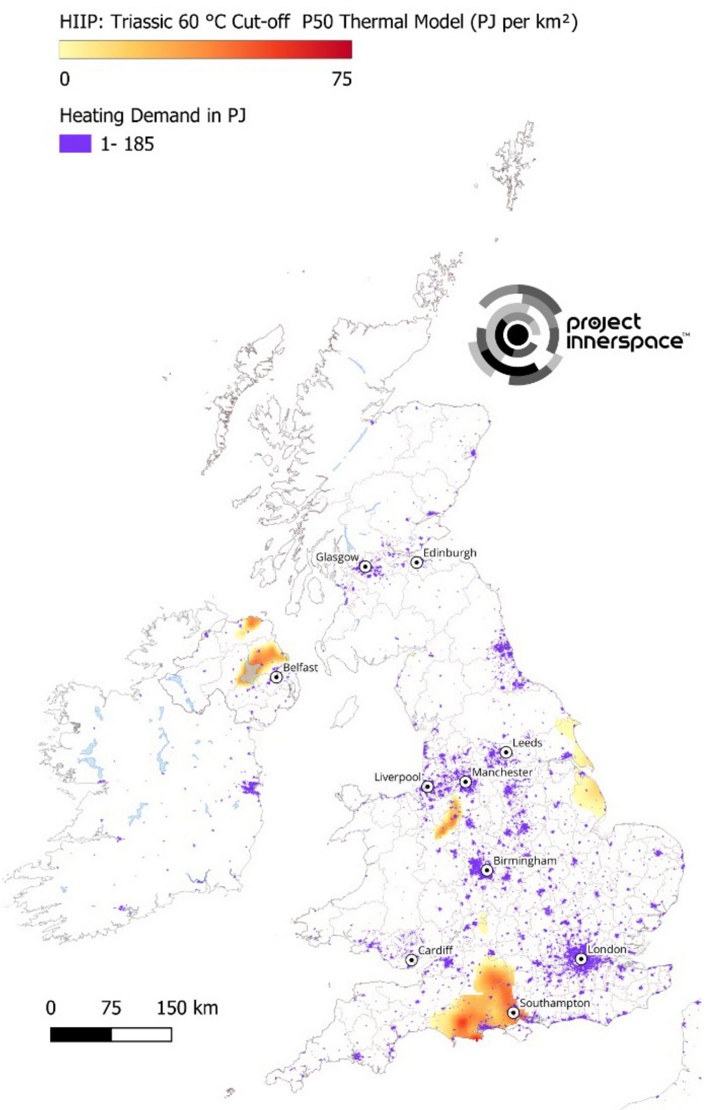
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥60°C USING MAX THERMAL MODEL

Figure 3.A.11: Geothermal resource potential in Triassic reservoirs ≥60°C using the Max thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



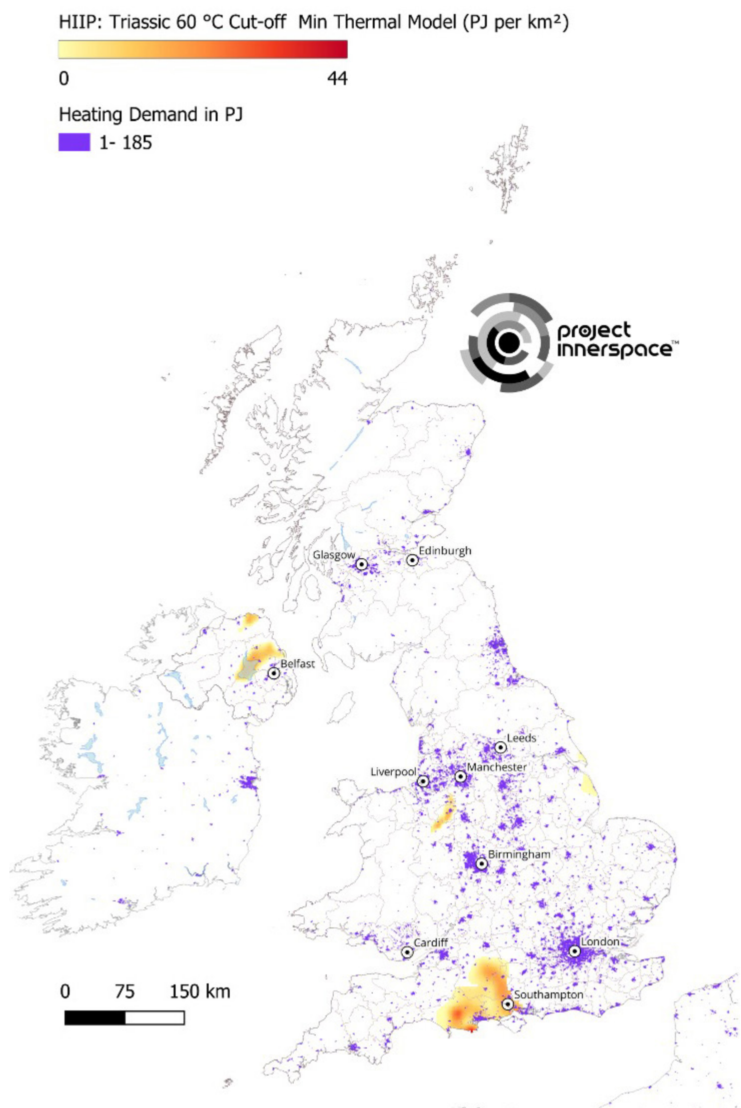
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥60°C USING P50 THERMAL MODEL

Figure 3.A.12: Geothermal resource potential in Triassic reservoirs ≥60°C using the P50 thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



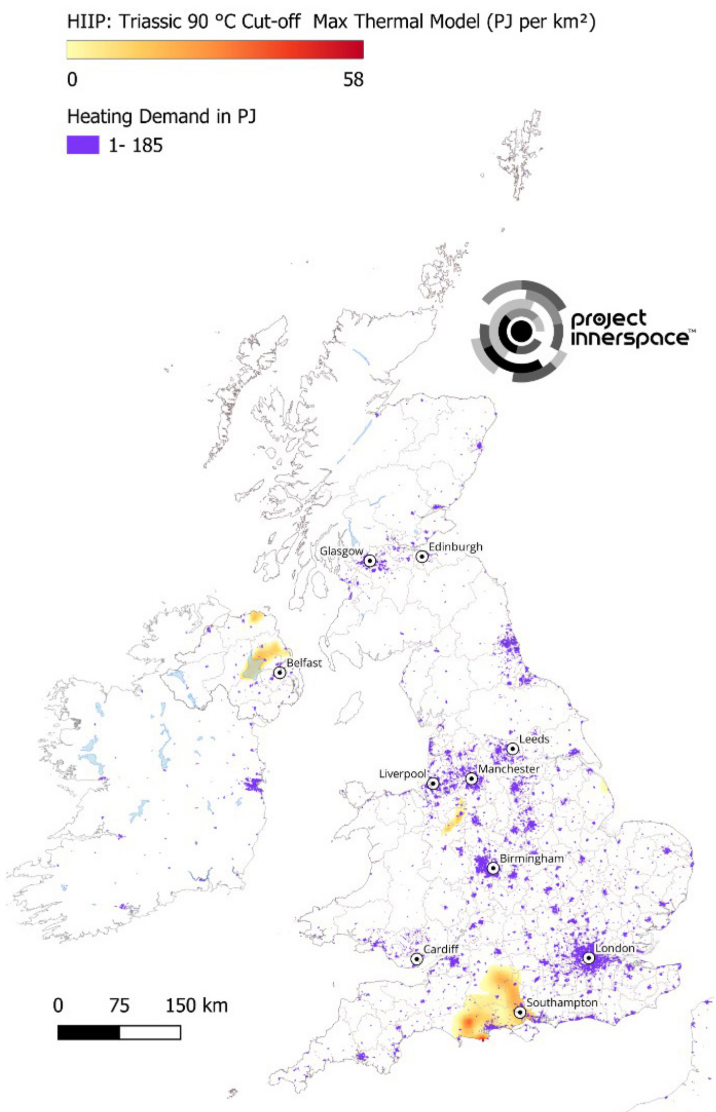
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥60°C USING MIN THERMAL MODEL

Figure 3.A.13: Geothermal resource potential in Triassic reservoirs ≥60°C using the Min thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



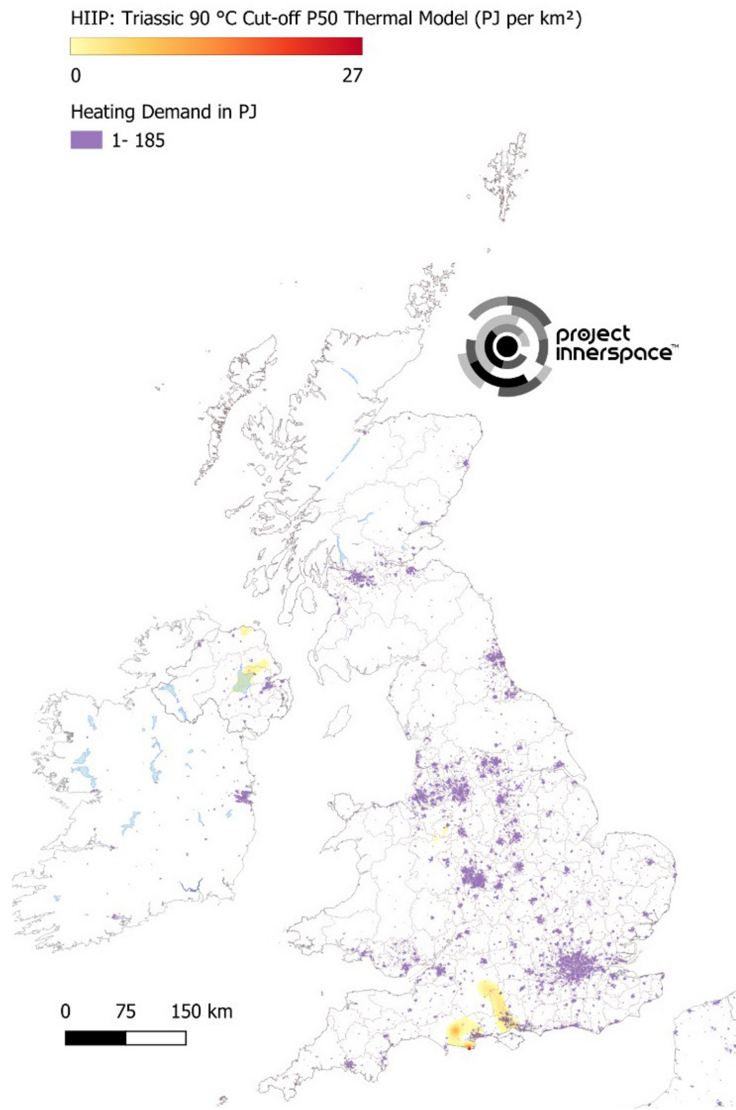
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥90°C USING MAX THERMAL MODEL

Figure 3.A.14: Geothermal resource potential in Triassic reservoirs ≥90°C using the Max thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥90°C USING P50 THERMAL MODEL

Figure 3.A.15: Geothermal resource potential in Triassic reservoirs ≥90°C using the P50 thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



Modelling Future Production Scenarios for the Wessex Basin

Introduction

This section sets out a best-practice, project-based assessment of the Wessex basins that is consistent with the DoubletCalc-based modelling.[99]

In the past, Busby and Terrington evaluated the potential for engineered geothermal systems to contribute to electricity generation in Great Britain.[100] In addition Limberger et al.[101] provided a related regional to global perspective. Neither study embedded a realistic, even if conceptual, project framework, which is a common limitation when translating play or basin potential into deployable capacity. Applying a single average recovery factor at basin, regional, or national level overlooks practical development limits. Only a finite number of doublets can be developed and sustained within any potential area, an issue analogous to drainage area in hydrocarbon extraction. Empirical data and modelling indicate that the licence boundary of a geothermal doublet can be set at approximately twice the spacing between injector and producer to avoid thermal interference between adjacent licences.[102]

Land accessibility further constrains what can actually be built. Shale gas development provides a useful analogue. Harrison et al. 2019[103] documented operational difficulties in densely populated parts of England, where traffic, proximity to national parks, and competing land uses create significant barriers. Taylor et al.[104] estimated that a single well pad with 10 horizontal wells would require daily access by 11 trucks during the first two years of drilling and completion. Building on this, Clancy et al.[105] showed that when both surface and subsurface constraints are applied, the average carrying capacity within licensed shale gas blocks falls to about 26%, which in turn limits the recoverable resource base. These findings translate directly to geothermal siting and scheduling, since similar access, permitting, and footprint constraints apply.

To address these limitations, our Wessex Basin assessment adopts a transparent, project-based workflow consistent with UNFC practice. We represent development as doublets with explicit spacing and interference limits; we solve the coupled mass, momentum, and energy balances using the TNO semi-analytical framework (DoubletCalc) to estimate sustainable flow, pump duty, and indicative thermal power; and we anchor inputs to location-

GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥90°C USING MIN THERMAL MODEL

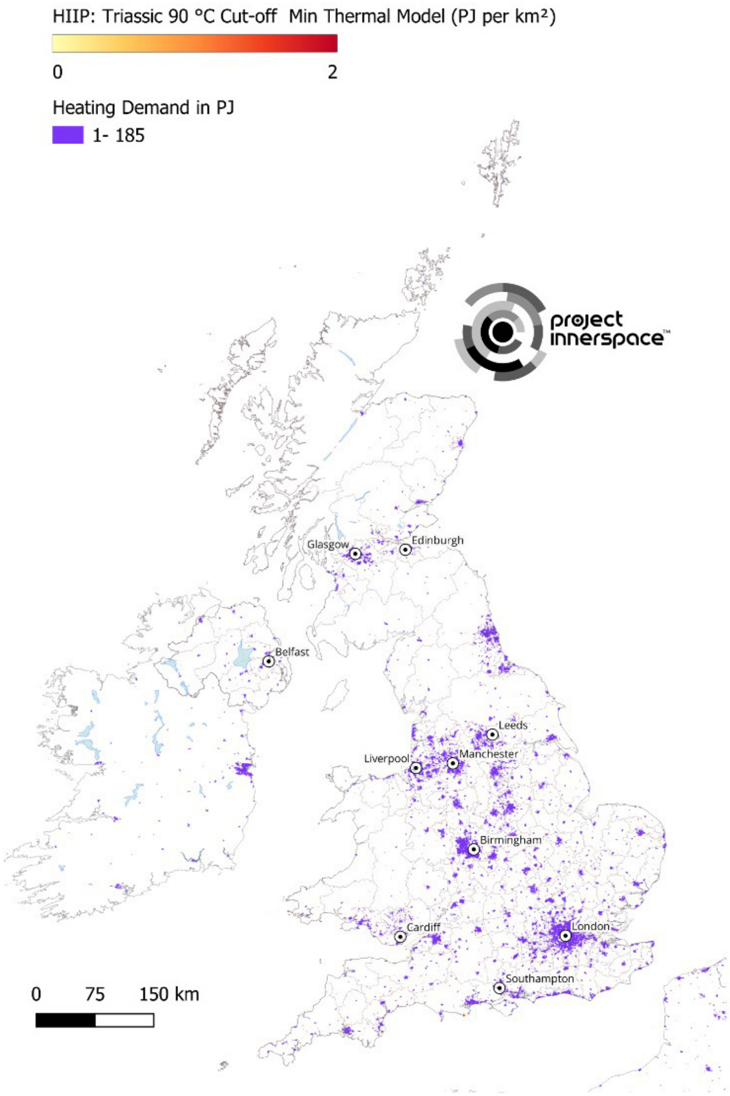


Figure 3.A.16: Geothermal resource potential in Triassic reservoirs ≥90°C using the Min thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.

specific reservoir properties. Overburden properties are held constant to isolate reservoir effects. Key reservoir controls—namely permeability, top depth, and temperature—are treated as uncertain and parameterised with beta-PERT distributions defined by minimum, most likely, and maximum values. Uncertainty is propagated with Monte Carlo simulation using Latin Hypercube Sampling, with 1,000 realisations per site, to produce comparable P10, P50, and P90 outcomes across locations.

Within the UNFC,[106] bottom-up assessment requires aggregating quantities from development projects in the same categories. A national scale example for a single geological play is Case Study 5, Dutch Rotliegend Play Area: Nationwide, led by Mijnlieff in Falcone et al.,[107] and later revisited and expanded by Mijnlieff and colleagues in two studies.[108,109] That sequence shows how explicit project definitions, clear development constraints, and consistent classification enable robust aggregation.

We implement the semi-analytical solution originally implemented by TNO.[110] The model, known as DoubletCalc, is intended to provide an indicative thermal power for a doublet development by specifying the key reservoir properties and details of the well design, including pump. Using the governing equations for mass, momentum, and energy, the flow through the geothermal system can be obtained.

The model inputs are constrained by location-specific reservoir properties. We assume an average density, conductivity, and heat capacity of the overburden and do not vary this. We use 2.715 (W/(m.K) for the thermal conductivity, 955 (W/m.K) for the heat capacity, and 2,480 (kg/m^3) for the overburden density. For each location, we vary (i) reservoir permeability, (ii) reservoir top depth, and (iii) the reservoir temperature. For all reservoir properties, due to the generally limited amount of data, a beta-PERT probability distribution is used as a subjective description of the parameter variability. This distribution is a smooth alternative to the triangular distribution and is described in terms of a minimum (a), modal (b), and maximum value (c): X~betaPERT(a,b,c). For each location, a Monte Carlo simulation with Latin Hypercube Sampling (LHS) is used to characterise the PDF of the model response. A set of 1,000 samples is used for each location.

We make the following assumptions in the modelling that remain unchanged at each site:

- Salinity = 100,000 ppm
- kh/kv ratio = 0.7
- Reservoir density = 2,460kg/m^3
- Reservoir heat cap = 930kJ/(kg·K)
- Thermal conductivity of the overburden rock = 2.715 W/(m·K).
- Heat capacity of the overburden rock = 955 kJ/(kg·K).
- Density of the overburden rock = 2480 kg/m^3
- Surface temp = 9.25°C
- Temp of injected water = 60% of reservoir fluid temperature (°C)
- Pump depth = 300 m
- Pump pressure differential = 40 bar
- Pump efficiency = 0.61
- Outer-diameter injector = 8.125 in.
- Outer-diameter producer = 8.125 in.
- Casing thickness = 0.0254 in.

We assume the producer and injector pair are effectively co-located at the surface and then build out at a 30° angle at 500 metres depth. The distance between wells at the reservoir depth will vary between locations. As an example, for the Bournemouth location, a top reservoir depth of 1,681 metres total vertical depth gives a reservoir separation of 1,372 metres.

APPENDIX B

From Potential to Feasible Development: Defining, De-Risking, and Classifying Projects

Gioia Falcone

Project Definition

The UNFC is designed as a project-based system where a project is a defined development or operation that provides the basis for environmental, social, economic, and technical evaluation and decision-making. In the early stages of evaluation, including verification, the project might be defined only in conceptual terms, whereas more mature projects will be defined in significant detail.[111] Although defining a project at an early stage of evaluation is challenging, no estimate of potentially recoverable quantities can be made without it. As reported by Falcone and colleagues,[112] "The creation of notional or hypothetical 'standard' Prospective Projects (with associated Reference Point) may allow an estimate and classification of all the nation's Geothermal Energy Resources, including those not yet linked to defined Projects."

The United Nations Economic Commission for Europe and International Geothermal Association (UNECE-IGA) specifications define geothermal energy resources as "the cumulative quantities of geothermal energy products that will be extracted from the geothermal energy source from the effective date of the evaluation forward (till the end of the project lifetime/limit), measured or evaluated at the declared Reference Point(s)." In addition, the specifications state, "For national resource reporting, the aggregation of individually reported resource estimates from commercial, non-commercial and/or governmental organizations may not cover the total national geothermal energy resources."

TYPICAL DEEP GEOTHERMAL PROJECT PHASES

	Project Description	Exploration	Drilling - First well	Resource Development	Construction	Operation	Decommissioning
Financing options	• Subsidies/grants/ donations • Crowdfunding (E/R) • Direct lending combined with governmental guarantee • Governmental lease	• Subsidies/grants/ donations • Crowdfunding (E/R) • Direct lending combined with governmental guarantee • Governmental lease	• Subsidies/grants • Crowdfunding (E/(L)/R) • Direct lending combined with governmental guarantee • Governmental lease • Green bond • Regular loan • Regular bond • Equity	• Crowdfunding (E/(L)/R) • Direct lending combined with governmental guarantee • Governmental lease • Green bond • Regular loan • Regular bond • Equity	• Crowdfunding (L/R) • Direct lending • Leasing	• Crowdfunding (L/R) • Direct lending • Leasing	• Retained profits • Governmental subsidies
Social engagement	• Announcement of the project • Information of responsible authorities • Correct and factual information • Identification of opportunities and risks • Far-reaching transparency, accessibility of information materials	• Information of responsible authorities • Planning permits • Asking for need of information/ communication • Offering financial participation opportunities • Description of the process, different phases • Direct communication with relevant stakeholder groups	• Drilling permits • Documentation • Regional information markets, topic tables • Dialogue groups • Local office with sufficient consultation times • Site visits of existing projects/video/VR/3D presentations		• Construction permits • Regional information markets, topic tables • Dialogue groups • Public construction diary	• Monitoring information to the stakeholders/ public according to legal framework • Offering further financial participation opportunities • Spin-off to other joint energy projects • Operation starting party • "Local energy party" • Operation diary, website showing produced energy/saved CO2 emissions	• Decommissioning information-inform ation to the stakeholders/ public according to legal framework (focus environment, risks, post-utilization) • Dialogue with citizens for future plans

Figure 3.B.1: Different phases of a typical deep geothermal project, corresponding with de-risking financial options and social engagement strategies. Source: Ioannou, A., & Falcone, G. (2021). Guidelines for developers and promoters of geothermal energy. CROWDTHERMAL.

Project De-Risking

The risk of a geothermal project varies over its lifetime, and so does the estimate of the quantities it could produce. **Figure 3.B.1** shows different phases of a typical deep geothermal project, together with de-risking financial options and social engagement strategies that could be implemented at each phase.

There are also potential environmental impact risks associated with deep geothermal for power production. Corresponding mitigation actions could include, for example, the adoption of an induced seismicity traffic light protocol in combination with the installation of local seismic monitoring networks. (See Chapter 7, "Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices," for more.[113])

Ussher et al.[114] describe the formalisation of a methodology for assessing the Probability of Discovery (PoD) for hydrothermal prospects that was driven by a specific request from a government-based funding organisation in Indonesia to assess PoD as part of its own risk evaluation for lending on exploration drilling programs. In this case, PoD is a key part of the lending decision and could factor directly in the financial assessment of loan parameters. The experience shows that many developers find PoD important when evaluating and comparing geothermal projects in a portfolio. The PoD is also an essential parameter to calculate risked resources if resource assessment is done at national level. Falcone and colleagues define PoD as "the chance that further exploration, drilling, and well testing of a potential geothermal energy source will result in the confirmation of a known geothermal energy source. This will typically be assessed considering the key factors that are required to achieve a discovery which may include temperature, permeability and fluid chemistry or other relevant parameters that are important for the type of project planned to evaluate the technical feasibility of the project."[115] PoD was introduced in the UNFC for geothermal specifications to reflect the high level of uncertainty that is typical of most conventional types of deep geothermal systems when progressing from surface-based studies to actual drilling, and it has since proven to have growing support in the industry, as it can be truly valuable for decision-making. This is critical as a potential modifier for energy estimates for prospective projects, which can be very high risk and have less certainty that they will progress in development.

Project Classification

Within the UNFC, the products of a resource project are classified on the basis of the three fundamental criteria of environmental-socio-economic viability (E), technical feasibility (F), and degree of confidence in the estimate (G). Categories and sub-categories are defined for the three criteria. The E set designates the degree of favourability of those conditions in establishing the viability of the project, including consideration of market prices and relevant legal, regulatory, social, environmental, and contractual conditions. The F set designates the maturity of technology, studies, and commitments necessary to implement the project. The G set designates the degree of confidence in the estimate of the quantities of products from the project, with G1 representing high confidence and G3 representing lower confidence in the estimated quantities of a resource.[116]

The resource classification process consists of the following actions:

1. Defining a project associated with (at least) one geothermal energy source.
2. Estimating the quantities of energy that can be sold, used, or otherwise delivered as geothermal energy products over the project's lifetime.
3. Classifying the geothermal energy resource based on the criteria defined by the E, F, and G categories.

Degree of Confidence in the Estimate of Resources

For estimating the quantities of energy that can be sold, it is necessary to define the following:

- Start date
- Project life
- Plant life
- Duration of licences and environmental permits

- Duration of energy sales agreements
- Capacity that may be achieved
- Potential decline of source supply or equipment performance
- Possible future projects

Collectively, these considerations capture the uncertainty in the energy that will be produced by a given project, as qualitatively represented in **Figure 3.B.2**.

Annex 1 in the UNFC overview E/F/G table[117] summarises definitions and supporting explanations of UNFC G categories and sub-categories, highlighting that quantity estimates may be categorized as a range of uncertainty as reflected by either (i) three specific deterministic scenarios (low, best, and high cases) or (ii) a probabilistic analysis from which three outcomes (P90, P50, and P10) are selected. In both methodologies, the estimates are then classified as G1, G1 + G2, and G1 + G2 + G3, respectively. See **Figure 3.B.3** for a probabilistic analysis example.

Technical Feasibility

Annex 1 in the UNFC overview[118] summarises definitions and supporting explanations of UNFC F categories and sub-categories, highlighting the criteria to consider when assessing a project's technical feasibility. The F4 category is specifically provided for situations where

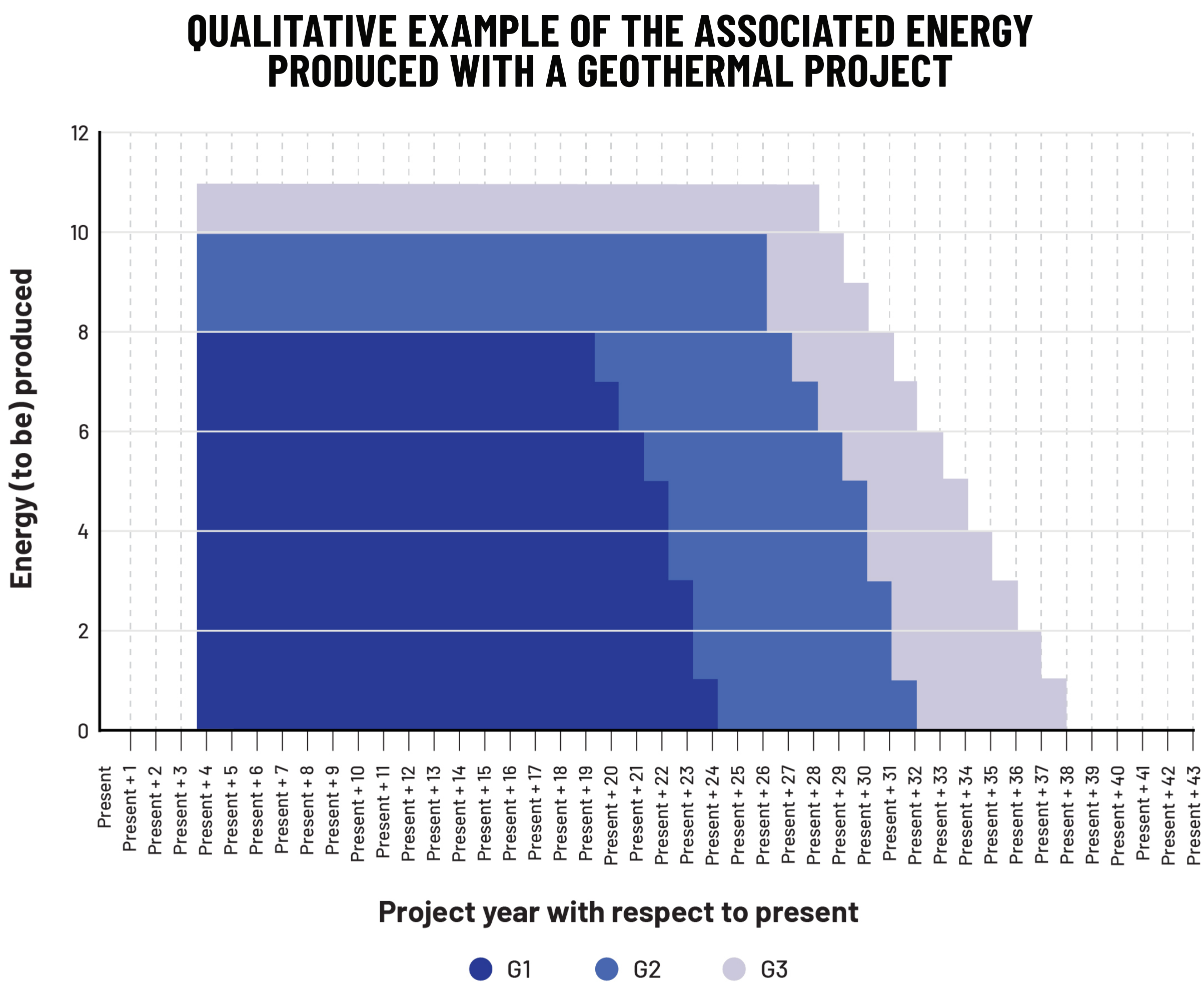


Figure 3.B.2: Qualitative example of the associated with a geothermal energy project. G1 = high confidence in the estimated quantities of a resource; G3 = lower confidence in the estimated quantities of a resource. Source: adapted from various training materials jointly produced by the United Nations Economic Commission for Europe and International Geothermal Association group of expert volunteers developing the United Nations Framework of Classifications for geothermal.

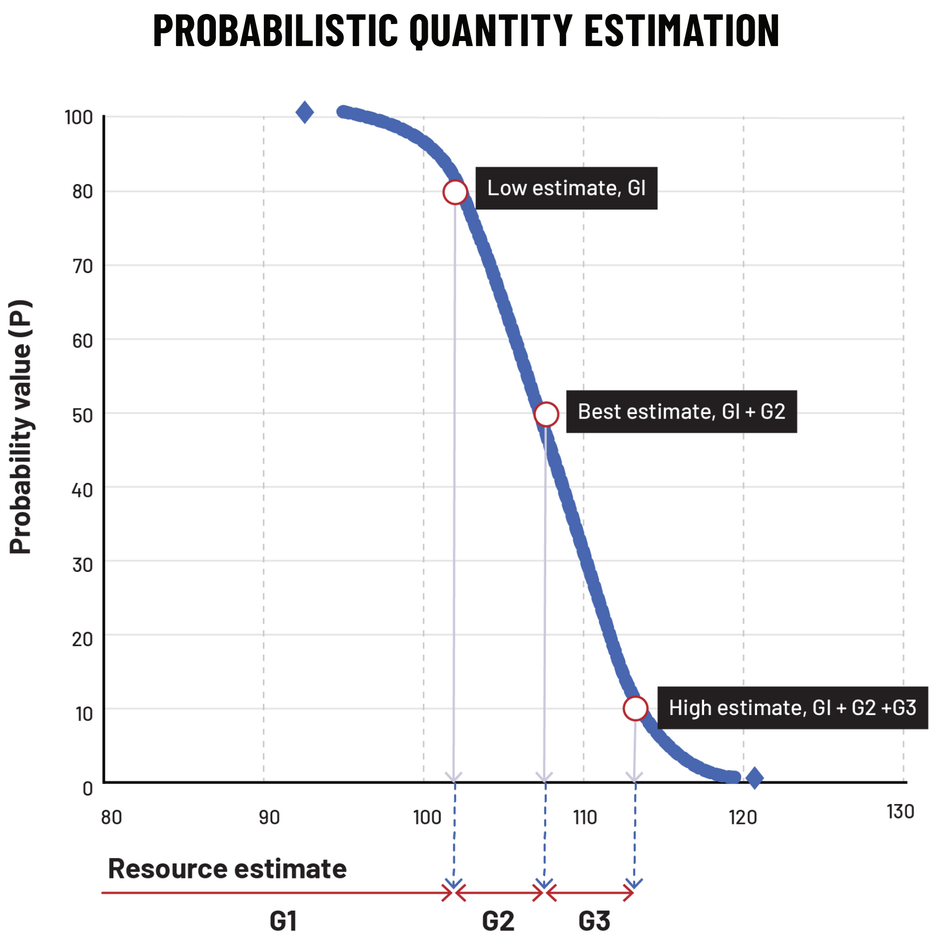


Figure 3.B.3: Example of probabilistic quantity estimation with corresponding G1, G1+G2, and G1+G2+G3 range of uncertainty. G1 = high confidence in the estimated quantities of a resource; G3 = lower confidence in the estimated quantities of a resource. Source: adapted from various training materials jointly produced by the United Nations Economic Commission for Europe and International Geothermal Association group of expert volunteers developing the *United Nations Framework Classifications for Resources* for geothermal.

a notional project is defined based on technology that is yet to be demonstrated as technically feasible. The F4 sub-category definitions then enable the identification of the current status of the development of the technology. This is in recognition of the fact that there are different readiness levels of technology and that where pilot studies are yet to be conducted (or even when they have been conducted), the necessary technology may yet have to be demonstrated to be technically feasible for the given project. Some closed-loop advanced geothermal systems (AGS), for example, have not yet been demonstrated as viable at commercial scale, so they would fall under the F4 category.

Environmental-Socio-Economic Viability

Annex 1 in the UNFC overview summarises definitions and supporting explanations of UNFC E categories and sub-categories, highlighting a situation that often applies to renewable energy projects (such as when development is made viable through government subsidies).[119] If multiple E issues apply to a given project, the overall ranking is that of the lowest potential E category, which should be assigned to the ultimate project classification (as shown in the example in **Table 3.B.1**).

ASSIGNING PROJECT CLASSIFICATION

Issue/potential contingency	Level of engagement	Probability of approval	Potential E category
Legal	Relevant licences	Done	E1
Regulatory	Relevant permissions	Granted	E1
Market access	Local use	99%	E1
Land access	Local use	99%	E1
Social	No objections expected	90%	E1
Economic	Project screened economic	95%	E1
Political	No worries expected	99%	E1
External approvals/ commitments	Commitments made	100%	E1
Environmental	Licence approval in process. Issue with the black rimmed beetle frog habitat.	50%	E2
Timing (<5 years or >5 years)	<5 years	Uncertain (see Environmental)	E2
Total = lowest ranking issue			**E2**

Table 3.B.1: Assigning project classification when there are multiple E issues. Source: United Nations Economic Commission for Europe. (2021). *Guidance for social and environmental considerations for the United Nations Framework Classification for Resources*. Prepared by the Social and Environmental Considerations Working Group of the Expert Group on Resource Management. Committee on Sustainable Energy, Twelfth Session, Geneva Annex II. See Table 1 on page 11.

CHAPTER REFERENCES

1 Goffey, G., & Gluyas, J. G. (Eds.). (2020). *United Kingdom oil and gas fields: 50th anniversary commemorative volume* (Geological Society Memoir No. 52). Geological Society of London. https://doi.org/10.1144/M52

2 Fellgett, M., & Monaghan, A. A. (2024). *User guide: BGS UK geothermal catalogue first digital release, legacy data* (British Geological Survey Open Report OR/23/060). British Geological Survey.

3 Rollin, K. E. (1995). A simple heat-flow quality function and appraisal of heat-flow measurements and heat-flow estimates from the UK Geothermal Catalogue. *Tectonophysics, 244*(1–3), 185–196. https://doi.org/10.1016/0040-1951(94)00227-Z

4 Department for the Economy. (n.d.). *Geothermal* [Data sets]. Geological Survey of Northern Ireland. https://gsni-data.bgs.ac.uk/geonetwork/dcf9834d-9499-446f-adcd-a88ef29f81a0/eng/catalog.search#/home

5 Department for the Economy. (n.d.). *GSNI data catalogue*. Geological Survey of Northern Ireland. https://gsni-data.bgs.ac.uk

6 OpenDataNI. (n.d.). *Department for the Economy datasets* [Data sets]. https://www.opendatani.gov.uk/search?fq=organization:department-for-the-economy

7 Farndale, H., & Law, R. (2022). An update on the United Downs Geothermal Power Project, Cornwall, UK. In *Proceedings of the 47th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.

8 Allen, D., Brewerton, L., Coleby, L., Gibbs, B., Lewis, M., MacDonald, A., Wagstaff, S., & Williams, A. (1997). *The physical properties of major aquifers in England and Wales*. British Geological Survey.

9 Downing, R. A. (1993). Groundwater resources, their development and management in the UK: An historical perspective. *Quarterly Journal of Engineering Geology, 26*(4),335–58. http://dx.doi.org/10.1144/GSL.QJEGH.1993.026.004.09

10 Allen et al., 1997.

11 Allen et al., 1997.

12 Ó Dochartaigh, B. E., MacDondald, A. M., Fitzsimons, V., & Ward, R. (2015). *Scotland's aquifers and groundwater bodies*. British Geological Survey & Scottish Environmental Protection Agency. https://nora.nerc.ac.uk/511413/1/OR15028.pdf

13 Law, R., Nicholson, D., & Mayo, K. (2007). Aquifer thermal energy storage in the fractured London Chalk: A thermal injection/withdrawal test and its interpretation. In *Proceedings of the 32nd Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.

14 Jackson, M. D., Regnier, G., & Staffell, I. (2024). Aquifer thermal energy storage for low carbon heating and cooling in the United Kingdom: Current status and future prospects. *Applied Energy, 376*, 124096. https://doi.org/10.1016/j.apenergy.2024.124096

15 Arthur, S., Streetly, H. R., Valley, S., Streetly, M. J., & Herbert, A. W. (2010). Modelling large ground source cooling systems in the Chalk aquifer of central London. *Quarterly Journal of Engineering Geology and Hydrogeology, 43*(3), 289–306. https://doi.org/10.1144/1470-9236/09-039

16 Gropius, M. (2010). Numerical groundwater flow and heat transport modelling of open-loop ground source heat systems in the London Chalk. *Quarterly Journal of Engineering Geology and Hydrogeology, 43*(1), 23–32. https://doi.org/10.1144/1470-9236/08-105

17 Ó Dochartaigh et al., 2015.

18 Bloemendal, M., & Hartog, N. (2018). Analysis of the impact of storage conditions on the thermal recovery efficiency of low-temperature ATES systems. *Geothermics, 71*,306–19. https://doi.org/10.1016/j.geothermics.2017.10.009

19 Sommer, W., Valstar, J., van Gaans, P., Grotenhuis, T., & Rijnaarts, H. (2013). The impact of aquifer heterogeneity on the performance of aquifer thermal energy storage. *Water Resources Research, 49*(12), 8128–38. http://dx.doi.org/10.1002/2013WR013677

20 Law et al., 2007.

21 Price, M. (1987). Fluid flow in the Chalk of England. *Geological Society of London Special Publications, 34*(1), 141–156. https://doi.org/10.1144/GSL.SP.1987.034.01.10

22 Bloomfield, J., Brewerton, L., & Allen, D. J. (1995). Regional trends in matrix porosity and dry density of the Chalk of England. *Quarterly Journal of Engineering Geology and Hydrogeology, 28*, S131–42. https://doi.org/10.1144/GSL.QJEGH.1995.028.S2.04
23 Butler, A. P., Mathias, S. A., Gallagher, A. J., Peach, D. W., & Williams A. T. (2009). Analysis of flow processes in fractured chalk under pumped and ambient conditions (UK). *Hydrogeology Journal, 17*, 1849–58. https://doi.org/10.1007/s10040-009-0477-4
24 Arthur et al., 2010.
25 Medici, G., West, L. J., Mountney, N. P. (2019). Sedimentary flow heterogeneities in the Triassic UK Sherwood Sandstone Group: insights for hydrocarbon exploration. *Geological Journal*, 54(3), 1361–78. http://dx.doi.org/10.1002/gj.3233
26 Allen et al., 1997.
27 Hirst, C. M., Gluyas, J. G., & Mathias, S. M. (2015). The late field life of the Midlands Petroleum Province; A new geothermal prospect? *Quarterly Journal of Engineering Geology and Hydrogeology, 48*(1), 104–114. https://doi.org/10.1144/qjegh2014-072
28 Hirst, C. M., & Gluyas, J. G. (2015). The geothermal potential held within Carboniferous sediments of the East Midlands: A new estimation based on oilfield data. In *Proceedings of the World Geothermal Congress 2015*. Melbourne, Australia.
29 Narayan, N. S., Adams, C. A., & Gluyas, J. G. (2021). Karstified and fractured Lower Carboniferous (Mississippian) limestones of the UK: A cryptic geothermal reservoir. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften (Journal of Applied Regional Geology), 172*(3), 251–265.
30 Gluyas, J., De-Paola, N., Imber, J., Jezierski, T., Jones, R., Jordan, P., McCaffrey, K., Nielsen, S., Pongthunya, P., Satterley, A., Sowter, A., Wilkinson, M., & Moors, A. (2020). The Humbly Grove, Herriard and Hester's Copse fields, UK onshore. In G. Goffey & J. G. Gluyas (Eds.), *United Kingdom oil and gas fields: 50th anniversary commemorative volume*. Geological Society of London. https://doi.org/10.1144/M52-2018-78
31 Aditama, M., Huuse, M., Healy, D., Jones, D., & Hollis, C. (2025). Growth, demise and platform to basin transition, of Mississippian carbonate platform in the Southern Irish Sea Basin, UK: Insights from seismic data [Manuscript submitted for publication]. *Basin Research*.
32 Aditama, M., Hollis, C., Huuse, M., & Healy, D. (2025). Multi-scale fault and fracture networks of the UK's Mississippian carbonate platforms (MCP): Implications for extracting geothermal energy [Manuscript submitted for publication]. *Geothermics*.
33 Aditama, M. R. (2025). *Multiscale analysis of Mississippian carbonate platforms in the Irish Sea and adjacent areas* [Unpublished doctoral dissertation]. University of Manchester.
34 Hirst, C. M., Gluyas, J. G., Adams, C. A., Mathias, S. A., Bains, S., & Styles, P. (2015). UK low enthalpy geothermal resources: The Cheshire Basin. In *Proceedings World Geothermal Congress 2015*. Melbourne, Australia. https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2015/16067.pdf
35 Johnstone, D. J. (2024). *A subsurface geological model to assess geothermal energy and hydrogen storage potential in North West England* [Doctoral thesis]. University of Manchester. https://pure.manchester.ac.uk/ws/portalfiles/portal/1424700273/FULL_TEXT.PDF
36 University of York. (n.d.). *Deep geothermal energy project*. https://www.york.ac.uk/about/sustainability/campus-operations/climate-action/geothermal-energy/. This project secured £35 million in funding from the Public Sector Decarbonisation Scheme to support exploration, drilling capability to ~5 kilometres depth, seismic surveys, and supply of geothermal heat to university buildings.
37 Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *Evidence report supporting the deep geothermal energy white paper:* The case for deep geothermal energy—unlocking investment at scale in the UK. British Geological Survey. https://nora.nerc.ac.uk/id/eprint/535567/
38 Ireland, M. T., Brown, R., Wilson, M. P., Stretesky, P. B., Kingdon, A., & Davies, R. J. (2021). Suitability of legacy subsurface data for nascent geoenergy activities onshore United Kingdom. *Frontiers in Earth Science, 9*, 629960. https://doi.org/10.3389/feart.2021.629960

39 Doran, H., & Matt, V. (2025). *Global lithosphere thermal model*. Project InnerSpace.

40 Mijnlieff, H. F., Obdam, A. N. M., van Wees, J. D. A. M., Pluymaekers, M. P. D., & Veldkamp, J.G. (2014). *DoubletCalc 1.4 manual: English version for DoubletCalc 1.4.3*. TNO. https://www.nlog.nl/sites/default/files/6ab98fc3-1ca1-4bbe-b0a2-c5a9658a3597_doubletcalc%20v143%20manual.pdf

41 Ireland, M., Doran, H. & Falcone, G. (2025). *Geothermal energy potential of the Triassic Sandstone Reservoirs in the Wessex Basin* [Manuscript in preparation].

42 Office for National Statistics. (2023). *Built-up areas (December 2011); Boundaries EW BGG (V2)* [Data set]. Government of the United Kingdom. https://geoportal.statistics.gov.uk/datasets/0249dcf56c7d41e5a82bcd89cc37668f_0/explore

43 Energie-Cites. (2001). *Geothermal energy district heating scheme: Southampton (United Kingdom)*. https://geocom.geonardo.com/assets/elearning/5.13.SOUTH_EN.PDF

44 Department for Energy Security and Net Zero. (2025). *DESNZ: Heat networks planning database*. Government of the United Kingdom. https://www.data.gov.uk/dataset/065d267f-23bc-4d0e-9a56-52d388d5835c/Department for Energy Security and Net Zero-heat-networks-planning-database

45 Office of Gas and Electricity Markets (Ofgem). (2025). *State of the market report: Energy retail markets highlights*. Government of the United Kingdom. https://www.ofgem.gov.uk/sites/default/files/2025-04/OFG2296_State%20of%20the%20Market%20Report.pdf. Typical domestic consumer values: electricity = 2,700 kWh/year; gas = 11,500 kWh/year.

46 Department for Energy Security and Net Zero. (2025). *Greenhouse gas reporting: conversion factors 2025*. Government of the United Kingdom.https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2025

47 Conti, P., & Falcone, G. (2019). Regional and country-level assessments of geothermal energy potential based on UNFC principles. In *European Geothermal Congress 2019*. The Hague, The Netherlands. https://eprints.gla.ac.uk/190955/

48 Limberger, J., Boxem, T., Pluymaekers, M., Bruhn, D., Manzella, A. Calcagno, P., Beekman, F., Cloetingh, S., & van Wees, J. D. (2018). Geothermal energy in deep aquifers: A global assessment of the resource base for direct heat utilization. *Renewable and Sustainable Energy Reviews, 82*, 961–975.

49 Scottish Government. (2024). *Scotland heat map: Information*. https://www.gov.scot/publications/scotland-heat-map-documents/pages/scotland-heat-map-interactive-website

50 Rollin, 1995.

51 Jones, D. J. R., Randles, T., Kearsey, T., Pharaoh, T. C., & Newell, A. (2023). Deep geothermal resource assessment of early Carboniferous limestones for Central and Southern Great Britain. *Geothermics, 109*, 102649. https://doi.org/10.1016/j.geothermics.2023.102649

52 Raine, R. J., & Reay, D. M. (2021). *Geothermal energy potential in Northern Ireland: Summary and recommendations for the Geothermal Advisory Committee* (GSNI Technical Report 2021/EM/01). Geological Survey of Northern Ireland. https://nora.nerc.ac.uk/id/eprint/531393/33/GSNI-%20NI%20Geothermal%20Energy%20Summary%20for%20GAC%202021_report.pdf

53 Fellgett & Monaghan, 2024.

54 Ireland et al., 2021.

55 Jones et al., 2023.

56 British Geological Survey. (n.d.). *Regional geological visualisation models*. National Geological Model Project. https://www.bgs.ac.uk/geology-projects/geology-3d/regional-geological-visualisation-models/

57 British Geological Survey. (n.d.). *Aquifers and shales data* [Data download page]. https://www2.bgs.ac.uk/groundwater/shaleGas/aquifersAndShales/data.html

58 Micenko, M. (2016). *Seismic window: The age of multi-client seismic*. CSIRO Australia.

59 Ireland, M., Dunham, C., & Gluyas, J. (2023, September 4). Seismic for geothermal. *Geoscientist*. https://geoscientist.online/sections/unearthed/seismic-for-geothermal/

60 Beamish, D., & Busby, J. (2016). The Cornubian geothermal province: Heat production and flow in SW England: Estimates from boreholes and airborne gamma-ray measurements. *Geothermal Energy, 4*, 4. https://doi.org/10.1186/s40517-016-0046-8

61 Turan, A., Brown, C. S., Shail, R., & Sass, I. (2024). Probabilistic assessment of deep geothermal resources in the Cornubian Batholith and their development in Cornwall and Devon, United Kingdom. *Geothermics, 122*, 103081. https://doi.org/10.1016/j.geothermics.2024.103081

62 Martin, V. (2025). Chapter 5: Electricity. In *Digest of UK Energy Statistics (DUKES) 2025*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/688a28656478525675739051/DUKES_2025_Chapter_5.pdf. Winter peak demand in Great Britain was reported as 47.4 gigawatts.

63 Manning, D. A. C., Younger, P. L., Smith, F. W., Jones, J. M., Dufton, D. J., & Diskin, S. (2007). A deep geothermal exploration well at Eastgate, Weardale, UK: A novel exploration concept for low-enthalpy resources. *Journal of the Geological Society, 164*(2), 371–382. https://doi.org/10.1144/0016-76492006-015

64 Younger, P. L., & Manning, D. A. C. (2010). Hyper-permeable granite: Lessons from test-pumping in the Eastgate Geothermal Borehole, Weardale, UK. *Quarterly Journal of Engineering Geology and Hydrogeology, 43*(1), 5–10. https://doi.org/10.1144/1470-9236/08-085

65 Raine & Reay, 2021.

66 Olver, T., & Law, R. (2025). The United Downs Geothermal Power Plant, Cornwall, UK: Combining the generation of geothermal electricity and heat, with the extraction of critical raw materials. In *Proceedings of the 50th Workshop on Geothermal Reservoir Engineering (SGP-TR-229)*. Stanford, CA, United States. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2025/Olver.pdf

67 Beamish & Busby, 2016.

68 Olver & Law, 2025.

69 Abesser et al., 2023.
70 Olver & Law, 2025.
71 Olver & Law, 2025.
72 Olver & Law, 2025.
73 Farndale, H., & Law, R. (2023). The effects of soft stimulation on reservoir growth and injectivity at the United Downs Geothermal Project, Cornwall. In *Proceedings, 48th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States.
74 Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *The case for deep geothermal energy—unlocking investment at scale in the UK*. North East Local Enterprise Partnership and BGS.
75 Evans, A. J. M., Farrell, N. J. C., Neave, D. A., Hartley, M. E., Healy, D. Waters, J. P., McElhinney, T. R., Shea, J. J., Bigaroni, N., & Hunt, S. A. (2025). Fracture analysis of the lithium-bearing Cligga Head granite: Impacts on critical mineral mobilisation and fluid flow. *Journal of Structural Geology, 201*, 105510. https://www.sciencedirect.com/science/article/pii/S0191814125001853
76 Olver & Law, 2025.
77 Olver & Law, 2025.
78 Olver & Law, 2025.
79 Department for Energy Security and Net Zero. (2025). *UK geothermal energy review and cost estimations*. Government of the United Kingdom. https://www.gov.uk/government/publications/uk-geothermal-energy-review-and-cost-estimations. Table 28 shows first-of-a-kind (FOAK) drilling costs of £7.8 million at 4 kilometres and £9.5 million at 5 kilometres (~£15.6 million–£19.0 million per well pair).
80 El-Sadi, K., Gierke, B., Howard, E., & Gradl, C. (2024). Review of drilling performance in a horizontal EGS development. In *Proceedings of the 49th Workshop on Geothermal Reservoir Engineering* (SGP-TR-227). Stanford, CA, United States. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2024/Elsadi.pdf
81 The Driller Staff. (2025, June 10). *Fervo Energy pushes geothermal to new depths*. The Driller. https://www.thedriller.com/articles/93475-fervo-energy-pushes-geothermal-to-new-depths
82 Richter, A. (2025, June 10). *Fervo Energy further demonstrates EGS scalability with Cape Station appraisal well*. ThinkGeoEnergy. https://www.thinkgeoenergy.com/fervo-drills-15000ft-500f-egs-appraisal-well-in-utah/.
83 Williams, C. F., Reed, M. J., & Anderson, A. F. (2011). Updating the classification of geothermal resources. In *Proceedings, 36th Workshop on Geothermal Resource Engineering*. Stanford, CA, United States. https://www.energy.gov/sites/prod/files/2014/02/f7/updating_classification_geothermal_resources_paper.pdf
84 Olver & Law, 2025.
85 Pocasangre, C., & Fujimitsu, Y. (2018). A Python-based stochastic library for assessing geothermal power potential using the volumetric method in a liquid-dominated reservoir. *Geothermics, 76*, 164–176.
86 Rollin, K. E., Kirby, G. A., Rowley, W. J., & Buckley, D. K. (1995). *Atlas of geothermal resources in Europe: UK revision*. British Geological Survey. https://webapps.bgs.ac.uk/data/publications/publication.html?id=21735106
87 Hurter, S., & Haenel, R. (Eds.). (2002). *Atlas of geothermal resources in Europe*. European Commission. https://op.europa.eu/en/publication-detail/-/publication/9003d463-03ed-4b0e-87e8-61325a2d4456
88 Rollin et al., 1995.
89 Hurter & Haenel, 2002.
90 Rollin et al., 1995.
91 Hurter & Haenel, 2002.
92 Raine, R., Reay, D., Wilson, P., & Millar, R. (2020). *The Sherwood Sandstone Group as a potential geothermal aquifer across Northern Ireland* [Poster presentation]. Irish Geological Research Meeting (IGRM) 2020. https://nora.nerc.ac.uk/id/eprint/530783/
93 van den Hoogen, J., Lembrechts, J., SoilTemp, Nijs, I., & Lenoir, J. (2021). *Global Soil Bioclimatic variables at 30 arc second resolution* (Version 1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4558732

94 Patton, A. (2024). *The geothermal resource of Permo-Triassic basins in the UK*. British Geological Survey. https://nora.nerc.ac.uk/id/eprint/538809/1/Permo_trias%20factsheet.pdf
95 ZetaWare. (n.d.). *Genesis feature examples*. https://zetaware.com/products/genesis/features.html
96 English, K. L., English, J. M., Moscardini, R., Haughton, P. D. W., Raine, R. J., & Cooper, M. (2024). Review of Triassic Sherwood Sandstone Group reservoirs of Ireland and Great Britain and their future role in geoenergy applications. *Geoenergy, 2*(1). https://doi.org/10.1144/geoenergy2023-042. See Table 3 and Figure 13, as well as the references.
97 English et al., 2024.
98 ZetaWare. (n.d.). *ZetaWare*. https://zetaware.com/
99 Mijnlieff et al., 2014.
100 Busby, J., & Terrington, R. (2017). Assessment of the resource base for engineered geothermal systems in Great Britain. *Geothermal Energy*, 5, 7. https://doi.org/10.1186/s40517-017-0066-z
101 Limberger et al., 2018.
102 Babaei, M., & Nick, H. M. (2019). Performance of low-enthalpy geothermal systems: Interplay of spatially correlated heterogeneity and well-doublet spacings. *Applied Energy*, 253, 113569. https://doi.org/10.1016/j.apenergy.2019.113569
103 Harrison, B., Oueidat, T., & Falcone, G. (2019). Selecting an appropriate unconventional play analog for the *Bowland Shale While acknowledging operational constraints in the UK*. AAPG Annual Convention and Exhibition, San Antonio, TX, United States.
104 Taylor, C., Lewis, D., & Byles, D. (2013). *Infrastructure for business: Getting shale gas working*. Institute of Directors.
105 Clancy, S. A., Worrall, F., Davies, R. J., & Gluyas, J. G. (2018). An assessment of the footprint and carrying capacity of oil and gas well sites: The implications for limiting hydrocarbon reserves. *Science of the Total Environment, 618*, 586–594. https://doi.org/10.1016/j.scitotenv.2017.02.160
106 Falcone, G., Beardsmore, G., Conti, P., Kastl, S., Mijnlieff, H., Nádor, A., Ussher, G., Brommer, M., Griffiths, C., & Tulsidas, H. (2025). 8 years on: Incremental impact of worldwide implementation of the United Nations Framework Classification for Geothermal Energy Resources. In *Proceedings, 50th Stanford Geothermal Workshop*. Stanford, CA, United States.
107 Falcone, G., Antics, M., Baria, R., Bayrante, L., Conti, P., Grant, M., Hogarth, R., Juliusson, E., Mijnlieff, H., Nádor, A., Ussher, G., & Young, K. (with Beardsmore, G., & Rueter, H. as observers). (2017). *Application of the United Nations Framework Classification for Resources (UNFC) to geothermal energy resources: Selected case studies*. Economic Commission for Europe (ECE).
108 Mijnlieff, H., van Kempen, B., Tolsma, S., de Vries, C., Esteves Martins, J., Veldkamp, H., Struijk, M., & Vrijlandt, M. (2019). *Dutch geothermal resource reporting: A first attempt of Dutch nationwide geothermal resource using the UNFC Resource Classification System*. European Geothermal Congress, The Hague, Netherlands.
109 Mijnlieff, H., van Kempen, B., Tolsma, S., de Vries, C., Esteves Martins, J., Veldkamp, H., Struijk, M., Vrijlandt, M., & van Wees, J.-D. (2021). The Dutch geothermal resource base: Classified using UNFC Resource Classification System and its potential to meet the Dutch geothermal ambition. In *Proceedings World Geothermal Conference 2020+1*. Reykjavik, Iceland. https://www.worldgeothermal.org/pdf/IGAstandard/WGC/2020//16062.pdf
110 Mijnlieff et al., 2014.
111 United Nations Economic Commission for Europe. (2020). *United Nations Framework Classification for Resources*. https://unece.org/sites/default/files/2023-10/UNFC_ES61_Update_2019.pdf
112 United Nations Framework Classification for Resources Ad Hoc Committee of the International Geothermal Association. (2022). *Supplementary specifications for the application of the United Nations Framework Classification for Resources (Update 2019) to geothermal energy resources*. United Nations. https://unece.org/sites/default/files/2022-12/UNFC_Geothermal_Specs_25October2022.pdf. See page 7.

113 Yaghoubi, A., Schultz, R., Hickson, C., Wigston, A., & Dusseault, M. B. (2024). Induced seismicity traffic light protocol at the Alberta No. 1 geothermal project site. *Geothermics, 117*, 102860. https://doi.org/10.1016/j.geothermics.2023.102860
114 Ussher, G., Calibugan, A., & McDowell. J. (2024). Probability of discovery as a useful concept for communicating exploration drilling uncertainty. *GRC Transactions, 48*, 706–714.
115 United Nations Framework Classification for Resources Ad Hoc Committee of the International Geothermal Association, 2022, p. 13.
116 United Nations Economic Commission for Europe, 2020.
117 United Nations Framework Classification for Resources Ad Hoc Committee of the International Geothermal Association, 2022. See pages 20 and 21.
118 United Nations Framework Classification for Resources Ad Hoc Committee of the International Geothermal Association, 2022. See page 19.
119 United Nations Framework Classification for Resources Ad Hoc Committee of the International Geothermal Association, 2022. See pages 16 and 17.