The Future of Geothermal in the UK

AFFORDABLE, RENEWABLE, AND LOCALLY PRODUCED ENERGY FOR A RESILIENT FUTURE

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Affordable, Renewable, and Locally Produced Energy for a Resilient Future

Edited by:

Smita Satiani

Drew Nelson

Contents

Lead Authors

(alphabetical order)

Dr. Charlotte Adams serves as CEO of the National Geothermal Centre. Her interest in geothermal was sparked while undertaking her PhD when she realised the geothermal potential of disused mines. She has been active across the sector for more than 20 years and was instrumental in the delivery of the UK's largest geothermal heat scheme at Gateshead. Adams has worked in consultancy, academia, and the public sector managing commercial contracts and R&D and geothermal drilling programmes. Her work has been featured on *Countryfile*, *The One Show*, *ITV Tonight*, and *Channel 4 News*. She has received awards from the Geological Society and the Energy Institute for her work on geothermal.

Puja Balachander is an investor and founder accelerating the just transition. She is currently a principal at Ocean14 Capital, where she invests in and supports growth-stage companies in the blue economy. Alongside her investing role, Balachander is the co-founder of UpGreen, a climate technology company developing solutions to decarbonise the UK real estate through retrofit implementation and finance. Before this role, she was director of venture at Carbon13, where she supported early-stage founders in building and scaling ventures that drive deep decarbonisation across industries. Earlier in her career, Balachander co-founded Devie, a venture-backed direct-to-consumer health tech start-up, and she worked in civic innovation within the City of Austin (Texas), the White House Presidential Innovation Fellows, and the World Bank in Madagascar. She has an MBA from the University of Oxford and a BA in international studies from American University.

David Banks has worked in the field of ground source heating and cooling (GSHC) since before the turn of the century. He has been involved in the feasibility study, testing, and design of numerous shallow geothermal systems as a consultant; offered GSHC training to geologists and engineers; and researched shallow and deep geothermal as an academic. Banks has a background in hydrogeology and environmental geochemistry, with a particular interest in minewaters, and he has been instrumental in founding the discipline of thermogeology (as an analogue to hydrogeology). He is the author of the textbook *An Introduction to Thermogeology: Ground Source Heating and Cooling*, published by Wiley. Banks currently works as a senior research fellow at Glasgow University and as a principal hydrogeologist at Envireau Water. He is also "on call" to the humanitarian relief organisations Groundwater Relief and Norwegian Church Aid.

Michael Chendorain leads Arup's global groundwater and geothermal engineering practice and is a contaminated land expert with more than 28 years of experience. Chendorain spent the first 15 years of his career in California and the next nine years in London. After nearly five years in Singapore, he is back in London. Chendorain has worked on a wide range of geothermal engineering projects (both shallow and deep) in Europe, Asia, the Americas, India, and Africa.

John Clegg has worked in engineering and operations roles with upstream technologies for well construction since the mid-1980s. He holds a master's degree in engineering science and a master's diploma in global business, both from Oxford University. Clegg is president and chief technology officer of Hephae Energy Technology, which focuses on developing technology and solutions for drilling high-temperature wells, and he also previously served as an adviser for Project InnerSpace.

Rachael Coffey is a senior managing associate at Sidley Austin LLP. She advises on a broad range of issues in banking law, with a particular focus on the infrastructure sector, acting for both UK and international infrastructure funds, lenders, and noteholders across the full range of infrastructure financing products, including syndicated loans, multi-creditor platforms, and private placements in the European and U.S. markets. Coffey has also advised private equity sponsors, banks, and direct lenders on project finance and general acquisition finance transactions in Australia, including a secondment with a global financial services group.

Lucy Cotton is a principal geologist at Eden Geothermal. Previously a senior geologist and geothermal group manager at Geoscience Ltd, Cotton has unrivalled geological experience while drilling deep geothermal wells in the United Kingdom. She was the lead site geologist during the drilling of the Eden Geothermal well at Eden Project and both wells at the United Downs Deep Geothermal Project. She has spent the past three years focusing on the decarbonisation of heat for UK industries, carrying out feasibility studies for multi-national corporations such as distilleries, pharmaceutical companies, and large food manufacturers and dairies. Alongside her technical role, she has developed great skill in communicating groundbreaking technologies to all ages in the renewable sector, including by designing and delivering the education programme for the United Downs Deep Geothermal Power project, creating the *Miss Molecule and Friends* animated series, and presenting the film *Power to the People* by Cornwall Climate Care.

Dr. Helen Doran is the lead geologist at Project InnerSpace, where she is responsible for delivering Phase I of the Global Mapping Project. This phase comprises seven fully funded research grants designed to enhance the quality, resolution, and metadata of key subsurface data sets. Together, these data sets underpin the creation of GeoMap™, a comprehensive global geothermal subsurface map intended to accelerate geothermal exploration worldwide. With 25 years of experience, Doran is a specialist in heat flow modelling in sedimentary basins. Her career began in the oil and gas sector before she moved into geothermal. Within Project InnerSpace, Doran is responsible for the global borehole temperature data set, the management and integration of external data sets, and the development of models and maps that form the project's core geothermal analytics. These outputs support resource screening, favourability assessment, and exploration strategy across multiple geothermal settings.

Gioia Falcone holds the Rankine Chair of Energy Engineering at the University of Glasgow, where she is the director of the Glasgow Centre for Sustainable Energy, associate director of the Centre for Sustainable Solutions, and deputy head of the Energy and Sustainability Research Group. Prior to entering academia, she gained industrial experience with several of the major multi-national energy companies. Falcone is vice-chairperson of the Bureau of the Expert Group on Resource Management of the United Nations Economic Commission for Europe, co-chair of its Renewables Working Group, and chair of its Geothermal Sub-Group.

Dr. Michael Feliks has 20 years of experience in low-carbon and deep geothermal energy. Working since 2008 in the then–newly created Department of Climate Change, he played a key role in the genesis of low-carbon heat policy in the United Kingdom, liaising with the Renewable Energy Association (REA) during the development of the flagship Renewable Heat Incentive. He later led on deep geothermal policy, overseeing two rounds of the Deep Geothermal Challenge Fund. In 2011, he left the civil service to join a deep geothermal start-up company, Cluff (later Hotspur) Geothermal, where he worked on a range of geothermal projects in the United Kingdom, Africa, and Indonesia while also chairing REA's Deep Geothermal sub-group. Since 2020, Feliks has been a freelance consultant working on deep geothermal and low carbon energy issues, including for REA.

Jon Gluyas is a geologist with experience in industry and academia. He works on fluid rock interaction, initially on petroleum systems and now on geothermal energy, carbon geostorage, natural hydrogen, and helium exploration together with environmental impacts, including human-induced seismicity. He holds the Orsted/Ikon Chair in Geoenergy, Carbon Capture, and Storage at Durham University and is the president of the Geological Society. Previously at Durham, Gluyas was the executive director of the Durham Energy Institute, dean of knowledge exchange, and head of the Department of Earth Sciences. In 2024, he founded the UK National Geothermal Centre, and in 2011–12, he served as chair of the Development Board for the UK Carbon Capture and Storage Research Community. Gluyas has also been chair of the British Geological Survey and president of both the Petroleum (now Geoenergy) Exploration Society of Great Britain and the Earth Science Teachers Association. In 2001, he founded his first energy company, and he has gone on to be the founder of 14 more companies in energy and Earth observation, including Snowfox Discovery, a hydrogen exploration company, in 2023. Gluyas has published five books and more than 200 peer reviewed papers.

Augusta Grand is the CEO of Eden Geothermal and has led Eden Geothermal through funding, procurement, drilling, and construction and into operation. In 2023, Eden Geothermal became the first deep geothermal project to come online in the UK since 1986. Grand now leads an enhanced team to help other organisations do the same. Before taking on leadership of Eden Geothermal in 2019, Grand was the head of policy at Eden Project, developing Eden's sustainability and science programme. An expert in communication of sustainability issues, she joined Eden Project at its opening in 2001 and worked on policy, public education, and science communication projects across a range of subjects, including energy, climate, carbon, transport, biodiversity mining, and horticulture. She is a winner of Project InnerSpace's PIVOT 2023 Five on Fire international awards as one of the geothermal catalysts of the year.

Mark Griffiths is a chartered hydrogeologist and associate at Arup with 15 years of experience advancing geothermal development and sustainable water management. After leading major hydrogeological and sustainability initiatives across industry and consultancy, he now supports the growth of geothermal energy at Arup. Griffiths specialises in resource assessment, subsurface characterisation, and the integration of geothermal solutions into complex infrastructure projects, helping clients deliver low-carbon, resilient energy systems.

David Horan leads Sidley Austin LLP's London real estate team. He has a broad range of experience in advising clients about acquiring, disposing of, developing, financing, and managing a wide variety of real estate assets, including offices, residential (in particular student accommodation, later living, and co-living), industrial, life sciences, and other mixed-use schemes. Horan works closely with Sidley Austin's private equity, energy and infrastructure, and finance practices on transactions with a strong real estate focus. He has a particular interest in the energy sector and has previously advised clients such as Anesco in relation to its solar farm developments and Related Argent in relation to district heating networks.

Dr. Mark Ireland is a senior lecturer at Newcastle University in the United Kingdom and also the associate director for research and innovation in Newcastle's School of Natural and Environmental Sciences. A geologist by training, Ireland holds a PhD from Durham University and an MESci in exploration and resource geology from Cardiff University. He began his career with bp, where he spent nine years in technical roles within their upstream operations. His current research focuses on the decarbonisation of energy systems, particularly the application of geosciences to low-carbon technologies and the use of seismic methods. Ireland leads collaborative geoscience projects across academia and industry, with a diverse portfolio encompassing geothermal energy, energy storage, carbon capture and storage, and ground engineering. He is also chair of the Energy Group of the Geological Society of London.

Matthew D. Jackson is a professor in geological fluid mechanics in the Department of Earth Science and Engineering at Imperial College London. His research is broadly focussed on subsurface fluid flow across a wide range of applications, including geothermal energy and underground thermal energy storage. He currently leads two major consortium projects (ATESHAC and SMARTRES) that aim to grow the deployment of geothermal and energy storage in the United Kingdom, tackling technical, economic, and societal barriers to widespread uptake. He leads the UK contribution to a large European Union project (FindHEAT) focussed on geothermal energy exploration. He has published more than 130 scientific papers and received the 2022 Alfred Wegener Award from the European Association of Geoscientists and Engineers. Jackson holds a bachelor's degree in physics from Imperial College London and a doctorate in geological fluid mechanics from the University of Liverpool.

Peter Ledingham has worked in geothermal research and industry for 45 years and brings a wealth of experience to a wide variety of geothermal applications and resource types. He has worked on heat and power projects in the United Kingdom, Europe, the United States, and the Asia-Pacific region as part of project teams, providing advice to operators, regulators, and investors and carrying out due diligence, project evaluations, and feasibility studies. From 1999 to 2001, Ledingham was the geothermal technical coordinator for the European Commission, carrying out technical oversight of the Commission's funded demonstration projects, and he has been an expert evaluator of funding applications in the 5th, 6th, and 7th Framework Programmes and the Horizon 2020 programme. From the inception of the United Downs Deep Geothermal Power project until May 2020, Ledingham served as the project manager, responsible for all aspects of the Cornwall-based technical and engineering operations, public relations, community outreach, and education programmes. More recently, he has focused on the promotion of geothermal as a low-carbon alternative to fossil fuels for industrial and commercial heating applications.

Tim Lines is the chairman of geothermal operator Geothermal Wells UK Ltd, a subsidiary of a Texas-based company for which he is the CEO, and an adviser to Project InnerSpace. He is a former energy policy adviser to the European Commission's Central and Eastern European aid programme and led the drafting of district heat legislation and regulation for the Accession countries. Lines has worked in the energy sector for 40 years and served on the board of three oil and gas companies. He advises Project InnerSpace on finance and engineering and chairs the Deal Development and Deployment Council of the $165 million Geothermal Energy from Oil and Gas Demonstrated Engineering (GEODE) project on their behalf. Lines is a chartered engineer and a fellow of the Energy Institute and the Geological Society of London.

Iain Martin is a technology manager at the Net Zero Technology Centre (NZTC). A business-focused technical specialist with more than 25 years of experience across carbon capture, utilisation, and storage (CCUS); consultancy; and delivery of first-of-a-kind projects, Martin leads the CCUS road map at NZTC, where he is responsible for identifying and delivering key projects. Martin has delivered NZTC's innovation call for ideas process, resulting in more than 200 ideas, 20 approved projects, and more than £5 million in funding. He has also helped secure £3 million from the Department for Energy Security and Net Zero to deliver a first-of-a-kind direct air capture pilot plant. Martin holds an MSc in oil and gas innovation and an MSc in research in geophysics, and he is a certified Project Management Professional.

Ben Thompson is a partner at Sidley Austin LLC who advises on a broad range of issues in banking law. He has a particular focus on the energy and infrastructure sectors, structuring and documenting the debt, equity, and security arrangements involved in complex finance transactions for both UK and international infrastructure funds, lenders, and noteholders across the full range of energy and infrastructure financing products, including syndicated loans, multi-creditor platforms, and private placements in the European and U.S. markets. Thompson has also advised private equity sponsors, banks, and direct lenders on leveraged and general acquisition finance transactions in both London and New York, including spending more than 18 months on secondment to international financial institutions. He is recognized in the Legal 500 UK 2025 for Infrastructure: M&A and Acquisition Financing.

Jordan Weddepohl is a chartered senior geologist and a core member of Arup's Global Geothermal team. He brings extensive practical, technical, and commercial expertise across all stages of shallow and deep geothermal development, having contributed to more than 70 projects worldwide. Weddepohl was lead author of the 2025 *UK Geothermal Energy Review and Cost Estimations* report for the Department for Energy Security and Net Zero and received the 2024 Glossop Award for Outstanding Young Geologist.

Contributing Authors and Reviewers

(alphabetical order)

Cathy Hollis, University of Manchester

Sarah Mackintosh, Cleantech for UK

Frankie Mayo, Ember Energy

Anne Murrell, Geothermal UK

Tony Pink, Pink Granite Consulting

Iain Stewart, University of Plymouth

Sam Wilks, Energy Transitions Commission

Editors

Smita Satiani is the director of market development at Project InnerSpace and a policy adviser to climate technology start-ups. Previously, she spent more than six years at X (formerly GoogleX), Alphabet's Moonshot Factory, working across several deep tech climate and connectivity projects, from sustainable agriculture to circular economy to wildfire mitigation technologies. Before X, Satiani spent a decade funding and scaling social impact companies and projects as the deputy director of the White House's Presidential Innovation Fellows program, a fellow at the Clinton Foundation, and a program manager at Ashoka. From 2019 to 2025, she ran her own climate-friendly business, Alaya Tea, a loose-leaf tea company that sourced teas directly from Indian farmers pioneering regenerative farming at the base of the Himalayas. Her work has been featured at the MIT Media Lab and in Forbes.com, TechCrunch, the *Wall Street Journal*, and more.

Drew Nelson is the vice president of programs, policy, and strategy at Project InnerSpace. Prior to joining InnerSpace, Nelson served as a senior program officer at the Catena Foundation, where he oversaw the Climate and Clean Energy Program and managed a grant portfolio of more than $30 million. Prior to joining Catena, Nelson held a similar position at the Texas-based Cynthia and George Mitchell Foundation. Earlier in his career, Nelson spent seven years at the Environmental Defense Fund (EDF), where he undertook a variety of roles, including running EDF's international methane work. He began his career at the U.S. State Department, where he served as a lead negotiator on key issues at the Conference of the Parties.

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Comments and questions are welcome and should be addressed to:

Smita Satiani
Director of Market Development
Project InnerSpace
68 Harrison Ave., Suite 605
PMB 99590
Boston, Massachusetts 02111-1929 US

Email: reports@projectinnerspace.org

More information about Project InnerSpace is available at www.projectinnerspace.org.

Tables

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Definitions

Advanced geothermal system (AGS): Occasionally referred to as closed-loop geothermal systems, a geothermal technology (with many configurations) that allows the circulation of fluid in the subsurface without fluid leaving the wellbore. Fluid is pumped from the surface, picks up heat from the surrounding formation (primarily through conduction), and flows back to the surface, where the heat is harvested for direct-use or power applications. AGS can be deployed in various rock types, can use engineered fluids such as supercritical carbon dioxide (sCO_2) to improve efficiency, and is considered scalable.

Brittle-ductile transition zone: The zone of the Earth's crust that marks the transition from the upper, more brittle (fractured) crust to the lower, more ductile (plastically flowing) crust.

Caldera: A large volcanic depression, generally circular in form, with a diameter many times greater than that of a crater. A caldera forms when a volcano's magma chamber empties during an eruption, causing the ground above to collapse.

Conventional geothermal: A geothermal extraction method that requires a hydrothermal system and does not use hydraulic fracturing to artificially engineer a subsurface reservoir. Horizontal drilling may be used, but only to improve access to otherwise naturally occurring reservoirs and naturally occurring fluid.

Conventional hydrothermal system (CHS): Also known as a traditional geothermal system or hydrothermal geothermal system, a geothermal resource that is often accessible close to the surface and at times has surface manifestations, such as hot springs, volcanic rock formations, geysers, or steam vents, among others. A CHS has a combination of sufficient permeability in the subsurface, sufficient heat transfer into the system, and the natural presence of circulating water, which produces an exploitable geothermal resource. Heat flow is convection dominant (that is, conduction and advection contribute to the movement of heat). Most of the world's developed geothermal capacity is currently produced from CHS resources.

Direct-use geothermal system: Instead of using geothermal heat to generate electricity, uses the heat contained in geothermal fluids to enable various heating and cooling applications. This system can be shallow or deep.

- Shallow direct-use applications typically use a ground source heat pump to harvest the constant temperature of the shallow subsurface for a variety of low-temperature applications, including heating and cooling buildings.
- With deep direct-use applications, wells are drilled to reach higher subsurface temperatures that can be used for various applications, including industrial and commercial direct heating or numerous industrial and manufacturing processes. Deep direct-use applications may still use heat pumps but do so at much higher temperatures. Wells can target deep aquifers or human-made places filled with water, like mines.

Engineered/enhanced geothermal system (EGS): A geothermal technology that uses hydraulic fracturing to engineer a subsurface reservoir by creating or enhancing existing fractures in rock. Fluids are then circulated through the fracture network, where they heat up and are then brought to the surface for generating electricity or for direct use. This system can be deployed in various rock types and is considered scalable.

- **Traditional engineered geothermal system:** A system that uses hydraulic fracturing to engineer or enhance a subsurface reservoir to produce geothermal heat or electricity but does not use advanced directional drilling or multi-stage fracturing techniques. This system is typically developed by drilling vertical or deviated wells and can be deployed in various rock types, but the development of the system has historically focused on basement rock formations.

- **Next-generation engineered geothermal system:** Not to be confused with the umbrella "next-generation geothermal" concept, a sub-type of EGS that still uses hydraulic fracturing to engineer or enhance a subsurface reservoir while also incorporating advanced drilling and/or hydraulic fracturing techniques, including but not limited to horizontal drilling and multi-stage fracturing. This system can be deployed in a variety of rock types.

Geophysics: The study of the Earth's physical properties and processes, combining knowledge from geology, physics, mathematics, and other sciences. In geothermal exploration, geophysical methods are used to map the Earth's subsurface, including the distribution of rock types, geological structures, temperatures, magnetic and gravity fields, occurrence of groundwater, and other features.

Geothermal gradient: The rate at which temperature increases with depth in the Earth.

Geothermal system: A system involving the transfer of heat from the Earth's interior to the surface.

Granite: A coarse-grained, light-colored intrusive igneous rock composed mainly of quartz, feldspar, and mica minerals. It often contains relatively high concentrations of radioactive elements such as uranium, thorium, and potassium, which release radiogenic heat as they decay, contributing to the Earth's internal heat.

Ground source (Geothermal) heat pump (GSHP): Pump that harvests the ambient temperature in the top 1 metres to 2 metres of the subsurface, where the ground remains at a relatively constant temperature of 13°C. GSHPs have traditionally been used to heat and cool buildings, but these pumps are increasingly used in higher-temperature industrial and commercial applications.

Hydraulic fracturing: The application of pressure exceeding that of the subsurface to create or expand cracks in the rock underground, which has been used to produce oil and gas but can also increase the efficiency of geothermal energy production.

Hydrothermal: Relating to hot water, especially in processes involving heated fluids within a geothermal system.

Magma: Molten or semi-molten natural material located beneath or within the Earth's crust that forms igneous rocks as it cools and solidifies. Magma temperatures generally range from 700°C to 1,300°C but can exceed 1,800°C.

Manifestation: Surface features where geothermal fluids are discharged (for instance, hot springs, hot lakes/pools, and fumaroles) and those formed by hot fluid-rock interactions and hydrothermal mineral deposition at the ground surface.

Mohorovičić (Moho) discontinuity: The boundary between Earth's crust and the underlying mantle. It is typically found at depths of between 5 kilometres and 10 kilometres beneath the ocean floor and between 30 kilometres and 40 kilometres beneath the continents.

Next-generation geothermal: An umbrella term for any geothermal extraction technology that harvests subsurface energy outside the geography of a conventional hydrothermal system. In most cases, next-generation geothermal technologies rely on advances from the oil and gas industry and expand the geographic potential of geothermal.

Pluton: A massive body of igneous rock that forms below the Earth's surface by the slow cooling and solidification of magma.

Radiogenic: Related to radioactivity. Radiogenic heat is thermal energy released by the radioactive decay of elements in the Earth's crust and mantle, contributing to geothermal heat.

Rock types

- **Igneous rock:** A rock formed by the solidification of molten rock material (magma) generated deep within the Earth.
- **Sedimentary rock:** A rock formed from the accumulation and cementation of sediments, which may include fragments of other rocks, minerals, or biological materials. These rocks typically form in sedimentary basins and are heated by conductive heat from the Earth's interior and by radiogenic heat from decaying elements.
- **Metamorphic rock:** A rock created when existing rocks (igneous, sedimentary, or metamorphic) are gradually transformed by heat and pressure without melting. This transformation alters the rock's mineralogy and texture and can generate residual heat that may be extracted.

Sedimentary geothermal system: A type of conduction-dominated geothermal resource found in sedimentary rock formations (with some convection cells in complex settings). These sedimentary rocks—including sandstone, shale, and limestone—often contain water within their pores that can be harvested for geothermal energy production. Most sedimentary basins are closed systems, unless they have experienced uplift, in which case surface springs may highlight geothermal potential.

Supercritical: Refers to a state above the critical temperature and pressure at which a substance becomes a supercritical fluid. Such fluids exhibit properties of both gases and liquids, making them highly efficient for heat extraction in geothermal systems.

Superhot rock (SHR): A term given to geothermal technologies that aim to exploit hot-rock resources above approximately 373°C, the supercritical point of water. In volcanic regions of the world, SHR may be encountered relatively close to the surface; in other regions, SHR may require drilling to as deep as 10 kilometres or more, so SHR is sometimes referred to as *deep geothermal*.

Tectonic plates: Massive slabs of the Earth's lithosphere (crust and upper mantle) that move slowly across the planet's surface. There are two main types: oceanic and continental plates. Their movement drives many geological processes, including earthquakes, volcanism, and mountain formation.

Abbreviations

This list defines the report's frequently used abbreviations.

AGS: advanced geothermal system

AI: artificial intelligence

ASHP: air source heat pump

ATES: aquifer thermal energy storage

ATESHAC: Aquifer Thermal Energy Storage for the Decarbonisation of Heating and Cooling

BGS: British Geological Survey

BHE: borehole heat exchanger

BTES: borehole thermal energy storage

BUS: Boiler Upgrade Scheme

CAFRE: College of Agriculture, Food and Rural Enterprise

CAPEX: capital expenditure

CCGT: combined-cycle gas turbine

CfD: Contract for Difference

CO_2: carbon dioxide

COD: Commercial Operation Date

COP: coefficient of performance

CR: consistency ratio

°C: Celsius

dBA: A-weighted decibels

DHCNs: district heating and cooling networks

EA: Environment Agency

EGS: engineered geothermal system

EIA: Environmental Impact Assessment

FORGE: Frontier Observatory for Research in Geothermal Exploration

GEL: Geothermal Engineering Ltd

GES: geothermal energy storage

GHG: greenhouse gas

GSHC: ground source heating and cooling

GSHP: ground source heat pump

GSNI: Geological Survey of Northern Ireland

GW: gigawatts

GWh: gigawatt-hours

GWHC: groundwater heating and cooling

GWHP: ground water heat pump

HDR: hot dry rock

HiP: heat-in-place

HSA: hot sedimentary aquifer

HSAs and CSAs: heat and cooling supply agreements

HVAC: heating, ventilation, and air-conditioning

IEA: International Energy Agency

LCA: life cycle assessment

LCOE: levelised cost of electricity

MAA: Minewater Access Agreement

MGES: minewater geothermal energy schemes

MHGR: metamorphic-hosted geothermal resource

MHGS: metamorphic-hosted geothermal systems

MTES: mine thermal energy storage

MW: megawatts

MWh: megawatt-hours

NCG: non-condensable gas

NDC: Nationally Determined Contribution

NE LEP: North East Local Enterprise Partnership

NERC: National Environment Research Council

NHS: National Health Service

NSTA: North Sea Transition Authority

O&M: operations and maintenance

PPA: Power Purchase Agreement

PSDS: Public Sector Decarbonisation Scheme

SDES: Southampton District Energy Scheme

SMARTRES: Smart Assessment, Management and Optimisation of Urban Geothermal Resources

SuRV: Scale-up Readiness Validation

TJ: terajoules

TVD: true vertical depth

TWh: terawatt-hours

UKRI: UK Research and Innovation

UKOGL: UK Onshore Geophysical Library

UTES: underground thermal energy storage

VOC: volatile organic compound

Methodology for Calculating the UK'S Geothermal Potential

To characterise the distribution of geothermal resources across the United Kingdom, the Project InnerSpace GeoMap team developed a national data set identifying areas with the highest geothermal theoretical potential. Geothermal theoretical potential represents the physically accessible subsurface energy, or heat-in-place (HiP). The data set was produced using the HiP method following the approach of Pocasangre and Fujimitsu,[1] which quantifies total subsurface heat by separating it into heat stored in the rock matrix and heat contained within the pore fluids.

For direct-heat utilisation, an HiP calculation was performed to assess the low- to-medium temperature resource present from the surface to 3.5 kilometres depth beneath the United Kingdom. A cutoff temperature of 60°C was used to delineate volumes with potential for heat extraction, and a uniform 500 metre reservoir thickness was applied at each depth interval.

Default thermo-physical properties for both the rock matrix and formation water were used:

- **Rock matrix:** density = 2,600 kilograms per cubic metre; heat capacity = 0.79 kilojoules per kilogram-kelvin
- **Formation water:** density = 1,000 kilograms per cubic metre; heat capacity = 4.18 kilojoules per kilogram-kelvin

Heat-conversion assumptions reflected a moderately conservative development case, incorporating a 20% recovery factor, a 60% thermal efficiency, and a 30-year plant life.

The total HiP for the 0 kilometre to 3.5 kilometre interval was estimated as 3.04×10^7 petajoules (30.4 million petajoules), and the derived thermal potential, after applying the conversion parameters, was approximately 3,900 gigawatts thermal of technical potential. This assessment includes non-sedimentary formations using a constant 5% porosity assumption, representing the technical maximum resource across all UK land areas.

For electricity generation, an HiP calculation was performed to assess the high-temperature resource present between 4 kilometres and 4.5 kilometres depth beneath the United Kingdom. A cutoff temperature of 150°C was used to delineate volumes with potential for power generation, and a uniform 500 metre reservoir thickness was applied across the mapped 4,000 metre deep surface.

Default thermo-physical properties for both the rock matrix and formation water were used:

- **Rock matrix:** density = 2,600 kilograms per cubic metre; heat capacity = 0.79 kilojoules per kilogram-kelvin
- **Formation water:** density = 1,030 kilograms per cubic metre; heat capacity = 4.18 kilojoules per kilogram-kelvin

Power-conversion assumptions reflected a moderately conservative development case, incorporating a 15% recovery factor, a 90% capacity factor, and a 30-year plant life.

The resulting area above the 150°C cutoff was approximately 2.49 square kilometres by 10^5 square kilometres, with a rock volume of 1.24 cubic kilometres by 10^5 cubic metres, of which around 24% exceeded the temperature threshold. The total HiP for this interval was estimated as 1.33×10^6 petajoules, and the derived electrical potential, after applying the conversion parameters, was approximately 26.9 gigawatts electric, which was rounded to 25 gigawatts electric of technical potential. A drawdown temperature correction was not included.

This methodology has evolved from the one that Project InnerSpace developed for the International Energy Agency's recent *The Future of Geothermal* report. For more information on this method, see pages 42–44 of that report, which provides more details in the calculations, formulas, and assumptions.[2]

METHODOLOGY REFERENCES

1 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. https://doi.org/10.1016/J.GEOTHERMICS.2018.07.009

2 International Energy Agency (IEA). (2024). *The future of geothermal energy*. https://www.iea.org/reports/the-future-of-geothermal-energy

Executive Summary

Drilling into the United Kingdom's Geothermal Potential

Project InnerSpace

Geothermal energy can become a cornerstone of the United Kingdom's future energy system—yet it is often overlooked. With a growing pipeline of heat projects and a domestic resource for nationwide heating and cooling and selective electricity generation, the UK can mitigate exposure to future external shocks, and strengthen energy security, while creating tens of thousands of jobs, lowering bills, and meeting binding climate targets.

The United Kingdom is at an inflection point: After recent price shocks, the region needs clean, reliable energy that lowers bills, strengthens energy security, and supports industrial competitiveness while meeting binding climate targets. Geothermal energy can help deliver on all three needs, as the country sits above a major domestic geothermal resource that can be used for heating and cooling, storage, and even electricity generation.

The UK has benefitted from naturally heated groundwater for nearly two millennia—most famously via the Roman Baths, constructed at a hot spring in the town of Bath. Today, thanks to advancements in technology, geothermal can be used much more widely. In the United Kingdom, geothermal is primed to address one of the region's biggest and most overlooked energy demands: heat.

About 80% of the UK's household energy is used for space heating, water heating, and cooking,[1,2] and much of that energy comes from external fuel supplies. In 2024, net energy imports across the UK increased to more than 43% of all energy used.[3]

This figure indicates that across the United Kingdom, deploying more geothermal heat is central to protecting households and businesses from volatile fuel prices and to meeting climate goals. (See Chapter 2, "The Geothermal Opportunity in the United Kingdom," for more details.)

The opportunity for the UK is big. Project InnerSpace estimates that the UK has about 3,900 gigawatts of total technical potential for heating and cooling (down to 3.5 kilometres) and about 25 gigawatts of total technical potential for electricity (down to 5 kilometres). Those 3,900 gigawatts of heat are more than enough to meet the nation's entire heating demand for more than 1,000 years.[4] And the potential for 25 gigawatts of electricity equals about 75% of the electricity the UK uses each year.[5] Despite this potential, however, geothermal supplied only 0.3% of annual heat demand in 2021, primarily through residential ground source heat pumps and a handful of deep direct-use and minewater projects.[6] Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface Geology," assesses the potential for various types of geothermal energy across the United Kingdom.

Ground source heat pumps are a great solution to the nation's energy needs, but the UK also has many other geothermal options (**Figure ES.1**). The Southampton District Energy Scheme has drawn geothermal heat from a deep well since the 1980s, demonstrating continuous performance in an urban setting, in addition to helping the area avoid an estimated 12,000 tonnes of carbon dioxide emissions and saving consumers £600,000 each year.[7] In Gateshead, a minewater-based heat system has been operational since March 2023 and currently serves more than 350 homes and a number of public and commercial buildings. These projects demonstrate how geothermal can deliver value for the UK today.

DISTRIBUTION OF KEY GEOLOGICAL SETTINGS RELEVANT TO UK GEOTHERMAL POTENTIAL

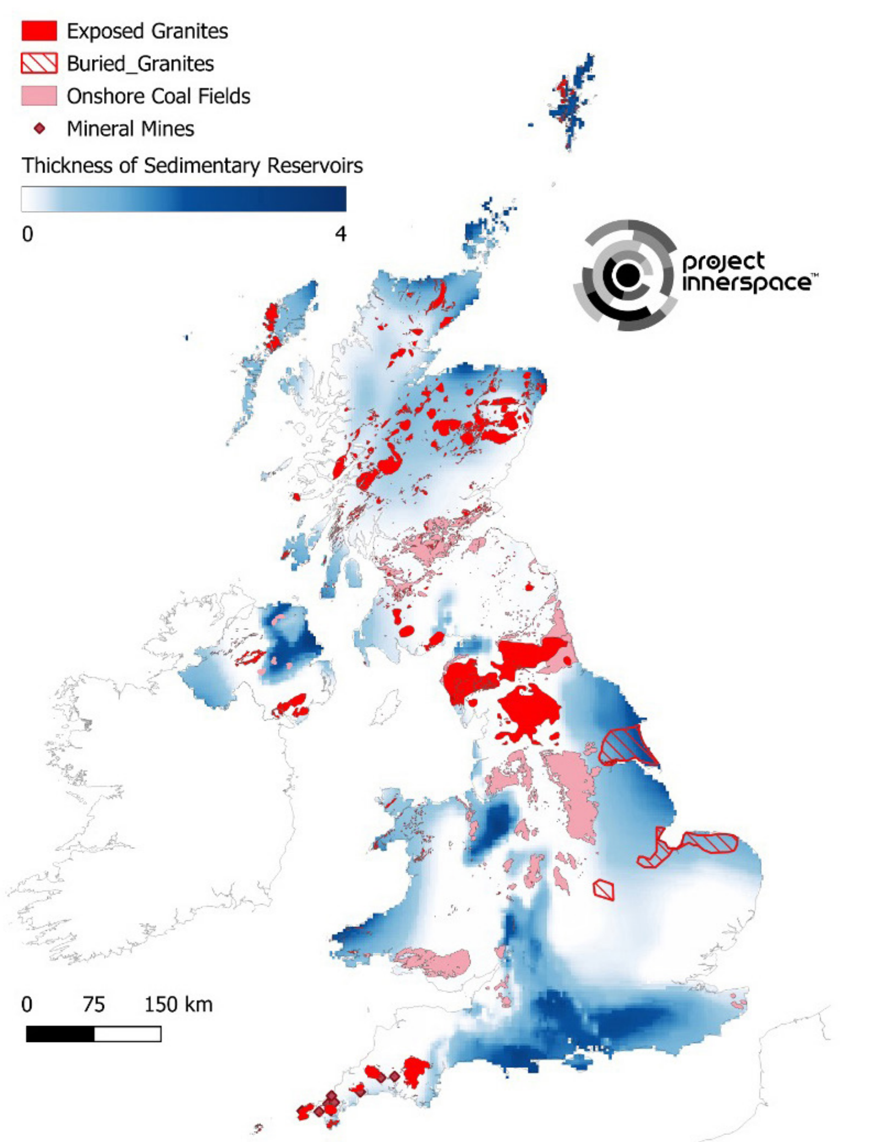

Figure ES.1: The map shows the extent and depth of sedimentary reservoirs, locations of exposed granites and buried granites, and areas of historic or active mining. In the southwest, red granite areas are the most likely option for electricity generation, while sedimentary aquifers have potential for heating and cooling, complemented by areas where former mines could be used for heating and cooling. Projection: OSGB36/British National Grid. Map created by Project InnerSpace. Data sources: Holdt et al. (2025). *Global sediment thickness (in preparation).* Project InnerSpace; ArcGIS Hub. (2025). Mineral mines. *UNESCO WHC sites dossiers elements core points;* Fleiter et al. (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 et al. (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.

Expanding the use of geothermal systems across the country can accomplish the following:

- **Enhance energy security and resilience:** Geothermal is domestic, reliable, and not subject to fuel price shocks; it can provide baseload heat and (where feasible) electricity.
- **Lower costs over time:** Geothermal has lower operating costs and reduces consumer costs—particularly when it is deployed through networks and integrated planning.
- **Create environmental, economic, and energy-system benefits:** Geothermal deployment reduces emissions, supports high-quality jobs, eases peak electricity demand via the direct use of heat, and strengthens grid resilience through thermal storage and shifting demand away from peak times.

RECOMMENDED POLICIES TO EXPAND THE UK'S GEOTHERMAL INDUSTRY

The UK's geothermal sector is emerging within a regulatory system that was not designed for geothermal deployment at scale. There is no obvious national legal framework in place for the ownership, licensing, and management of geothermal heat in the UK. Improved government focus on geothermal would create regulatory clarity and allow this resource to scale. (See Chapter 6, "Who Owns the Heat? Navigating Subsurface Rights in the United Kingdom's Legal and Regulatory System.") Permitting and oversight processes are spread across various agencies and requirements, from local planning, environmental, and water and mineral exigencies to subsurface access, depending on the technology and location. This fragmentation increases transaction costs; lengthens development timelines; and raises uncertainty for developers, investors, and prospective heat and cooling customers.

Developing minewater geothermal means working with the institutions responsible for legacy mine infrastructure, while deep geothermal projects face other requirements related to drilling, reservoir management, monitoring, and long-term stewardship. No single body manages the end-to-end pathway, making it more difficult to standardise requirements, build institutional capability, and reduce timelines. To deploy geothermal resources in the UK, policy needs to keep pace with possibility.

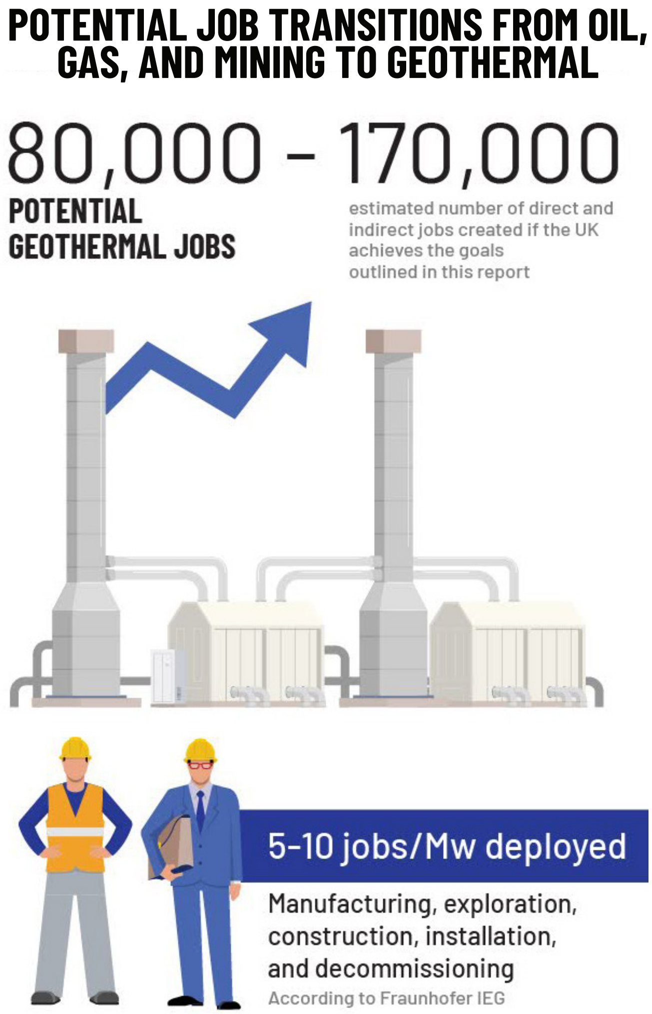

Figure ES.2: Potential job transitions from oil, gas, and mining to geothermal. Source: Bracke, R., & Huenges, E. (2022, February 2). *Shaping a successful energy transition* [Press release]. Fraunhofer IEG.

This report outlines an ambitious goal based on current technology and cost estimates: 15 gigawatts for heat and between 1.5 gigawattts and 2 gigawatts for electricity by 2050. Meeting this goal could create between 80,000 and 170,000 jobs.[8]

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POLICY MENU FOR ACCELERATED GEOTHERMAL DEVELOPMENT IN THE UK

Theme	Barrier or Challenge	Policy Solution or Recommendation	Responsible Party
Regulatory and Governance	Lack of national strategy or deployment targets, which undermines investor confidence. Fragmented regulation and unclear planning/permitting roles causing project delays.	**Policy Recommendation 1:** Publish a national geothermal strategy with explicit 2035/2050 heat and electricity goals. **Policy Recommendation 2:** Establish a "geothermal desk" for one-stop coordination between DESNZ and agencies with defined permit timelines; update national planning guidance to classify geothermal as a nationally significant, strategic, resilient, and renewable infrastructure.	DESNZ, Cabinet Office, HMT DESNZ; MHCLG; Environment Agency; Scottish government; Welsh government; Northern Ireland Executive; Mayoral Authorities
Financial and Investment	High up-front exploration and drilling risk that discourages private investors. Limited financial incentives compared with other renewables. Weak bankability of long-term heat offtake contracts.	**Policy Recommendation 3:** Create a geothermal resource insurance facility modelled on France and Germany. **Policy Recommendation 3:** Establish a geothermal exploration grant programme; include geothermal in Contract for Difference auctions; ring-fence funding in the GHNF. **Policy Recommendation 3:** Develop a geothermal financing framework using blended finance, tax breaks, and a contracts for heat regime with standardised heat purchasing agreements. Pair targeted capital support, loan guarantees, and resource insurance to reduce early drilling risk and unlock additional investment.	DBT, DESNZ, HMT Great British Energy, HMT, National Wealth Fund, DESNZ DESNZ, Ofgem, HNDU, local authorities
Market and Infrastructure	Low coverage of district heat networks, limiting viable demand.	**Policy Recommendation 4:** Introduce a public heat purchase obligation requiring public estate to procure low-carbon heat; designate geothermal opportunity zones within network areas.	Ministry of Defence, MHCLG, Cabinet Office, DESNZ, local authorities
Data, Coordination, and Integration	Incomplete or inaccessible subsurface data, which constrains exploration.	**Policy Recommendation 6:** Expand subsurface data resource mapping BGS Geothermal Data Map into a public National Geothermal Atlas; mandate open access to non-commercial well data.	BGS, DESNZ, GSNI
Skills and Awareness	Low awareness of technical skills and domestic capacity. Low public familiarity/examples; confusion with hydraulic fracturing.	**Policy Recommendation 5:** Create a Geothermal Skills Transition Fund for oil and gas workforce retraining; incentivise UK manufacturing of drilling and heat-exchange components by establishing local-content rules. **Policy Recommendation 7:** Run a national geothermal awareness campaign; develop national guidance distinguishing geothermal from hydraulic fracturing; highlight success stories (such as Southampton).	DESNZ, DBT, OPITO DESNZ, local authorities, industry associations

ES3: BGS = British Geological Survey; DBT = Department for Business and Trade; DESNZ = Department for Energy Security and Net Zero; GHNF = Green Heat Network Fund; GSNI = Geological Survey of Northern Ireland; HMT = HM Treasury; HNDU = Heat Networks Delivery Unit; MHCLG = Ministry of Housing, Communities and Local Government; Ofgem = Office of Gas and Electricity Markets; OPITO = Offshore Petroleum Industry Training Organisation. Source: author.

The good news is that the UK does not have to invent new concepts from scratch. It has a number of companies developing geothermal applications across the region. It has an experienced oil and gas and mining workforce with skills that translate to many areas of geothermal development. And it has a growing pipeline of pilot projects and proof-of-concept programs in operation. But fully tapping into the UK's geothermal potential requires additional policies that clarify roles and responsibilities—streamlining permitting, de-risking early exploration, and making long-term heat and electricity offtake easier to finance (**Figure ES.3**).

Fully tapping into the UK's geothermal potential requires additional policies that clarify roles and responsibilities—streamlining permitting, de-risking early exploration, and making long-term heat and electricity offtake easier to finance.

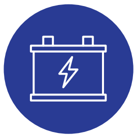
European and other international markets have successfully accelerated geothermal via many of the building blocks recommended in this report. (See Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," for more details.) Countries such as Germany, France, and the Netherlands are already deploying new policy mechanisms that can be a model for the UK.

Some recommended policy actions can be implemented quickly (such as in the next one to three years): standardised guidance, clearer agency handoffs, and expedited pathways for proven project types. Others—such as durable revenue support and scaled risk-mitigation facilities—will take longer to take effect. Implemented well, this agenda turns geothermal from one-off demonstrations into a clean, financially attractive infrastructure asset that can help lower consumer bills,[9] among other benefits.

MINDING THE GAP

About 30 deep geothermal projects are already in development nationwide, a number of minewater heat and district heating projects are underway, and more than a dozen companies have secured private and public funding for geothermal projects.[10,11] In interviews with many of the leaders of these companies, however, a common constraint cited is that the UK's early-stage technology financing structures have companies struggling to accommodate subsurface risk, long lead times, and permitting complexity. (See Chapter 10, "A New Age of Innovation: The United Kingdom's Geothermal Start-up Scene," for more.) Early-stage development carries high up-front costs, especially for drilling and resource confirmation, that are difficult to finance under conventional infrastructure models. The most important near-term task, then, is turning geological promise into bankable assets that can attract capital and then grow. In other words, geothermal's biggest barrier is not a lack of demand; it is the gap between resource potential and investable projects.

IDEAS TO IMPROVE FINANCIAL INCENTIVES FOR GEOTHERMAL IN THE UK



Include geothermal electricity in Contract for Difference (CfD) auctions with dedicated 200–500 megawatt allocation per round.

Establish a first-well failure guarantee covering 50% to 70% of drilling costs, modelled on French/German schemes.

Stand up the Geothermal Resource Insurance Facility + philanthropic first-loss package described to make exploration/appraisal bankable and reduce premiums over time.

Publish model "Contracts for Heat" and reference them in Green Heat Network Fund (GHNF)/CfD guidance so combined heat and power projects can finance heat and electricity revenues together.

Use a portfolio procurement approach for the first wave, then refinance and recycle public anchors via gilts/local climate bonds/ reserves-based lending.

Launch a £100–£200 million Exploration Grant Programme in high-potential basins (comparable in scale to GHNF) for pilot drilling and proving wells.

Launch a national exploration and pilot drilling programme in priority basins, including reprocessing legacy data sets and targeted new seismic to refine reservoir models, with standardised appraisal/flow-test protocols.

Taken together, these measures would bring geothermal to parity with wind, solar, biomass, and heat networks, aligning the sector with established UK support structures and unlocking significant private investment. Read more about financial instruments to accelerate the UK geothermal industry in Chapter 9.

Figure ES.4: Ideas to improve financial incentives for geothermal in the UK. Source: Chapter 9, "Minding the Gap: Financing Solutions to Advance Geothermal in the United Kingdom."

Geothermal's biggest barrier is not a lack of demand; it is the gap between resource potential and investable projects.

This report identifies a set of financial mechanisms designed to close this gap, particularly in the "first projects" phase, when uncertainty is highest and private capital is most cautious. (See Chapter 9, "Minding the Gap: Financing Solutions to Advance Geothermal in the United Kingdom.") These tools (such as targeted support for drilling, insurance, and heat offtake) are intended to work hand in hand with the policy solutions outlined in the report: clearer and faster permitting, defined responsibilities across regulators, stronger heat-network planning, and procurement and offtake structures that translate public ambition into investable demand.

One practical place to start is with the National Health Service estates. An analysis of geothermal resources in the Triassic sandstone reservoir beneath NHS facilities across the UK shows that there is substantial potential.

Expanding the use of geothermal also helps the UK move beyond today's largely bespoke model that treats every new project as a first of a kind. When multiple projects advance in the same region, geothermal becomes replicable: Regulators and planners build consistent pathways, and banks, insurers, lawyers, and contractors gain confidence through standardised templates and solid program track records. The result is faster timelines and lower costs.

TURNING UP THE HEAT

For geothermal to be widely deployed across in the UK, the most promising place to begin is with heating and cooling, which can be accessed fairly simply and fairly fast via ground source heat pumps (GSHPs), heat networks, and thermal storage.

The effectiveness of these systems, of course, depends on the subsurface temperatures that align with the heating needs above the surface. Fortunately, in the UK, thick sedimentary basins and legacy mining districts with heat resources sit beneath areas with significant heat demand.

One practical place to start is with the National Health Service (NHS) estates. An analysis of geothermal resources in the Triassic sandstone reservoir beneath NHS facilities across the UK shows there is substantial potential—an estimated 8,600 petajoules at or near 20°C; 3,250 petajoules at or near 40°C; and nearly 1,167 petajoules near 60°C—for low-carbon heating, cooling, and storage for these buildings. (See Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors.") NHS sites around Belfast, Birmingham, Liverpool, Manchester, and Southampton could make particularly good fits for implementing early heat projects, accelerating repeatable delivery models, and creating a pipeline where learning-by-doing rapidly reduces costs and risks (**Figure ES.5**).

A number of different geothermal heat applications are currently being deployed across Europe. The Mijnwater project in the Netherlands has operated since 2008 and currently supplies heating and cooling to more than 400 homes and 250,000 square metres of commercial buildings, with plans to expand to 30,000 homes.[12]

The Dutch also lead on low-temperature aquifer thermal energy storage (LT-ATES) with more than 3,000 systems—about 85% of all of the ATES systems on Earth—at work today.[13] The policy framework in the Netherlands has been explicitly designed to tap into this resource.[14] The UK has analogous geology and infrastructure in many regions but lacks the coordinated planning, permitting clarity, and financing tools to move at comparable speed. Widespread deployment of aquifer thermal energy storage could supply roughly 61% of the UK's current heating demand and 79% of cooling demand.[15] (For more about the various examples of geothermal heat and how they can be scaled, see Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors.")

NATIONAL HEALTH SERVICE FACILITIES OVER TRIASSIC AQUIFERS

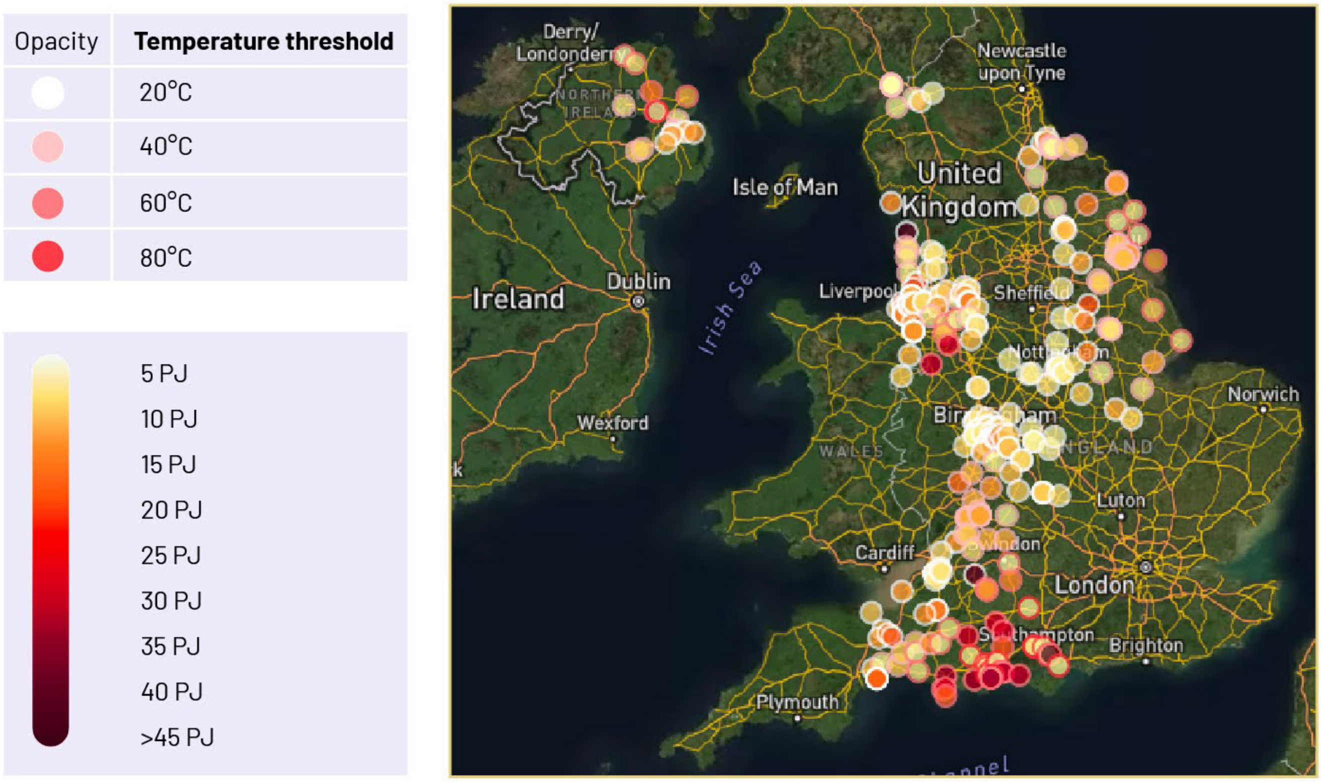


Figure ES.5: Project InnerSpace has mapped 301 National Health Service facilities that lie over Triassic aquifers, a suitable geothermal target. Hospitals that lie over sufficiently deep (and hot) and permeable aquifer units are considered to have the greatest geothermal potential. PJ = petajoules. Source: Project InnerSpace.

Widespread deployment of aquifer thermal energy storage could supply roughly 61% of the UK's current heating demand and 79% of cooling demand.

ELECTRICITY GENERATION

While more limited than heat, the UK also has the subsurface resources to deploy geothermal electricity generation in select areas. As noted, Project InnerSpace estimates approximately 25 gigawatts of total technical potential for electricity (down to 5 kilometres).

The value of using geothermal for electricity is that it is an always-on, low-carbon resource. Geothermal can reliably operate near full output for most hours of the year. As a result, it can reduce reliance on fossil fuel-based energy generation during periods of peak demand and stand in when renewable output is low. It is also a resilient energy source, as it is largely unaffected by surface weather and can quickly return to operation after disruptions.

In the UK in 2024, the grid's inability to transport or store energy curtailed about 8.3 terawatt-hours of wind energy, enough to power more than 2 million homes per year. This cost consumers nearly £400 million.[16] Because geothermal can be located closer to demand centres than many wind and solar resources, its use can also reduce transmission losses and congestion. In some cases, geothermal can even serve as means of long-term energy storage.

In the near term, targeted geothermal projects can provide meaningful grid support, resilience, and decarbonisation benefits at the local level, building momentum towards broader national impact as deployments scale.

DATA CENTRES

The UK's rapid expansion in artificial intelligence (AI) and data centres is driving unprecedented energy demand. Cooling alone currently accounts for about 40% of a data centre's electricity use, and demand is projected to rise substantially as AI-related compute requirements grow.[17]

This expansion creates a strategic opening for geothermal-based cooling, seasonal thermal storage, and heating and cooling networks that can reduce both electricity demand and peak loads. Notably, two of the government's confirmed AI Growth Zones (AIGZs)—Culham in Oxfordshire and Northumberland and Cobalt Park in North Tyneside[18]—sit atop resources that could enable efficient, stable, and secure geothermal cooling.

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POTENTIAL AREAS FOR DATA CENTRE COOLING AND/OR STORAGE

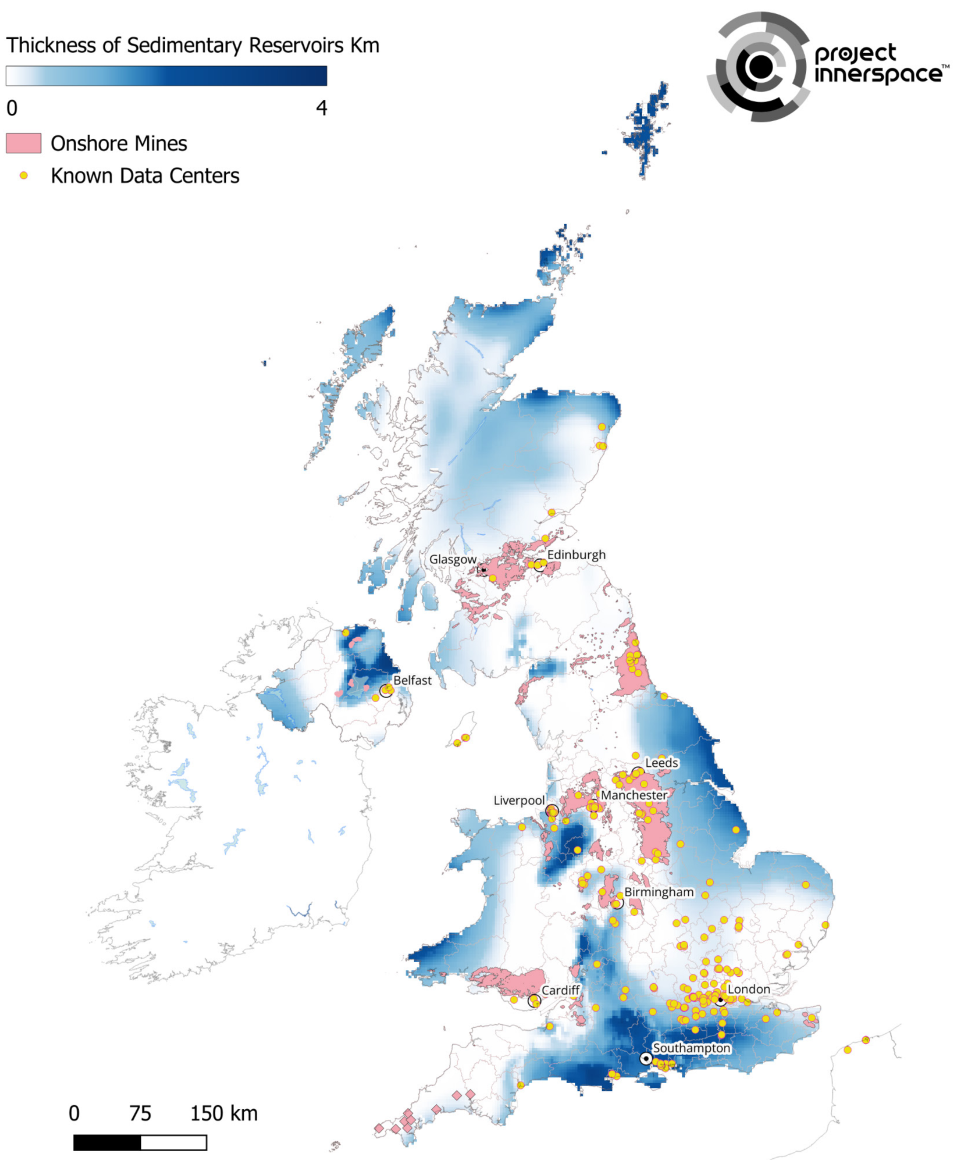

Figure ES.6: Thickness of sedimentary reservoirs across the UK. The overlap of thick aquifers, legacy mines, and digital infrastructure highlights priority zones for low-carbon cooling, thermal storage, and geothermal-ready AI Growth Zones. Sources: OSGB36/British National Grid. Map created by Project InnerSpace; Holdt et al. (2025). *Global sediment thickness* (in preparation). Project InnerSpace; ArcGIS Hub. (2025). Mineral mines. *UNESCO WHC sites dossiers elements core points;* Fleiter et al. (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 et al. (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.

More than 200 regions across the UK are interested in hosting AIGZs. Many of them—including Scotland, north-west England, Yorkshire and the Humber, and North Lincolnshire—are in areas with major sedimentary basins or onshore mines. These resources give the regions strong opportunities to deploy storage and cooling systems to support AI and digital campuses. Geothermal cooling can also be paired with heat recovery and local heat networks, turning waste heat into a resource and improving overall system economics.

LEVERAGING EXISTING SKILLS AND SUPPLY CHAIN

Many of the skills needed to scale geothermal for both heat and electricity—safety management, subsurface modelling, construction, compliance, reservoir management, and more—overlap with the UK's existing oil and gas and mining workforces. (See in Chapter 8, "Beyond the North Sea: Leveraging the United Kingdom's Oil and Gas Expertise to Advance

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

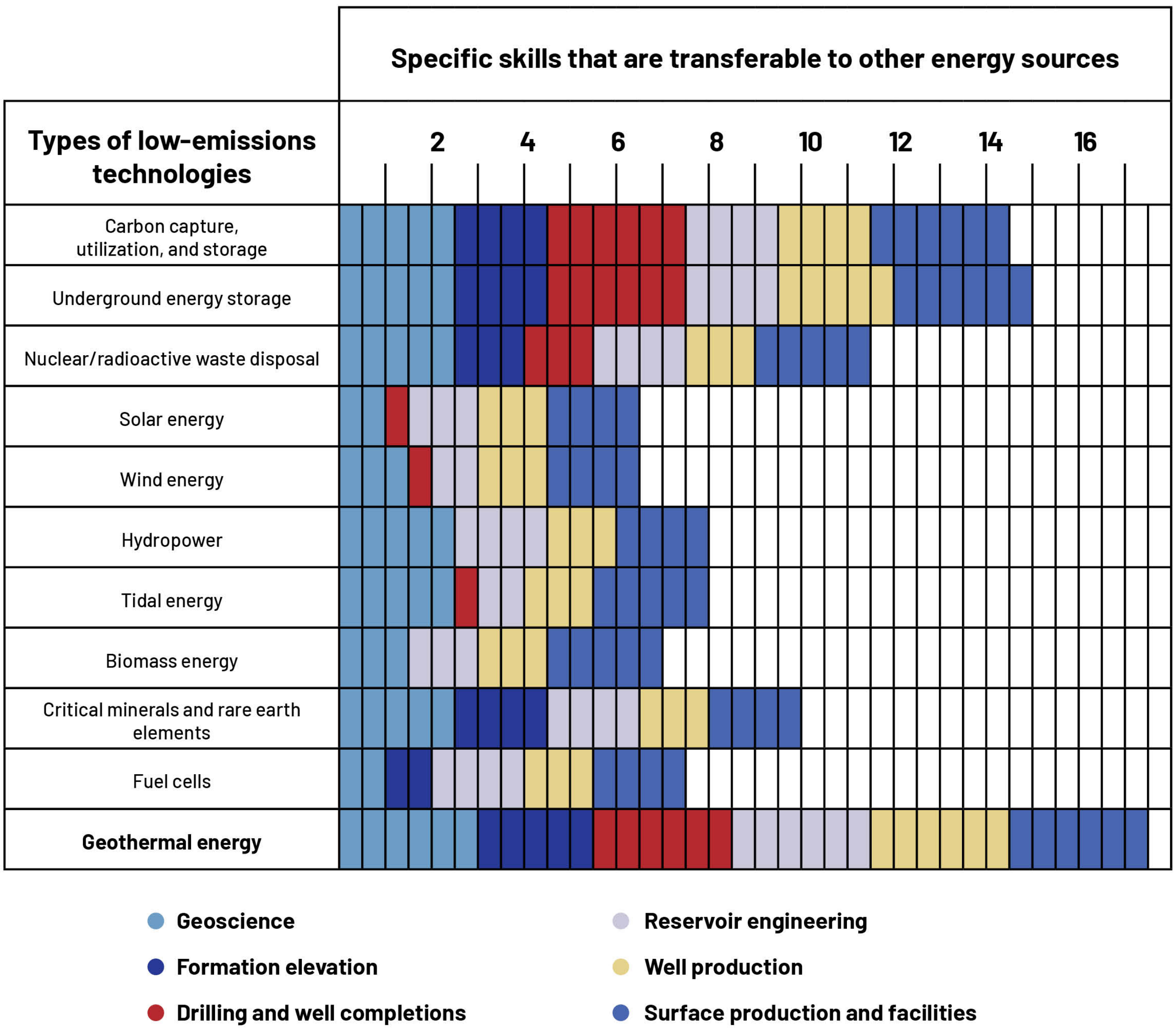

Figure ES.7: Geothermal requires the most skills from the oil and gas industry compared with all other clean energy production methods. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023). Oil and gas skills for low-carbon energy technologies. Society of Petroleum Engineers Annual Technical Conference and Exhibition, San Antonio, TX, United States.

Geothermal.") In addition, the UK's oil and gas supply chain (including manufacturers and service providers of drill bits, directional drilling tools, pumps, high-temperature wellhead equipment, and pipeline systems) is a ready-made infrastructure that can be adapted to geothermal development. By repurposing existing equipment, manufacturing capacity, and logistics networks, the supply chain can support both deep and shallow geothermal projects while also effectively training a new geothermal workforce in communities such as coal mining towns that have grappled with energy transitions. (See **Figure ES.7** for details on skills that can transfer to geothermal from oil and gas.)

GEOTHERMAL AND THE ENVIRONMENT

Geothermal can deliver substantial environmental benefits—especially when displacing fossil fuels. But it must be developed responsibly.

Reducing carbon dioxide (CO_2) emissions is one of the most significant environmental benefits of expanding geothermal energy.[19] In 2025, greenhouse gas emissions totaled roughly 371 million tonnes of CO_2-equivalent.[20] While national emissions have declined substantially over the past three decades, the UK is not on track to meet its 2030 climate targets, and the independent Climate Change Committee has called for accelerated deployment of low-carbon technologies across all sectors to close the gap.[21] With close to one-quarter of the UK's CO_2-equivalent emissions coming from fossil fuel combustion in building heating, decarbonising heat is essential to meeting the UK's legally binding climate targets.[22]

Geothermal operations also use the smallest land area of any renewable energy source.[23,24] Geothermal electricity plants typically use only 2.25% of the land that solar requires, 0.38% of the land needed for onshore wind, and 0.078% of the land needed by electricity plants that burn biomass for fuel (**Figure ES.8**). This small footprint makes geothermal particularly advantageous in space-constrained environments across the UK.[25]

As with any subsurface technology, geothermal development requires careful management of water, geochemistry, and ground conditions. These projects carry some known risks, including fluid migration and—when utilising hydraulic fracturing—induced seismicity. However, international and UK experience shows that such risks can be effectively managed. Modern geothermal systems are designed to reinject geothermal fluids, minimising surface impacts and supporting long-term reservoir sustainability, with plants capable of recovering up to 90% of the water they use.[26] Additional operational controls can further reduce the risk of contamination and environmental disturbance.[27]

In practice, the vast majority of UK geothermal projects will rely on low- to medium-enthalpy resources, which do not require hydraulic fracturing, for direct-use heating applications. In limited and highly controlled circumstances, however, geothermal hydraulic (primarily for electricity generation) should not be ruled out.

As explained in Chapter 7, "Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices," with good site selection, baseline data, continuous seismic monitoring, and clear regulatory requirements and reporting, the UK can manage environmental risks. When developed well, geothermal can be a low-footprint, low-emissions contributor to the UK's clean heat, cooling, and resilience agenda.

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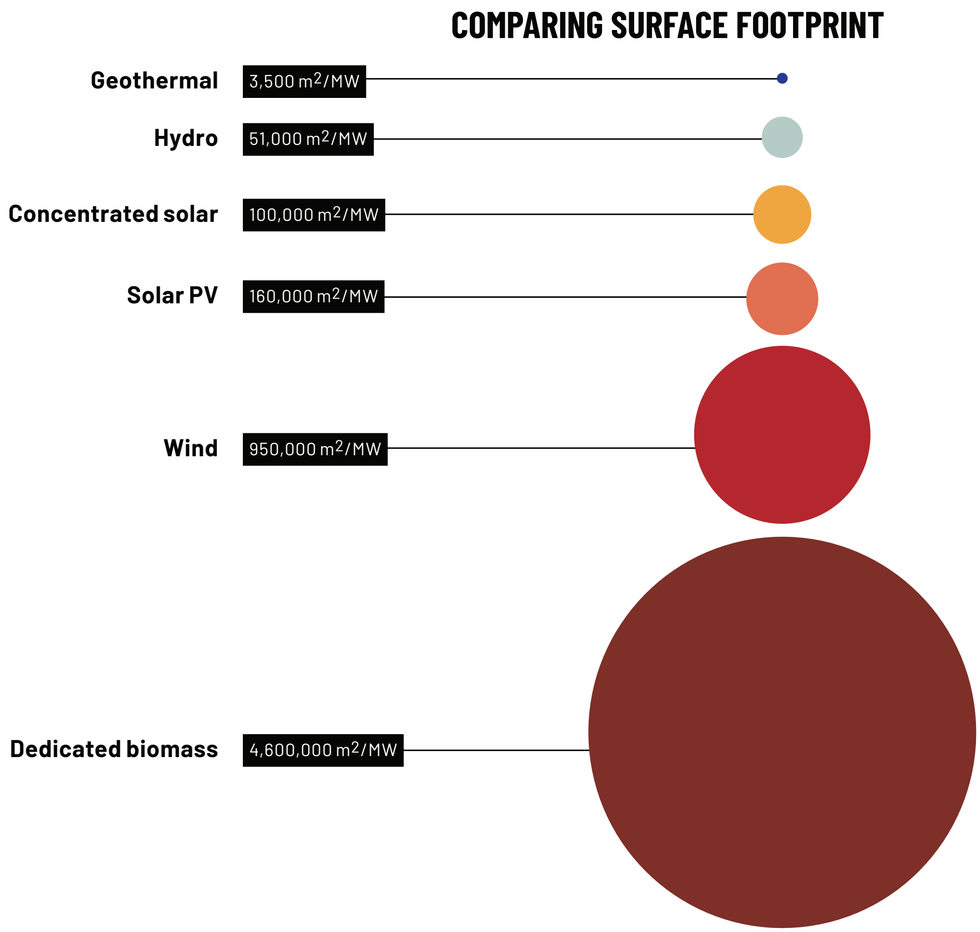


Geothermal has the smallest footprint of any renewable energy source

Figure ES.8: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables. PV = photovoltaic. Source: Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS ONE*, 17(7), e0270155; National Renewable Energy Laboratory (NREL). (2022). *Land use by system technology*.

CONCLUSION

The United Kingdom has the resources, ecosystem, and skills to become a geothermal leader. Tapping into even just a small portion of its geothermal resources increases the UK's energy security by reducing the need for imported energy. Yet, geothermal is often overlooked as a solution to the nation's energy challenges.

Geothermal can directly tackle volatility in heating costs—an issue that UK households feel acutely. Additionally, the UK cannot meet its long-term energy security and greenhouse gas emissions reduction goals without expanding its clean, reliable heating solutions.

Geothermal deployment at scale is achievable but not a given. Success depends on aligning three elements:

1. Clear rules and faster regulatory pathways—so geothermal projects can move through permitting and approvals with certainty.
2. Planned demand—through heat networks, zoning, and anchor customers such as hospitals, universities, and government estates.
3. Targeted financial tools—to bridge the early-stage risk gap, especially around drilling and subsurface uncertainty.

The payoff is multi-dimensional: lower bills, reduced reliance on imported fuels, durable local jobs, and a more resilient energy system that can support current and future demand such as data centre cooling and thermal storage. The UK's geothermal resource is domestic and dependable; turning it into a national industry is a strategic choice.

Keep calm. Geothermal is always on.

CHAPTER REFERENCES

1 Peñasco, C. (2024). From policy to practice: The role of national policy instruments and social barriers in UK energy efficiency adoption in households. *Energy Policy*, 194, 114308. https://www.sciencedirect.com/science/article/pii/S0301421524003288

2 Kavan, M. (n.d.). *How different households use energy and hos much it costs them*. Nesta. https://www.nesta.org.uk/project/finding-ways-to-deliver-cheaper-electricity-by-rebalancing-levies/how-different-households-use-energy

3 Harris, K. (2025). Chapter 1: Energy. In Department for Energy Security and Net Zero (Ed.)., *Digest of UK energy statistics (DUKES): Energy*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/6889eaa276f68cc8414d5b54/DUKES_2025_Chapter_1.pdf

4 Based on data from Department for Energy Security and Net Zero. (2025). *Energy consumption in the UK 2025*. Government of the United Kingdom. https://www.gov.uk/government/statistics/energy-consumption-in-the-uk-2025. See "ECUK 2025: End uses data tables."

5 Based on data from Department for Energy Security and Net Zero. (2025). *Energy trends: UK electricity*. Government of the United Kingdom. https://www.gov.uk/government/statistics/electricity-section-5-energy-trends. See "Supply and consumption of electricity (ET 5.2 - quarterly)."

6 Government Office for Science. (2024). *Future of the subsurface: Geothermal energy generation in the UK (annex)*. Government of the United Kingdom. https://www.gov.uk/government/publications/future-of-the-subsurface-report/future-of-the-subsurface-geothermal-energy-generation-in-the-uk-annex

7 Geothermal District Heating (GEODH). (n.d.). *Southampton*. http://geodh.eu/project/southampton/

8 Bracke, R., & Huenges, E. (2022, February 2). *Shaping a successful energy transition* [Press release]. Fraunhofer IEG. https://www.ieg.fraunhofer.de/de/presse/pressemitteilungen/2022/erfolgreiche-waermewende-gestalten.html

9 Gertler, C. G., Steeves, T. M., & Wang, D. T. (2025). *Pathways to commercial liftoff: Geothermal heating and cooling*. U.S. Department of Energy. https://igshpa.org/wp-content/uploads/LIFTOFF_DOE_Geothermal_HC.pdf

10 Government Office for Science, 2024.

11 Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *The case for deep geothermal energy—unlocking investment at scale in the UK*. Department for Energy Security and Net Zero, Government of the United Kingdom. https://www.northeastlep.co.uk/updates/white-paper-calls-for-acceleration-of-geothermal-energy-projects-in-the-uk/

12 Verhoeven, R., Willems, E., Harcouët-Menou, V., De Boever, E., Hiddes, L., Op't Veld, P., & Demollin, E. (2014). Minewater 2.0 project in Heerlen, the Netherlands: Transformation of a geothermal mine water pilot project into a full scale hybrid sustainable energy infrastructure for heating and cooling. *Energy Procedia*, *46*, 58–67.

13 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

14 Stemmle, R., Hanna, R., Menberg, K., Alberg Østergaard, P., Jackson, M., Staffell, I., & Blum, P. (2025). Policies for aquifer thermal energy storage: International comparison, barriers and recommendations. *Clean Technologies and Environmental Policy*, *27*, 1455–1478. https://link.springer.com/article/10.1007/s10098-024-02892-1

15 Jackson et al., 2024.

16 Drax. (2025, March 20). *UK urgently needs more energy storage to avoid wasting wind power—report* [Press release]. https://www.drax.com/uk/press_release/uk-urgently-needs-more-energy-storage-to-avoid-wasting-wind-power-report

17 Watson, S. (2023, March 16). *Cool runnings: Making data centres more energy efficient*. MODUS. https://ww3.rics.org/uk/en/modus/natural-environment/climate-change/cooling-data-centres.html

18 Cobalt Park. (2025, September 17). *Two sites in North East become 'AI growth zone.'* https://cobaltpark.co.uk/2025/09/17/two-sites-in-north-east-become-ai-growth-zone/
19 Kassem, M. A., & Moscariello, A. (2025). Geothermal energy: A sustainable and cost-effective alternative for clean energy production and climate change mitigation. *Sustainable Futures*, *10*, 101247. https://www.sciencedirect.com/science/article/pii/S2666188825008081
20 Department for Energy Security and Net Zero. (2025, March 27). *2024 UK greenhouse gas emissions, provisional figures*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/67e4060df356a2dc0e39b4cd/2024-provisional-greenhouse-gas-emissions-statistics-statistical-release.pdf
21 Climate Change Committee. (2024). *2024 progress report to Parliament*. https://www.theccc.org.uk/publication/progress-in-reducing-emissions-2024-report-to-parliament/
22 Department for Energy Security and Net Zero & Department for Business, Energy and Industrial Strategy. (2023). *Heat and building strategy*. Government of the United Kingdom. https://www.gov.uk/government/publications/heat-and-buildings-strategy/heat-and-building-strategy-accessible-webpage
23 Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS ONE*, *17*(7), e0270155. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0270155
24 National Renewable Energy Laboratory (NREL). (2022). *Land use by system technology*. NREL.
25 Lovering et al., 2022.
26 Hackstein, F. V., & Madlener, R. (2021). Sustainable operation of geothermal power plants: Why economics matters. *Geothermal Energy*, *9*, 10. https://link.springer.com/article/10.1186/s40517-021-00183-2
27 Jacobs, T. (2024, September 16). Fervo and FORGE report breakthrough test results, signaling more progress for enhanced geothermal. *Journal of Petroleum Technology*. https://jpt.spe.org/fervo-and-forge-report-breakthrough-test-results-signaling-more-progress-for-enhanced-geothermal

Part I

The Basics of Geothermal

Chapter 1

United Kingdom Underground: An Overview of Geothermal Technologies and Applications

Project InnerSpace

Because it is hot everywhere underground, and thanks to technological developments from the oil and gas industry, we can access underground heat in locations across the United Kingdom. In fact, the potential for geothermal development across a variety of applications and use cases is now truly global.

Geothermal is a naturally occurring, ubiquitous, and clean energy source. About 6,400 kilometres from the planet's crust, the core of the Earth is roughly as hot as the surface of the sun—roughly 6,000°C (see **Figure 1.1**). Geothermal heat is present across the entire planet—on dry land and on the ocean floor—and offers enough potential energy to power the whole world thousands of times over.

These resources have been exploited for centuries: In the 19th century, people started using heat from the Earth for industrial processes like heating and cooling buildings and generating electricity. The first documented instance of geothermal electricity generation was in Larderello, Italy, in 1904.[1]

But throughout history, these conventional hydrothermal systems have been geographically limited. They require specific subsurface conditions—sufficient heat, water, and rock permeability—which are typically found in tectonically active regions such as Iceland and the western United States.[2] Only when all three of these factors overlapped was there an exploitable geothermal resource. Even then, finding such a resource typically required a fourth natural phenomenon: an obvious surface manifestation such as a geyser or hot spring.[3] The need for these specific conditions severely restricted geothermal's broader global use, as few locations met these natural requirements.

Today, geothermal energy provides only 0.5% of global electricity.[4] Adoption of this energy is much higher in (primarily) volcanic regions, where geothermal resources—those conventional hydrothermal systems—are uniquely close to the surface. Conventional hydrothermal systems

Geothermal has the advantage of being a 24/7 clean baseload energy source. Unlike wind and solar, it is always on. Unlike natural gas and coal, it has no emissions or fuel costs. And unlike nuclear power, there is no need to dispose of radioactive material. Geothermal also has the advantage of inertia for frequency stabilisation and grid integrity.

account for 46% of electricity in Kenya, 33% in Nicaragua, and 30% in Iceland.[5] The United Kingdom has multiple geothermal heat projects, one of which (Bath) dates back to Roman times. The United Kingdom is also exploring geothermal power at the United Downs project.

But now, adoption of geothermal for various uses can be higher in many other locations as well. How?

Because it is hot everywhere underground, and thanks to technological developments from the oil and gas sector and a new generation of geothermal entrepreneurs, we can now access that heat. Geothermal projects that use these technologies are referred to as next-generation geothermal. These new approaches—ones that are reservoir-independent such as engineered geothermal systems and advanced geothermal systems—are expanding the future of geothermal energy beyond all of the previous geographical limitations. (See "The Evolution of Geothermal: From Constraints to Possibilities" later in this chapter.)

These newer technologies—directional drilling, deeper drilling, hydraulic fracturing techniques that create additional pore space for fluid flow, more efficient drill bits, or the introduction of fluids into subsurface areas where they may not naturally be present—can be very effective for electricity generation. They can enable us to create an artificial heat reservoir.

Geothermal Electricity Generation

With these new technologies, in general, the hotter the geothermal resource, the more efficient a geothermal power plant will be at producing electricity. The more efficient the production, the lower the cost. As shown in **Figure 1.2**, geothermal electricity generation is possible with fluid temperatures as low as 93°C using "binary" cycle power plants (in other words, two fluid cycles). Flash steam and dry steam electric turbines (see **Figure 1.3**) can be used when the fluid temperature rises above 180°C.[6] And some higher-temperature installations have started using novel binary-type configurations.

A report published in December 2024 by the International Energy Agency (IEA) says "the potential for geothermal is now truly global" and next-generation geothermal systems have the technical potential "to meet global electricity demand 140-times over."[7] That analysis also notes that by 2035, geothermal could be highly competitive with solar photovoltaics and wind when they are paired with battery storage.

TEMPERATURE OF THE EARTH'S INTERIOR

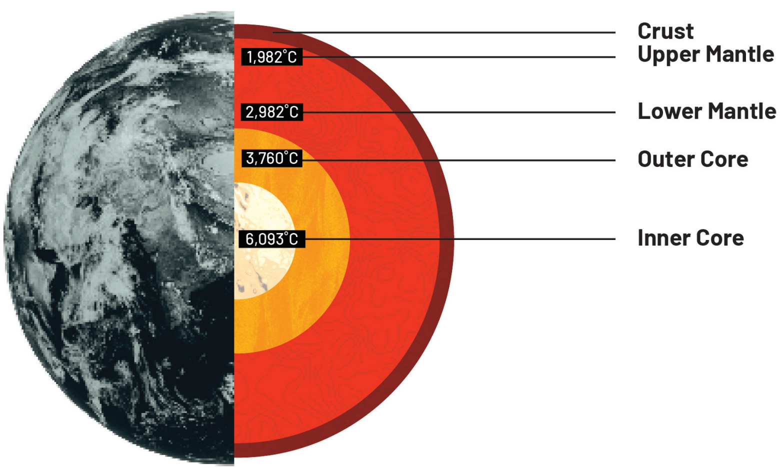


Figure 1.1: The temperature of the core of the Earth exceeds the temperature of the surface of the sun. Because the crust of Earth is an excellent insulator, enough heat is trapped beneath us to power the world hundreds of times over. Source: Project InnerSpace

GEOTHERMAL APPLICATIONS AND TEMPERATURE REQUIREMENTS

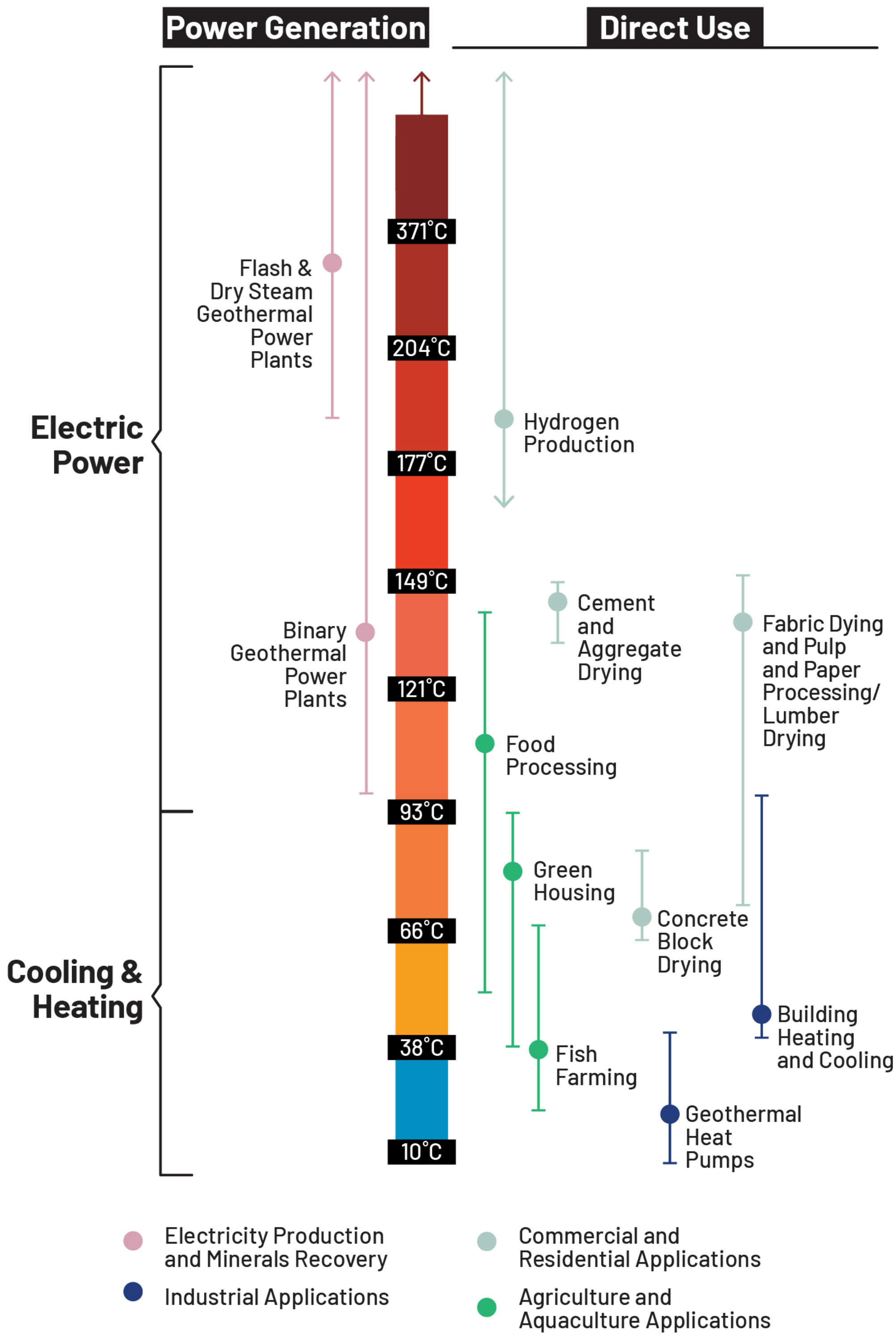


Figure 1.2: Geothermal energy can be used for generating electricity, heating and cooling homes, and manufacturing processes. There are also new and emerging applications such as geothermal energy storage, where the subsurface serves as an earthen battery, and geothermal critical minerals extraction for rare elements such as lithium. Adapted from Porse, S. (2021). *Geothermal energy overview and opportunities for collaboration*. Energy Exchange.

TYPES OF GEOTHERMAL ELECTRICITY GENERATION

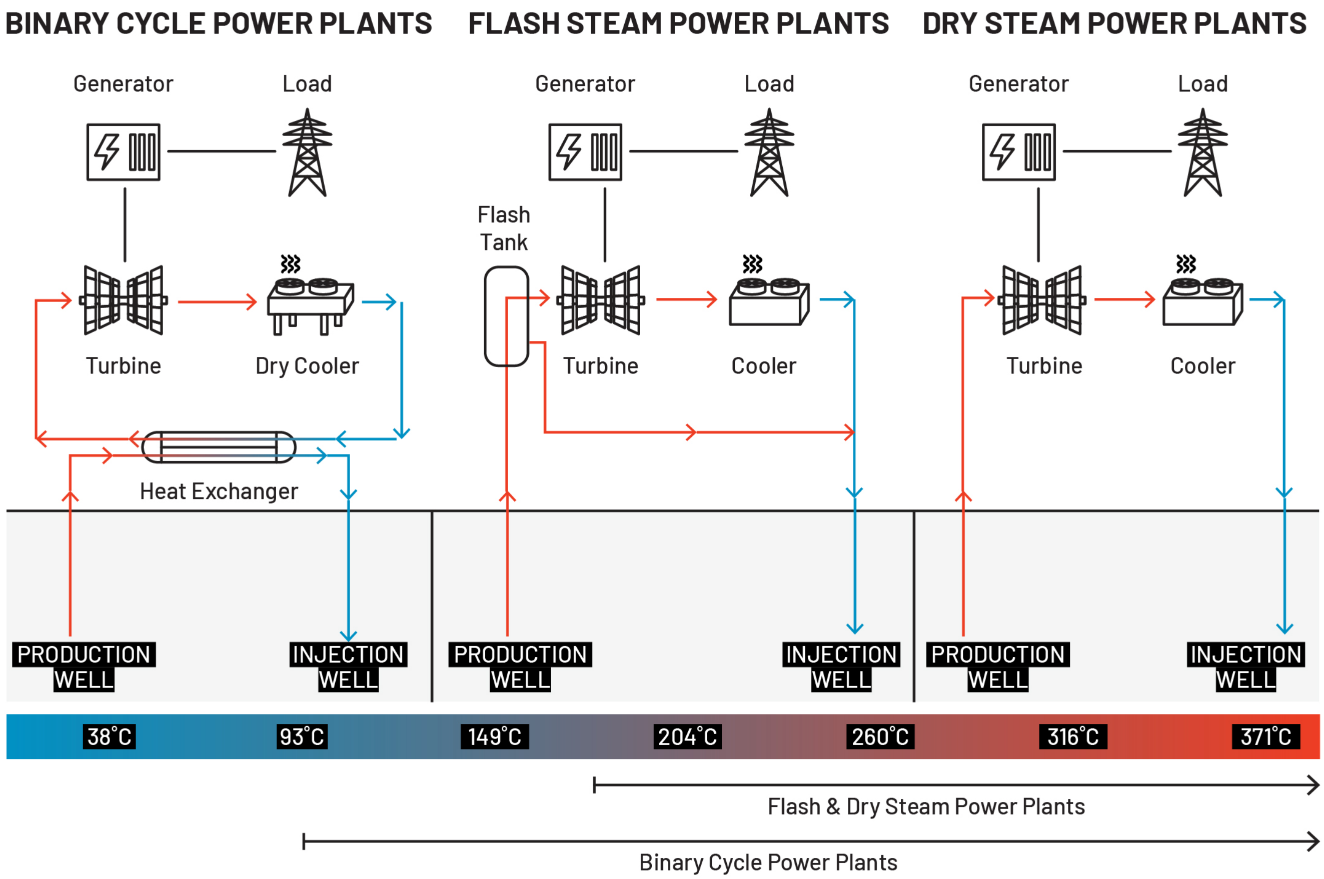


Figure 1.3: There are three primary configurations for generating electricity using geothermal: binary, flash steam, or dry steam. In general with these new technologies, the hotter the underground geothermal resource—whether conventional hydrothermal or next-generation geothermal—the more efficient the surface equipment will be at producing electricity. Binary geothermal electricity generation is possible with fluid temperatures as low as 95°C. Flash and dry steam geothermal electric turbines can be used when fluid temperature rises above ~182°C. Source: Beard, J. C., & Jones, B. A. (Eds.). (2023). *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State*. Energy Institute, University of Texas at Austin.

Globally, heat energy makes up about half of all energy consumption and contributes to about 40% of energy-related emissions.[8] This is a significant enough point to frame another way: Clean geothermal can address almost half of the world's energy demand. Until recently, this opportunity has been almost entirely overlooked.

Direct Use: Geothermal Heating, Cooling, and Industrial Process Heat

Approximately three-quarters of all heat used by humans—from building heating and cooling to industrial processes—is produced by directly burning oil, gas, and coal.[9] The rest is produced from other sources, like burning biomass, or via the electrification of heat—meaning electricity that is produced using solar, wind, or other fuels and then converted back into heat (for instance, electric strip heaters).

INDUSTRIAL PROCESS TEMPERATURES AND HEAT PUMP TECHNOLOGIES

Sector	Process	Temperature °C
Paper	Drying	90-240 °C
	Boiling	110-180 °C
	Bleaching	40-150 °C
	De-inking	50-70 °C
Food and Beverage	Drying	40-250 °C
	Evaporation	40-170 °C
	Pasteurization	60-150 °C
	Sterilization	100-140 °C
	Boiling	70-120 °C
	Distillation	40-100 °C
	Blanching	60-90 °C
	Scalding	50-90 °C
	Concentration	60-80 °C
	Tempering	40-80 °C
	Smoking	20-80 °C
Chemicals	Distillation	100-300 °C
	Compression	110-170 °C
	Thermoforming	130-160 °C
	Concentration	120-140 °C
	Boiling	80-110 °C
	Bioreactions	20-60 °C
Automotive	Resin molding	70-130 °C
Metal	Drying	60-200 °C
	Pickling	20-100 °C
	Degreasing	20-100 °C
	Electroplating	30-90 °C
	Phosphating	30-90 °C
	Chromating	20-80 °C
	Purging	40-70 °C
Plastic	Injection molding	90-300 °C
	Pellets drying	40-150 °C
	Preheating	50-70 °C
Mechanical engineering	Surface treatment	20-120 °C
	Cleaning	40-90 °C
Textiles	Coloring	40-160 °C
	Drying	60-130 °C
	Washing	40-110 °C
	Bleaching	40-100 °C
Wood	Gluing	120-180 °C
	Pressing	120-170 °C
	Drying	40-150 °C
	Steaming	70-100 °C
	Cocking	80-90 °C
	Staining	50-80 °C
	Pickling	40-70 °C
Several sectors	Hot water	20-110 °C
	Preheating	20-100 °C
	Washing/Cleaning	30-90 °C
	Space heating	20-80 °C

Temperature scale: 40, 60, 80, 100, 120, 140, 160, 180, 200

Technology Readiness Level

- Conventional heat pump less than 80°C, established in industry
- Commercially available high-temperature heat pump, 80°-120°C
- Prototypes and technology demonstration, 120°C+
- Ongoing laboratory research and development, 150°C+

Figure 1.4: Rough technology readiness levels of high-temperature heat pumps as of July 2023. Geothermal can enable industrial processes without heat pumps; however, combining the two technologies may prove even more useful. High-temperature industrial heat pumps above 100°C have seen significant advances in recent years. Source: Arpagus, C., et al. (2023). *Industrial heat pumps: Technology readiness, economic conditions, and sustainable refrigerants*. American Council for an Energy-Efficient Economy (ACEEE).

COOLING AND HEATING WITH GROUND SOURCE HEAT PUMPS

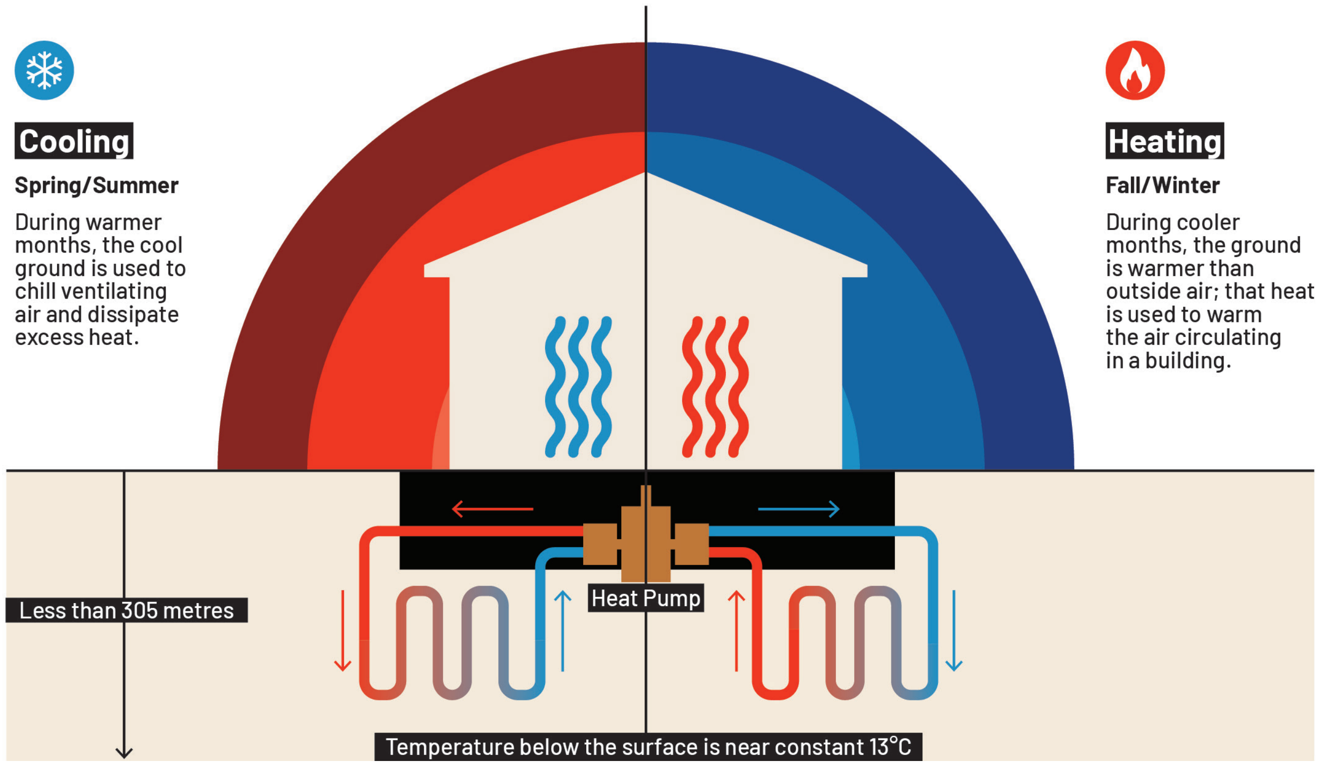


Figure 1.5: The constant temperature of the ground helps improve the efficiency of ground source heat pumps. Source: Beard, J. C., & Jones, B. A. (Eds.). (2023). *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State*. Energy Institute, University of Texas at Austin.

In the United Kingdom, the heating and cooling of buildings is the largest consumer of energy at 37%. The next largest is transportation at 27%.[10] That figure is higher in the residential sector in Europe.[11]

The good news is that geothermal technologies that can help meet this demand already exist: ground-source heat pumps (geothermal heat pumps) and geothermal district heating (also known as thermal energy networks, or TENS; see the chapter on direct-use geothermal in this report for more information). Geothermal heating and cooling has significant potential in the United Kingdom and can meet much of the heating and cooling demand with far less electricity needed than any other heating and cooling option.

Industrial process heat is used to make everything from pens to paper, pasteurised milk to pharmaceuticals (see **Figure 1.4**). Four of the most critical materials in the modern world—fertiliser, cement, steel, and plastics—all require significant amounts of heat to produce. In the industrial sector, thermal consumes more than half of total energy use and contributes the majority of the sector's emissions.[12]

All building heating and cooling (heating, ventilating, and air-conditioning; HVAC) and 30% of heat used for manufacturing processes worldwide use temperatures below 150°C (see **Figure 1.5**).[13] In many parts of the world, geothermally derived heat at this temperature is currently comparable in cost with coal, biomass, solar, and wind. The IEA report estimates that next-generation geothermal could economically satisfy 35% of all global industrial thermal demand for processes requiring temperatures below 200°C. The use of next-generation geothermal could thus save about 750 megatons of carbon dioxide (CO_2) emissions (equivalent to the annual emissions of Canada, the world's 12th-largest emitter).[14] **Figure 1.4** illustrates the range of sectors and processes that could use geothermal heat, with or without heat pumps, depending on whether a facility can reach the necessary heat at a reasonable subsurface depth.

GEOTHERMAL COOLING AND HEATING NETWORK

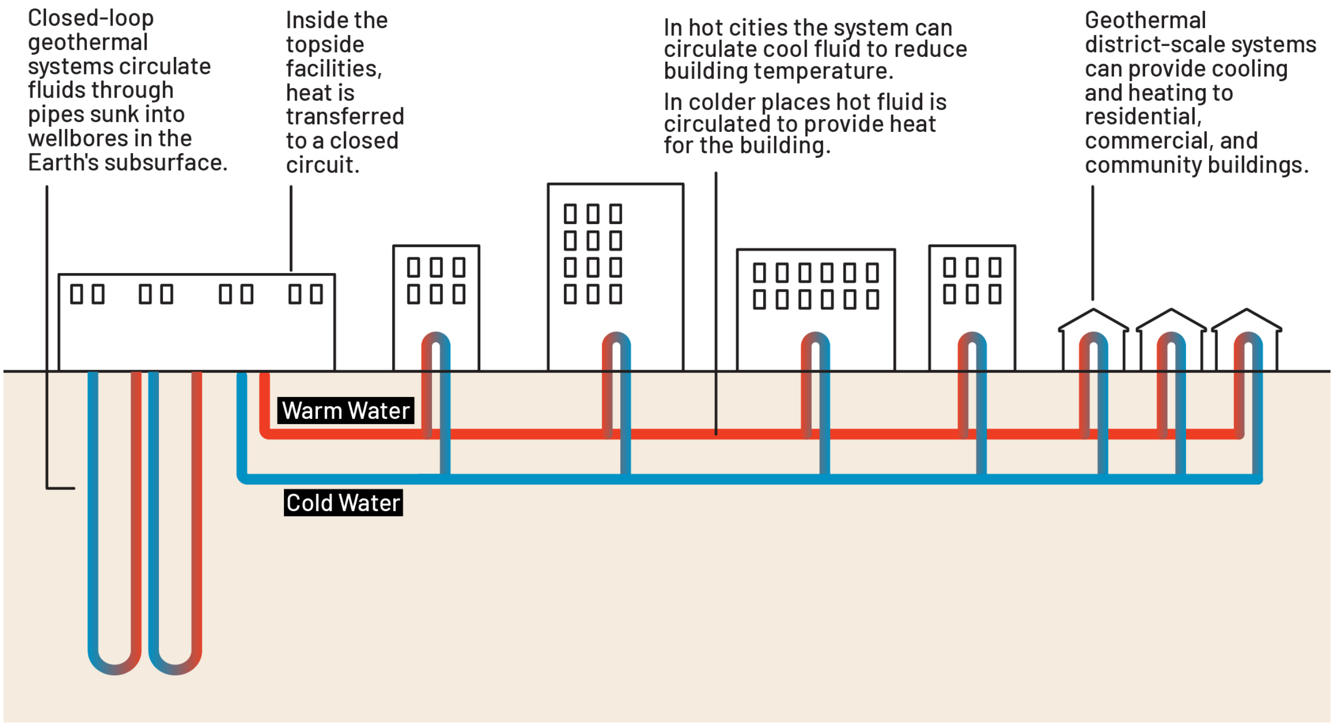


Figure 1.6: District heating system fluid is typically brought to the surface at a target temperature of around 21°C. That fluid is then passed through a heat pump to provide hot water in the winter for heating and cold water in the summer for cooling. This style of heating and cooling can be more than twice as efficient as traditional HVAC systems because the thermal load is shared between buildings. Source: Adapted from U.S. Department of Energy. *Geothermal district heating & cooling*.

COMPARING CAPACITY FACTOR

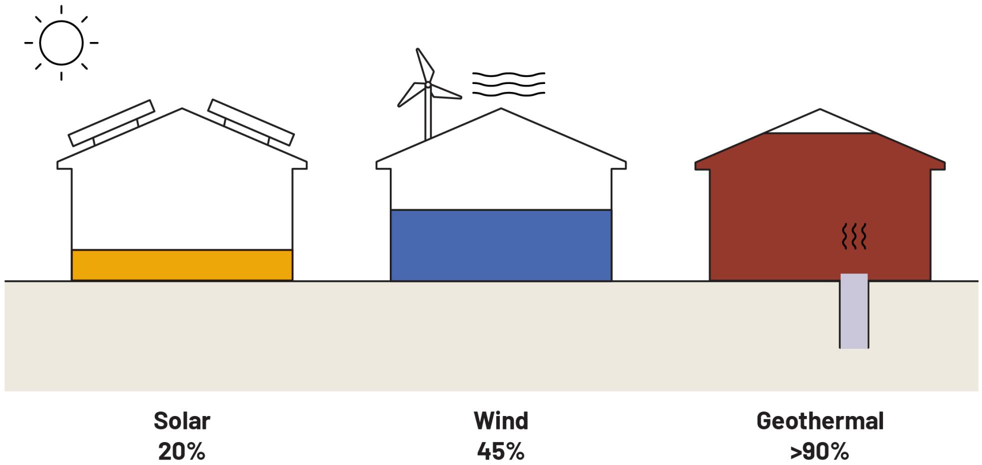


Figure 1.7: Capacity factor is the percentage of time that a power plant is generating electricity in a given day. Source: Adapted from International Energy Agency (IEA). (2024). *The future of geothermal energy*. IEA.

Geothermal Energy Storage

The United Kingdom's National Grid is a delicate, vital system requiring constant monitoring to balance electricity production against electricity demands. With more electrons flowing onto the grid from intermittent energy sources such as wind and solar, concerns about having power when needed have highlighted the need for energy storage.[15] Today, hydroelectric storage provides most global energy storage capacity,[16] and recent years have seen a significant expansion in the deployment of batteries for energy storage. A new approach, underground thermal energy storage—also known as geothermal energy storage (GES)—may offer an additional option.

GES systems capture and store waste heat or excess electricity by pumping fluids into natural and artificial subsurface storage spaces (e.g., aquifers, boreholes, mines). GES can be primarily mechanical, with hydraulic fracturing techniques storing pressurised fluid in subsurface reservoirs. Or it can be mechanical and thermal, with pressure and heat combined to return more energy than was required to pump the fluid underground.

Critical Minerals Extraction

Fluids, or brines, are often produced from geothermal systems. These brines are rich in dissolved minerals, including lithium, which can be harvested to meet the growing demand for lithium-ion batteries in electric vehicles and electric-grid storage solutions. This dual-purpose approach—providing clean energy and a domestic lithium source—could lower lithium extraction's environmental impact compared with traditional mining and improve the economics of a geothermal project.

A number of companies have been drilling and testing the potential of extracting lithium from the brines in Cornwall, where concentrations of lithium ions are greater than 100 ppm.[17] The company Cornish Lithium hopes to drill the first commercial production well soon.[18]

COMPARING SURFACE FOOTPRINT

Geothermal has the smallest footprint of any renewable energy source

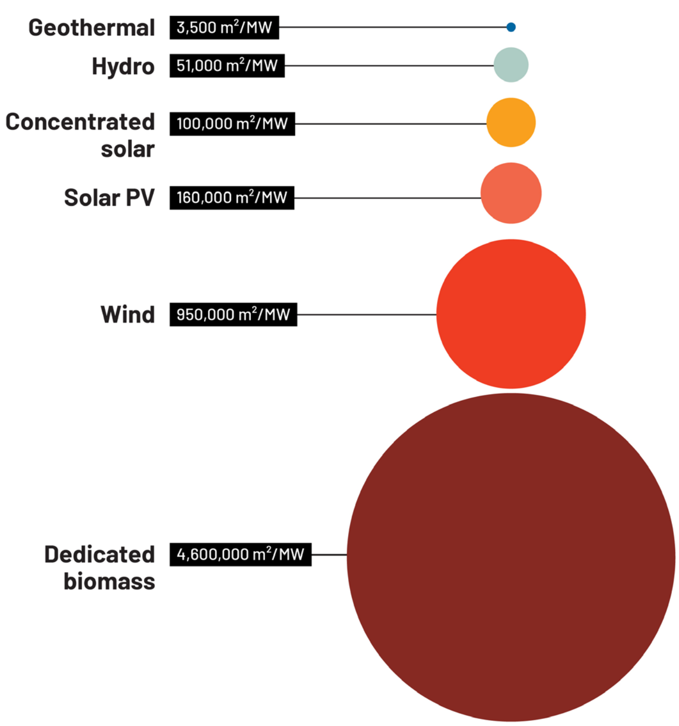


Figure 1.8: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables and coal. PV = photovoltaic. Source: Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS ONE, 17*(7), e0270155; National Renewable Energy Laboratory (NREL). (2022). *Land use by system technology.*

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

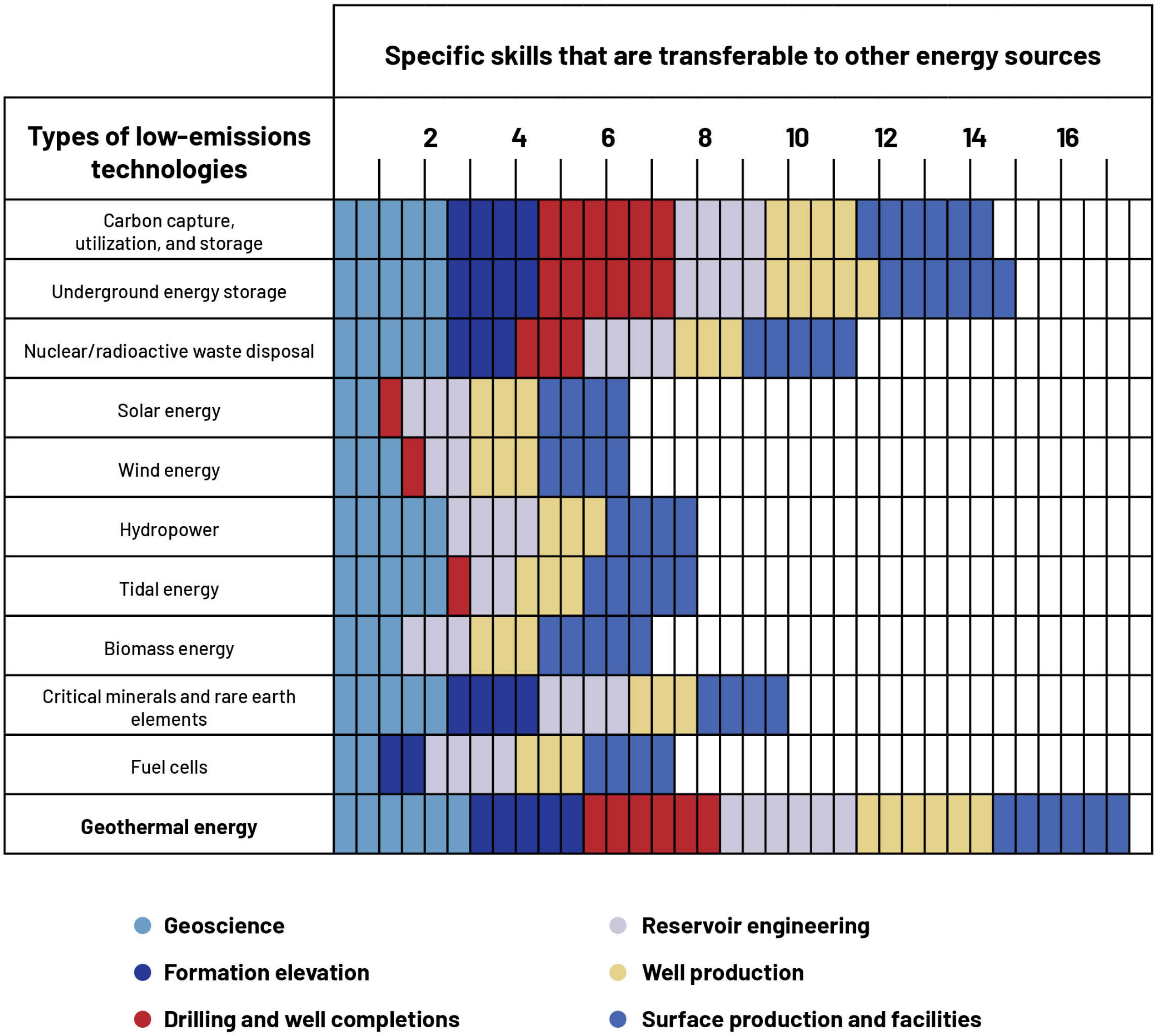


Figure 1.9: As shown, geothermal ranks highest when considering the potential impact of transferring oil and gas skills into other energy transition and low-carbon technologies. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023). *Oil and gas skills for low-carbon energy technologies*. Society of Petroleum Engineers Annual Technical Conference and Exhibition.

THE EVOLUTION OF GEOTHERMAL: FROM CONSTRAINTS TO POSSIBILITIES

As shown in **Figure 1.10**, the Earth's crust contains more potential thermal energy than is present in all fossil fuels and natural nuclear fissile material combined. The challenge, then, is how to identify the areas and technologies that can tap into that potential energy most efficiently and economically.

Figure 1.11 summarises the latest geothermal extraction technologies. The following sections describe these technologies in greater detail.

Engineered geothermal system (EGS): This kind of system uses both directional drilling and hydraulic fracturing to create artificial permeability, allowing for the use of geothermal energy far beyond the regions with naturally occurring hydrothermal. EGS extracts heat by introducing fluids into the subsurface, opening fissures in relatively impermeable rock, and circulating fluid between one or more wells. The more fractures, the greater the surface area for the flowing fluid to conduct heat from rock.

Although EGS was conceived as early as the 1970s,[19] its scalability has only been possible because of cost reductions, transferable skill sets from the oil and gas and mining industries (see **Figure 1.9**), and technological advances in drilling and stimulation techniques commercialised by the oil and gas industry over the past few decades. However, unlike hydraulically fractured oil and gas wells—which are only intended for one-way extraction of oil and gas—an EGS is designed to reuse fluids, so the same liquid flows continuously through hot rock in a convective loop.

EGS generally targets hot-rock formations with few natural fractures and limited natural permeability to minimise uncontrolled fluid loss. Well depths can vary depending on where sufficient temperatures and appropriate stress conditions are found.[20]

Fracturing methods are subject to some uncertainty; even the most accurate engineering model cannot perfectly predict how a subsurface rock will open or how fluids will flow. Nonetheless, as of mid-2025, EGS is seeing rapid technological advances, including at the U.S. Department of Energy's Frontier Observatory for

HOW ABUNDANT IS GEOTHERMAL ENERGY?

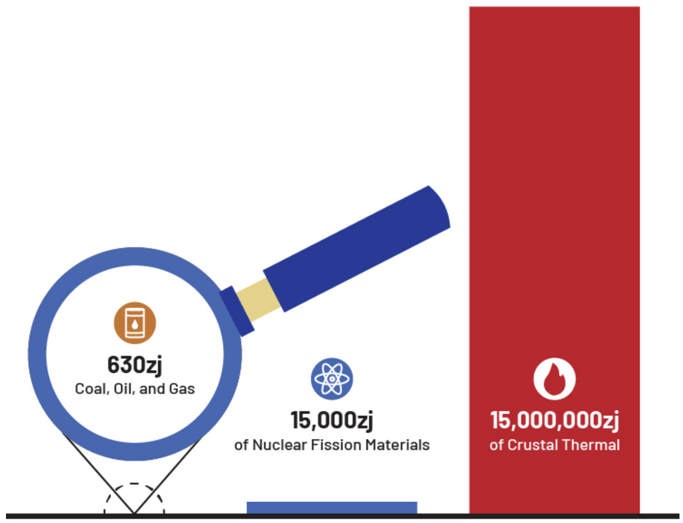


Figure 1.10: Total heat energy in Earth's crust, compared to that contained in fossil fuels and naturally occurring fissile materials. Note that total fossil fuels, when compared with crustal thermal energy, is the equivalent of less than one pixel at the bottom of the graphic, shown magnified to illustrate scale. Measurements in zettajoules ("zj"). Source: Beard, J. C., & Jones, B. A. (Eds.). (2023). *The future of geothermal in Texas: The coming century of growth and prosperity in the Lone Star State.* Energy Institute, University of Texas at Austin. Adapted from Dourado, E. (2021). *The state of next-generation geothermal energy.*

Research in Geothermal Energy and from EGS start-ups. Along with advances in technology, EGS is also being scaled for use in industrial-size projects. Fervo, a Texas-based EGS start-up, has signed a number of Power Purchase Agreements with utilities and companies across the western United States.[21]

Advanced geothermal system (AGS): Like EGS, AGS eliminates the need for permeable subsurface rock. Instead, AGS creates and uses sealed networks of pipes and wellbores closed off from the subsurface, with fluids circulating entirely within the system in a "closed loop."

Today, many AGS geothermal well designs are in development, including single well, U-shaped well "doublets" with injection and production wells and subsurface radiator designs. All of these designs use only their own drilled pathways; none require a conventional hydrothermal resource or hydraulic fracturing to create

TYPES OF GEOTHERMAL ENERGY SYSTEMS

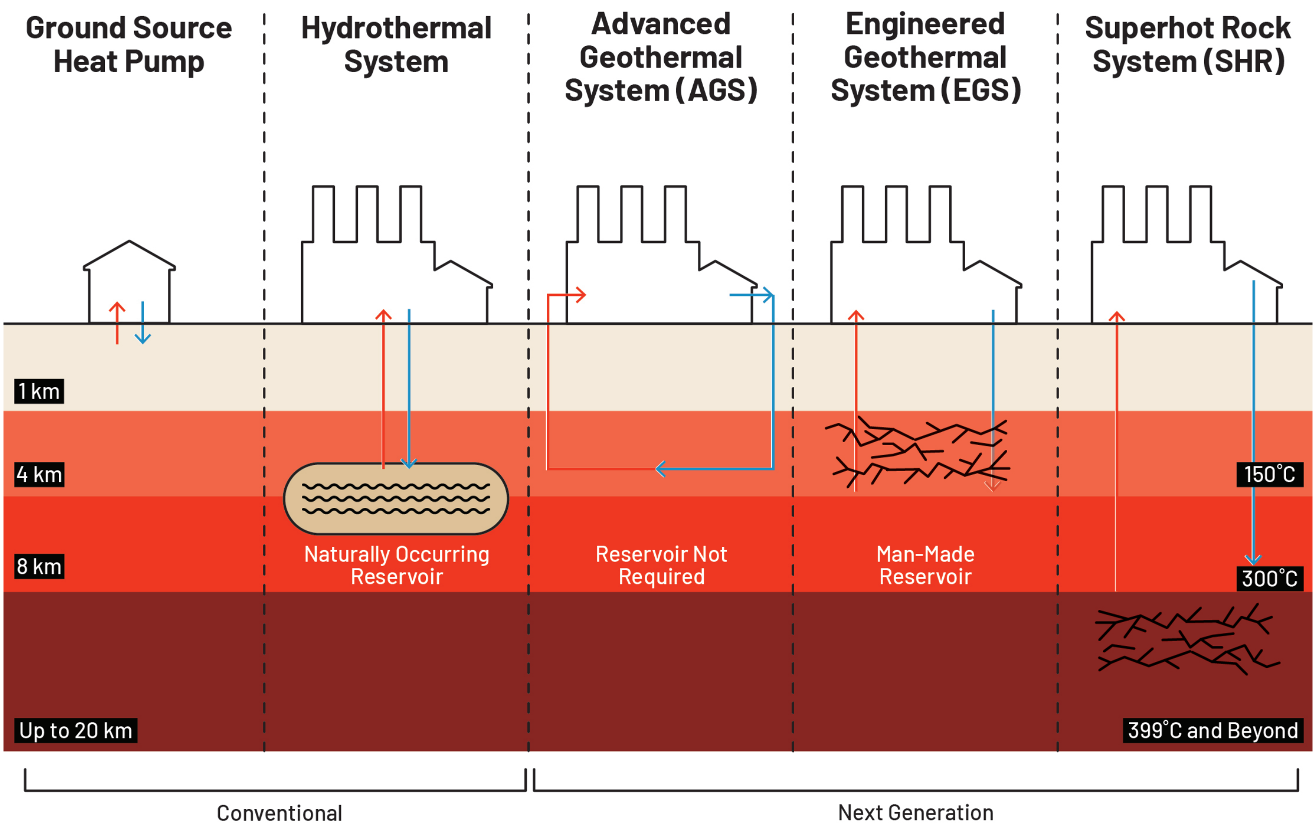


Figure 1.11: Comparison of key geothermal power generation technologies illustrating variations in resource type and heat extraction method for electricity production and industrial direct use. Ground source heat pumps (GSHPs) are also shown, illustrating a building heating scenario. In the GSHP scenario, fluid flow can be reversed to provide cooling. Source: Adapted from D'avack, F., & Omar, M. (2024). *Infographic: Next-generation technologies set the scene for accelerated geothermal growth*. S&P Global.

fluid pathways. All geothermal energy extraction relies on conduction, the heat transfer from hot rock to fluid (see "Geothermal Geology and Heat Flow" for more details). Thus, unlike EGS, which benefits from the substantial surface area created by hydraulic fracturing, AGS has only the walls of its wells to conduct heat. As such, an AGS must drill deeper, hotter, or longer well systems than an EGS to conduct similar amounts of heat energy. Because an AGS does not exchange fluids with the subsurface, it can more easily use engineered, nonwater working fluids, such as supercritical carbon dioxide.

An AGS can be developed in virtually any geological condition with sufficient subsurface heat. While an AGS guarantees a more definitive pathway for fluid flow in the subsurface relative to fracked EGS wells, drilling sufficiently long and deep AGS wells can be challenging and expensive.

Superhot rock (SHR): SHR is a type of next-generation geothermal targeting extremely deep, high-pressure rocks above approximately 373°C, the temperature at which water goes supercritical. SHR has the potential to revolutionise power production globally with superheated, supercritical geothermal steam capable of highly efficient heat transfer from the subsurface. Theoretically, SHR can employ either EGS or AGS well technologies, but no commercial SHR geothermal project has yet been developed because advances are needed in drilling technologies, rates, and costs to enable the economically competitive development of this next-generation concept.[22]

GEOTHERMAL GEOLOGY AND HEAT FLOW

The movement of heat from Earth's hot interior to the surface—what geologists call *heat flow*—is controlled by the geology of the planet. Heat from the core and mantle, as well as the decay of naturally occurring radioactive deposits in the Earth's crust, combine and emanate toward the surface of the planet.

Conduction, Advection, Convection, and Radiation

Heat flow in the Earth results from physical processes that contribute, to varying degrees, to the available heat in a geothermal resource.

- **Conduction:** The transfer of energy between objects in physical contact through molecular vibrations without the movement of matter. Conduction is efficient in some materials, like metals, and inefficient in others. Rock is a relatively poor conductor, but conduction is nonetheless considerable in the interior of the Earth.

- **Advection:** The transfer of heat due to the movement of liquids from one location to another. In geology, advection occurs in the movement of magma and groundwater, where the fluid carries heat as it moves through cracks, fractures, and porous rock formations. Advection is different from conductive heat transfer, which relies solely on direct contact between particles to transfer heat.

- **Convection:** A cycle of heat transfer involving conduction and advection that occurs when matter is heated, becomes less dense, rises, cools, increases in density, and sinks. Convection typically creates circulating loops of rising and sinking material. The Earth's mantle is almost entirely solid but behaves as a highly viscous fluid, thus allowing for convective heat transfer. The mantle's movement is extremely slow relative to human life but becomes significant over geologic periods.

- **Radiation:** Energy that moves from one place to another as waves or particles. Certain areas in the Earth's crust have higher concentrations of elements with natural radiation, like uranium-238, uranium-235, thorium-232, and potassium-40.

Geology and Energy Extraction

The geological processes described previously interact to contribute to geothermal energy extraction under three common geological settings:

Convection-Dominated

1. Geologically open geothermal systems: In these systems, water circulates freely (e.g., the Great Basin in the United States). These systems are typically targeted for power generation and open-loop heat.

Conduction-Dominated

2. Geologically closed systems, with limited porosity/permeability: Water does not flow naturally in these systems, and geothermal energy extraction requires engineered "enhancements" (e.g., hydraulic fracturing).

3. Geologically closed systems, with natural porosity/permeability: These systems have natural pore spaces to a certain depth, allowing some fluid flow. This is beneficial when considering storage for heating and cooling.

COMPARISON OF EXISTING AND EMERGING GEOTHERMAL TECHNOLOGIES AND CONCEPTS

Existing Geographies, Applications, and Technologies			
	Conventional Hydrothermal Geothermal	District Heating	Ground Source Heat Pumps
Basic Concept	Relies on natural hydrothermal systems with hot water and porous rock	Provides heating through interconnected building networks, using centralised geothermal systems	Uses shallow ground temperature stability to heat and cool buildings
Working Fluid	Naturally occurring fluids	Water or steam circulated through centralised pipes to buildings	Typically, water or antifreeze or refrigerant in a closed-loop system
Reservoir Type	Open to natural hydrothermal reservoir	Central reservoir supplying district buildings with hot water or steam	Closed-loop system buried at shallow depth
Geological Requirements	Natural hot aquifers in porous rock formations	Typically, sedimentary aquifers but can be used near conventional geothermal systems such as Iceland	No special geology; suitable for almost any location
Temperature Range	150°C - 350°C	Generally, around 80°C-100°C	All ranges
Drilling Depth	Shallow or deep, depending on hydrothermal location	Shallow to medium depth, depending on temperature requirements	Very shallow, typically between 3 metres and 152 metres for residential to deeper for industrial heat pumps
Scalability	Limited to those few regions with natural hydrothermal conditions	Scalable anywhere concentrated clusters of buildings can share interconnected hot water or steam	Highly scalable; can be installed almost anywhere
Environmental Impact	Lower impact but dependent on natural resource conditions	Low impact; minimal drilling required and low emissions	Minimal impact; closed system without subsurface interaction
Examples of Use	Traditional geothermal power plants, direct-use heating in regions with hydrothermal conditions	Geothermal district heating in Iceland, Paris, and some U.S. cities	Commonly used for residential and commercial building heating and cooling but increasing in use for industrial heat when combined with industrial heat pumps
Primary Advantages	Established technology in areas with existing hydrothermal resources	Efficient and cost-effective heating for multiple buildings in urban or suburban networks	Proven, simple, reliable system for year-round building climate control and a key technology for data center cooling
Challenges	Limited to specific geographical areas with natural conditions	High initial setup cost, complex infrastructure needed to connect multiple buildings	Higher upfront cost relative to conventional HVAC

Figure 1.12: Existing and new geographies, applications, and technologies.

New Geographies, Applications, and Technologies			
	Superhot Rock	**Sedimentary Geothermal System**	**Engineered Geothermal System**
Basic Concept	Exploits extremely high temperatures at great depths	Utilises sedimentary rock formations that may contain hot water in pores; can involve low-porosity rocks	Uses hydraulic fracturing to create artificial permeability for heat extraction
Working Fluid	Water, potentially reaching supercritical state	Typically, water from aquifers in sedimentary rocks; may require pumped circulation	Recirculates same fluid (water or otherwise) through fractures in hot rock
Reservoir Type	Open, targeting superhot rock	Open, with naturally porous and permeable rock acting as the reservoir for fluid flow	Open to reservoir with engineered fractures
Geological Requirements	High temperatures (above 373°C)	Sedimentary rock formations with some porosity and permeability for water flow	Requires heat and engineered permeability; benefits from high rock surface area for heat transfer
Temperature Range	373°C + (targeting supercritical steam)	Can vary (from low ~ 20°C to >200°C)	Typically, 50°C -300°C
Drilling Depth	Significant depth (potentially 10+ kilometres)	Variable depth range, from 500 metres to 8,000 metres	Typically < 3,000 metres, as high pressure and high drilling would incur additional costs
Scalability	Potentially scalable with improved deep-drilling technology	Scalable; 73% of continental land mass contains sedimentary basins	Scalable with advances in hydraulic fracturing and drilling but potentially limited to areas where hot dry rock is < 3,000 metres and does not contain natural fractures that will increase uncertainty and potential fluid losses
Environmental Impact	High-impact drilling; needs tech improvements for feasibility	Typically low	Possible induced seismicity, depending on geology; significant water use despite reuse of working fluid
Examples of Use	Experimental; no large-scale deployment yet	Residential and industrial heat applications: Southampton, United Kingdom; Paris	Department of Energy's FORGE project, Fervo's Project Red in Utah
Primary Advantages	High efficiency in power generation due to superheated steam	Cost-effective and scalable, particularly in well-explored basins. Stacked aquifer systems mean these basins could supply tiered geothermal, ranging from low-temp direct use to higher-temp electricity generation—and geothermal energy storage.	Unlocks geothermal potential in non-ideal rock formations with artificial permeability
Challenges	High-cost drilling; significant research and development required	Limited to areas with sufficient sedimentary rock in basins with moderate temperatures	Subsurface unpredictability in fracturing; possible seismic risks; high initial costs; high water use

New Geographies, Applications, and Technologies			
	Advanced Geothermal System	Geothermal Cooling	Thermal Storage
Basic Concept	Closed-loop system with no fluid exchange with subsurface	Uses ground or subsurface temperatures to provide cooling in buildings or industrial processes	Stores thermal energy in subsurface reservoirs for later use in heating, cooling, or power generation
Working Fluid	Circulates fluid (water, supercritical CO_2, or otherwise) entirely within sealed, engineered system	Water or refrigerant circulated to transfer cool temperatures to buildings	Water or other heat-transfer fluid for thermal storage; optimal recovery in pressurised reservoirs
Reservoir Type	Closed to reservoir; uses sealed pipes and engineered pathways	Closed or open loop with pipes in shallow ground, utilising ground cooling	Closed underground reservoirs or aquifers for energy storage, utilising natural or engineered pathways
Geological Requirements	No permeability needed; functions anywhere with heat availability	Generally, no special requirements; suitable for most shallow grounds with stable temperatures	Requires subsurface space with adequate pressure retention for heat and energy storage
Temperature Range	Variable; typically requires hotter rock (> 100°C) to achieve competitive heat extraction	Utilises both the shallow natural ground temperature (~13°C) for cooling purposes and the deep ground temperature with absorption cooling technology	Flexible; can be adapted for seasonal thermal storage or for high-temperature dispatch
Drilling Depth	Potentially deeper to access high heat, as system is inherently limited in the surface area available for conductive heat transfer	Both shallow, typically between 3 metres and 152 metres, as cooling requires lower temperatures, and deeper >100°C with absorption cooling technology	Depth varies; can be shallow for seasonal storage or deep for high-temperature storage
Scalability	Scalable, as system is independent of subsurface permeability	Scalable for residential, commercial, and industrial applications	Scalable; suitable for integration with renewable sources for energy balancing
Environmental Impact	Low impact; closed system with no interaction with surrounding rock fluids	Minimal impact; closed-loop systems ensure no ground contamination	Low impact; relies on pressure management for safe thermal storage
Examples of Use	Various closed-loop designs in development, technologies such as Eavor-Loop and GreenFire Energy's GreenLoop	ADNOC, in collaboration with the National Central Cooling Company PJSC (Tabreed), has initiated operations at G2COOL in Masdar City, Abu Dhabi.	Underground thermal energy storage, borehole thermal energy storage, and aquifer thermal energy storage
Primary Advantages	No fluid exchange with subsurface; suitable for areas lacking natural aquifers	Cost-effective cooling in regions with high air conditioning demand; reduces HVAC costs; could be used to optimise data center cooling	Provides energy storage to balance renewable power and support grid stability
Challenges	Expensive drilling costs; reduced heat transfer area compared with EGS; requires wells to touch more rock for heat exchange	Installation and initial costs; suitable ground area needed for installation	Requires specific geological settings for pressure control; drilling costs can be high

CHAPTER REFERENCES

1 Unwin, J. (2019, October 8). The oldest geothermal power plant in the world. *Power Technology.* https://www.power-technology.com/features/oldest-geothermal-plant-larderello/. Geothermal electricity was used as early as 1960 in the United States. See Rafferty, K. (2000, January). *Geothermal power generation: A primer on low-temperature, small-scale applications.* Geo-Heat Center. https://www.osti.gov/etdeweb/servlets/purl/894040#

2 National Renewable Energy Laboratory. (2017). *Annual technology baseline: Geothermal.* https://atb-archive.nrel.gov/electricity/2017/index.html?t=gt&s=ov

3 Datta, A. (2023). *Hot rocks: Commercializing next-generation geothermal energy.* Institute for Progress. https://ifp.org/hot-rocks-commercializing-next-generation-geothermal-energy/

4 IRENA (International Renewable Energy Agency) & IGA (International Geothermal Association). (2023). *Global geothermal: Market and technology assessment.* IRENA & IGA. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Feb/IRENA_Global_geothermal_market_technology_assessment_2023.pdf

5 U.S. Energy Information Administration. (n.d.). *International: Electricity, 2019–2023* [Data set]. https://www.eia.gov/international/data/world/electricity/electricity-generation

6 See Bhatia, S. C. (2014). *Advanced renewable energy systems.* Woodhead Publishing India. https://doi.org/10.1016/B978-1-78242-269-3.50014-0
7 International Energy Agency (IEA). (2024). *The future of geothermal energy.* IEA. https://www.iea.org/reports/the-future-of-geothermal-energy/executive-summary
8 International Energy Agency (IEA). (2023). *Renewables 2023: Heat.* https://www.iea.org/reports/renewables-2023/heat
9 International Energy Agency (IEA). (2022). *Renewables 2022: Renewable heat.* https://www.iea.org/reports/renewables-2022/renewable-heat
10 U.S. Energy Information Administration. (2023). *Use of energy explained: Energy use in homes.* https://www.eia.gov/energyexplained/use-of-energy/homes.php
11 European Commission. (n.d.). *Energy consumption in households.* Eurostat. Retrieved April 7, 2025, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_consumption_in_households
12 Bellevrat, E., & West, K. (2018). *Clean and efficient heat for industry.* International Energy Agency. https://www.iea.org/commentaries/clean-and-efficient-heat-for-industry
13 Solar Payback. (2017, April). *Solar heat for industry.* https://www.solar-payback.com/wp-content/uploads/2020/06/Solar-Heat-for-Industry-Solar-Payback-April-2017.pdf#page=2
14 IEA, 2024.
15 Webster, M., Fisher-Vanden, K., & Wing, I. S. (2024). The economics of power system transitions. *Review of Environmental Economics and Policy, 18*(1). https://doi.org/10.1086/728101
16 U.S. Energy Information Administration. (n.d.). *Electricity explained: Energy storage for electricity generation.* https://www.eia.gov/energyexplained/electricity/energy-storage-for-electricity-generation.php
17 Glover, P., Brabin, J., Torvela, T., & Yeomans, C. (2025). *Fracture modelling and geothermal lithium* [Abstract]. EGU General Assembly 2025. Vienna, Austria. https://meetingorganizer.copernicus.org/EGU25/EGU25-9935.html
18 Cornish Lithium. (n.d.). *Trelavour Lithium Project.* https://cornishlithium.com/trelavour-lithium-project
19 Kelkar, S., WoldeGabriel, G., & Rehfeldt, K. (2016). Lessons learned from the pioneering hot dry rock project at Fenton Hill, USA. *Geothermics, 63*, 5–14. https://doi.org/10.1016/j.geothermics.2015.08.008
20 U.S. Department of Energy. (2024). *Pathways to commercial liftoff: Next-generation geothermal power* [YouTube video]. https://www.youtube.com/watch?v=rZeObAoWAjg
21 Fervo Energy. (2024, September 10). *Fervo Energy's record-breaking production results showcase rapid scale up of enhanced geotherma*l [Press release]. https://fervoenergy.com/fervo-energys-record-breaking-production-results-showcase-rapid-scale-up-of-enhanced-geothermal/
22 Clean Air Task Force. (n.d.). *Superhot rock geothermal.* https://www.catf.us/superhot-rock/

Part II

Geothermal Resources and Applications in the UK

Chapter 2

The Geothermal Opportunity in the United Kingdom

Jordan Weddepohl, Mark Griffiths, and Michael Chendorain, Arup

Geothermal can strengthen the UK grid by shifting heat demand off electricity while also adding dependable, weather-independent supply in select locations. For the National Health Service, hospitals' constant heat loads and public procurement can turn geothermal from promising to bankable, lowering emissions and bills while improving resilience. With heat resources widely available, scaling geothermal can cut peaks, reduce costs to consumers, and ease network constraints for decades to come.

The United Kingdom depends heavily on foreign energy. In 2024, net energy imports rose to more than 43% of all energy used.[1] The top import, from Norway, was about 31 billion cubic metres of natural gas, representing roughly 75% of the UK's total gas imports and nearly half of the country's total gas consumption. Yet, the countries that make up the United Kingdom—England, Scotland, Northern Ireland, and Wales—sit on top of a major untapped opportunity.

The UK is home to considerable underground geothermal resources. Project InnerSpace estimates that there are around 3,900 gigawatts of total technical potential for heating and cooling (down to 3.5 kilometres) —and about 25 gigawatts of total technical potential for electricity generation (down to 5 kilometres). (See Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface Geology," and Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors," for extensive mapping of the subsurface resources available to develop geothermal.)

This chapter outlines the projected size of the UK's geothermal opportunity within the context of the nation's current and future energy mix, the potential costs and benefits of geothermal deployment, and tangible opportunities for geothermal expansion across the UK.

SETTING THE SCENE: ENERGY USE IN THE UNITED KINGDOM

Electricity

- In 2025, UK winter peak electricity demand was 47.4 gigawatts, with total annual demand reaching 319,000 gigawatt-hours.[2]
- In 2025, the UK generated roughly 289 terawatt-hours of electricity, with renewables contributing about 44% (127 terawatt-hours). Wind supplied 29.7% (85 terawatt-hours), with a peak capacity of 23.8 gigawatts, while solar produced 6.5% (19 terawatt-hours) and peaked at 14 gigawatts.[3]
- The National Energy System Operator Future Energy Scenarios predict that by 2035, electricity demand will increase to around 450 terawatt-hours, and around half of all homes will have heat pumps, which will more than double electricity demand for home heating, from 25 terawatt-hours to 57 terawatt-hours.[4]

Heating and Cooling

- In 2025, UK annual heating demand was more than 572,000 gigawatt-hours.[5]
- In England, heat networks currently supply around 12.4 terawatt-hours, with targeted expansion to 27 terawatt-hours by 2035—an increase from 3% to 7% of total heat demand. In Scotland, heat network supply targets 7 terawatt-hours by 2035.[6]
- In 2023, around 80% of household bills were spent on heating and hot water.[7]
- UK cooling demand was around 15.5 terawatt-hours in 2021[8] and is expected to rise sharply; London is projected to see the fastest cooling demand growth globally.[9,10]

THE UK'S ENERGY MIX, 2024

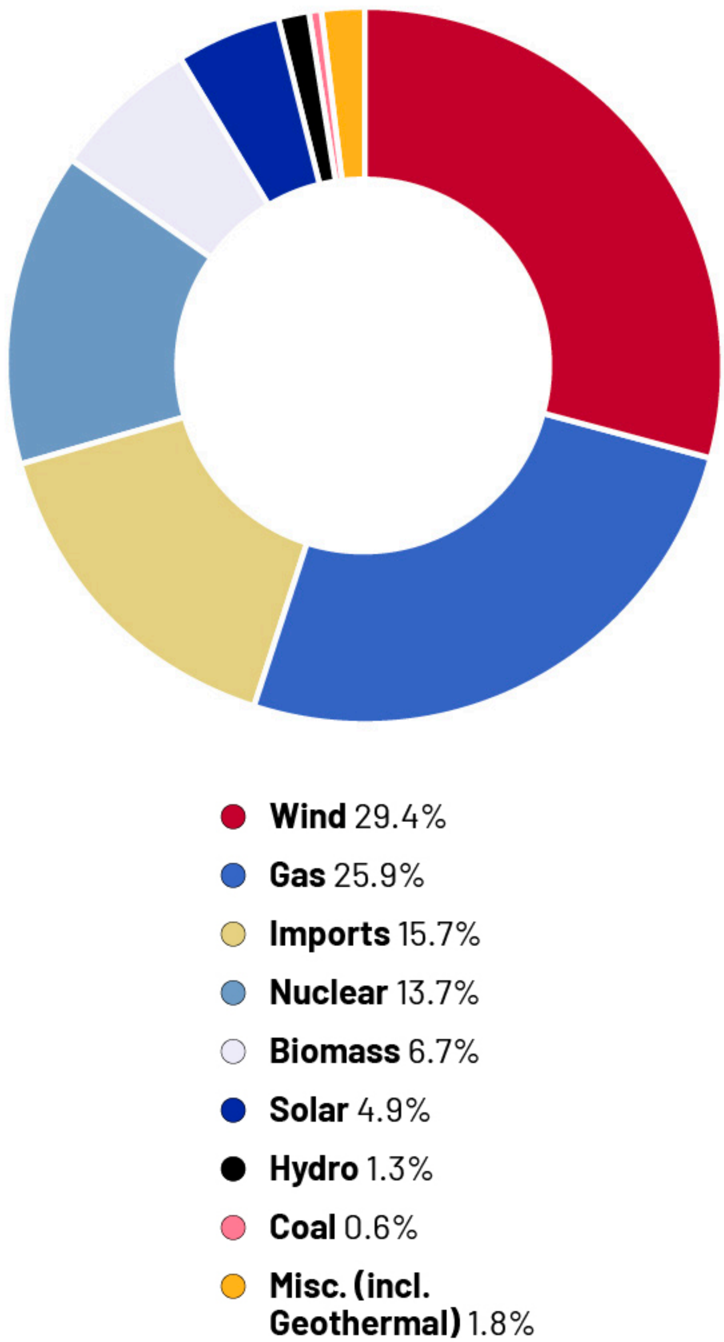


Figure 2.1: The United Kingdom's energy mix as of 2024. Source: Energy Oasis. (n.d.). *The UK's energy mix 2024: Progress, challenges, and what lies ahead*.

Geothermal resources could provide the country with a range of domestic, reliable, and secure energy for centuries. Crucially, scaling geothermal—especially for heat, where the resource is most widely available across the UK—can reduce peak electricity demand, lower system-balancing costs, and ease transmission and distribution constraints as the UK decarbonises heating and industry.

The British Geological Survey estimates that the UK has enough geothermal energy resources to meet the UK's entire heating demand for 100 years,[11] while Project InnerSpace analysis undertaken for this report shows there is well over 1,000 years of geothermal heat supply beneath the UK. Despite the availability of resources, geothermal was used for just 0.3% of annual heat demand in 2021, primarily through residential ground source heat pumps.[12]

The UK's geothermal resources could solve a number of domestic problems:

1. Use of imported fossil fuels made up close to 77% of the UK's total energy consumption in 2023. Relying heavily on these sources poses significant energy security risks. International fossil fuel markets are highly volatile; the UK remains exposed to fluctuations in global gas and oil prices, which have driven up energy bills and strained the economy.

2. Reliance on fossil fuels creates greenhouse gas emissions. Under the Climate Change Act 2008, the UK committed to reducing greenhouse gas emissions by 100% of 1990 levels by 2050.[13] Today, the nation aims to fully decarbonise heating across homes, industry, and public buildings in the next 24 years, cutting emissions 50% by 2035 and mobilising £100 billion in private investment by 2030.[14] Though emissions have decreased significantly over the past three decades, progress has lagged. According to the independent Climate Change Committee, the UK is not yet on track to meet its future carbon budgets or its 2050 target—and it won't get on track without implementing significantly stronger policies, particularly in heating, transport, and industry.[15] Considering that close to one-quarter of UK carbon dioxide–equivalent emissions come from fossil fuel combustion in building heating, decarbonising heat is essential to meeting the UK's legally binding climate targets.[16]

WHY DEVELOPING GEOTHERMAL IS A GOOD CHOICE

- **Energy security and independence:** The UK's reliance on imported oil and gas exposes the energy system to geopolitical risk and price volatility. Recent events, including the war in Ukraine, have demonstrated how external shocks can rapidly drive up energy costs and disrupt supply. Local geothermal resources would reduce dependence on foreign energy imports.

- **Low-carbon energy:** Geothermal energy is abundant and sustainable, with minimal greenhouse gas emissions. Investing in geothermal energy will help the UK meet its emission-reduction targets.

- **Lower operational costs:** Geothermal energy has no fuel costs, lacks predictable operating costs, and is significantly more efficient than other heating and cooling technologies, which means it can help reduce costs for consumers and businesses.[17] High system efficiencies also reduce electrical grid demand, and this can have a knock-on effect of reducing electrical costs for neighboring users. Geothermal could therefore reduce operational costs at a project level and at a broader energy-system level.

- **Baseload sustainable energy:** Unlike wind and solar, geothermal provides consistent, 24/7 energy, improving grid reliability and energy security.

- **Reduced demand:** Geothermal systems are typically more efficient than comparative heating and cooling systems.

- **Reduced pressure on the grid:** Networked geothermal systems deliver heat directly to buildings or districts, using significantly less grid electricity than comparative technologies. This helps lower overall electricity demand and reduce stress on the national grid, especially during peak winter periods.

- **Small footprint:** Geothermal has the smallest surface footprint of any renewable energy on an acre-for-acre basis.[18] Ground source heat pump (GSHP) systems are almost invisible, with most of the equipment buried below ground, and deep direct-heat schemes typically require only compact surface energy centres. Next-generation systems reduce this footprint even further.[19] (See Chapter 1, "United Kingdom Underground: An Overview of Geothermal Technologies and Applications," for more.)

- **Jobs and economic opportunity:** Geothermal projects create high-quality, long-term employment—with potentially between 5 and 10 jobs per megawatt deployed[20]—across multiple sectors. Several UK deep geothermal resources are located within regions identified for "levelling up"—areas prioritised for economic investment to reduce regional disparities in wealth and opportunity.[21]

- **Workforce compatibility:** Geothermal development requires skills similar to those needed for the oil and gas and mining industries—drilling, construction, engineering, operations, reservoir management, and more. Fortuitously, the UK has an experienced oil and gas workforce that can be retrained and redeployed, supporting an expansion of jobs and a just transition.

- **Cascaded and multi-use efficiency:** Geothermal energy can be used sequentially for multiple applications—such as electricity generation, industrial heat, district heating, agriculture, and thermal storage—because the water remains warm even after its hottest heat is extracted. This cascaded use maximises the energy extracted from each well, improving overall system efficiency, lowering costs, and increasing the economic and social value delivered per unit of land and infrastructure.[22]

GEOTHERMAL PROJECTS UNDERWAY IN THE UK

Geothermal energy is gaining traction in the UK, with about 30 deep geothermal projects in development, a number of minewater heat and district heating projects underway, more than 55,000 GSHPs installed nationwide,[23] and more than a dozen companies that have secured private and public funding for geothermal projects. (See Chapter 10, "A New Age of Innovation: The United Kingdom's Geothermal Start-Up Scene," for more.) These projects demonstrate geothermal's potential to provide low-carbon, reliable heating and support decarbonisation across homes, businesses, and public infrastructure.

A SELECTION OF MAJOR GEOTHERMAL PROJECTS IN THE UK

Project	Details
Ground Source Heat Pumps (GSHPs)	
Queens Medical Centre, Nottingham	Installing air- and ground source heat pumps with 64 boreholes (to 250 metres). Phase 1 delivers 4 megawatts of heating and 2.88 megawatts of cooling.
British Geological Survey Headquarters GSHP Project	£1.7 m Public Sector Decarbonisation Scheme–funded closed-loop GSHP system with 28 boreholes (to 225 metres), providing 300 kilowatts at 55°C.
Citigen (E.ON), London	2022 upgrade adding heat pumps and three 200 metre boreholes delivering 4 megawatts of heating and 2.8 megawatts of cooling, integrated with district heating networks, combined heat and power (CHP), and thermal storage.
Kensa "Heat the Streets," Cornwall	GSHP rollout across 98 homes, using shared ground-loop arrays; completed in 2023.
Colchester Northern Gateway	Government-funded 800 kilowatt open-loop GSHP for a district heat grid serving 300 homes and health care; uses five Chalk aquifer boreholes.
GeoEnergy NI—Stormont Estate	Feasibility study with four 250 metre hydrogeology boreholes and one 500 metre cored borehole to assess a ~15°C shallow aquifer for heat network design. Public engagement includes the GeoEnergy Discovery Centre.
Underground Thermal Energy Storage (UTES)	
UK ATES Installations	11 aquifer thermal energy storage (ATES) systems deployed in the UK: 9 in London (mainly in the Chalk aquifer), 1 in Manchester, and 1 in Brighton. First system installed in 2006; averaging about one new system per year.
BODYHEAT—SWG3, Glasgow	Low Carbon Infrastructure Transition Programme–funded system capturing body heat from dancers and storing it in shallow geothermal boreholes; 12 boreholes supply heating and cooling to the SWG3 venue.
Minewater	
Lanchester Wines (Felling, Gateshead)	Two commercial minewater heat schemes providing 2.4 megawatts and 1.2 megawatts to beverage warehouses. Drilled in 2015; issues with iron-ochre scaling, corrosion, and reinjection capacity have been progressively resolved. TownRock Energy has managed operations and maintenance since 2021.
Gateshead Mine Water Heating Scheme	Large-scale 6 megawatts thermal minewater system, extracting water from ~150 metres depth to supply offices, municipal buildings, 1,250 homes, an arts centre, and an industrial facility. Funded by the Heat Networks Investment Project and Gateshead Council.
Mining Remediation Authority (MRA) Mine-Water Heat Opportunity Programme	MRA has completed numerous feasibility studies and produced minewater heat opportunity maps for the Welsh coalfield and 10 English cities, integrated into Department for Energy Security and Net Zero Heat Network Zoning Reports.

Project	Details
Minewater	
Dawdon Mine Water Treatment Scheme (Seaham Garden Village)	Construction underway on an energy centre to supply 2.4 megawatts thermal to 750 homes using treated minewater.
South Wales Industrial Unit Scheme	Closed-loop heat exchanger utilising treated minewater to provide approximately 45 kilowatts thermal to an industrial site.
Bolsover District Council (Derbyshire)	Closed-loop scheme planned to use an abandoned flooded coal-mine shaft.
Cornwall Metal Mines (PUSH-IT Project)	Feasibility studies exploring heat and seasonal thermal-storage opportunities in flooded metal mines.
Deep Geothermal Systems	
City of Southampton Energy Scheme	UK's only deep-aquifer geothermal system; draws 76°C fluid from ~1,800 metres depth in the Triassic Sandstone. Began in the 1980s, expanded into a CHP-supported district-heating scheme serving 3,000 homes, 10 schools, and commercial buildings. Geothermal operations resumed after a 2020 pump replacement. Reported carbon dioxide savings of 131,564 tonnes since commissioning.
Bath & Matlock Bath Hot Springs	Long-running hydrothermal systems using naturally heated groundwater from deeply buried early Carboniferous Limestone with significant theoretical resource potential.
Salisbury District Hospital (GT/Star Energy)	Deep geothermal heat project in development to supply more than 20 gigawatt-hours per year for full hospital heat demand; seismic survey completed.
Wythenshawe Hospital, Manchester	Assessment underway for potential deep geothermal heat supply.
GeoEnergy NI—College of Agriculture, Food and Rural Enterprise Greenmount Campus	Feasibility study exploring the Sherwood Sandstone aquifer at approximately 2 kilometres depth. 2023 surveys conducted: gravity, magnetotellurics, and seismic geophysics.
United Downs Deep Geothermal Power Project (Cornwall)	Aims to be UK's first commercial deep-geothermal electricity project. Developed by Geothermal Engineering Ltd (GEL). Uses natural permeability of the Porthtowan Fault in the Carnmenellis granite. Two deviated wells drilled in 2018–19: UD-1 (5,275 metres, ~180°C, production well) and UD-2 (2,393 metres, injection well). A 5 megawatts electric binary plant (export limited to ~3 megawatts electric) was ordered following 2021 hydrotesting. Construction progressed through 2024, with operation expected in 2026. Fluids contain more than 300 ppm lithium, enabling a 100 tonnes per year direct lithium extraction demonstration plant.
Eden Geothermal Project (Cornwall)	Second UK deep geothermal project, developed by Eden Geothermal Ltd. Well EG-1 drilled May–Nov. 2021 to 4,871 metres true vertical depth (5,277 metres measured depth). A coaxial system installed to 3,850 metres has supplied 1.4 megawatts thermal since June 2023 to heat Eden's biomes and greenhouses via a 3.8 kilometre closed-loop. A second deep borehole is planned to create an electricity-producing doublet; waste heat would then supply the biomes.

Project	Details
Planned Deep Geothermal and District Heat Networks Projects	
University of York, Nottingham Queen's Medical Centre	The government also supports public sector decarbonisation, funding geothermal heating networks—and potentially electricity generation in the future—at the University of York (£35 million) and Nottingham University Hospital's Queen's Medical Centre (£36 million).[24]
GEL Cornwall Projects (Manhay, Penhallow, Tregath)	GEL is planning additional deep geothermal projects in Cornwall. Manhay and Penhallow received local planning approval in early 2025, while Tregath is awaiting determination.
NHS Grampian Deep Geothermal Feasibility (Aberdeen)	TownRock Energy is assessing geothermal potential for NHS Grampian across multiple sites in Aberdeen, including wells up to 5 kilometres deep.
Cornish Lithium—Cross Lanes (Chacewater)	Cornish Lithium drilled 8 boreholes to 2 kilometres depth to assess geothermal-brine lithium potential. In 2025, planning permission was granted for a commercial lithium production facility at Cross Lanes, which will also evaluate using the same geothermal fluids for local heat supply.
Weardale Lithium —Eastgate (North East England)	Planning permission granted in 2025 for geothermal-brine lithium extraction on a brownfield site at Eastgate, using existing deep wells for extraction and reinjection.
Swaffham Prior Heat Network (Cambridgeshire)	A village-scale heat network supplying 300 homes and public buildings, using 108 GSHP boreholes and 1.7 megawatts thermal of capacity, integrated with solar and air-source heat pumps.
Sutton Dwellings Retrofit (London)	Social housing retrofit where Kensa and Clarion Group installed 27 boreholes to 180 metres to supply ground-source heating to 81 flats via shared ground-loop arrays.
Geothermal Research	
UK Geoenergy Observatories (UKGEOS)	The UKGEOS facilities provide data on response of the subsurface to thermal, chemical and biological effects of low-carbon energy technologies, specifically UTES. The Glasgow site focuses on minewater heat and thermal storage, while the Cheshire site targets borehole and ATES within the Sherwood Sandstone.
UK FORGE	Funding request for a deep EGS geothermal research project aiming to recreate the significant cost reduction and scientific lessons learnt from the US FORGE and Fervo projects.

Figure 2.2: Major geothermal projects in the UK. Source: Adapted from Monaghan, A. A., Gonzalez Quiros, A., O'Grady, M., & Curtis, R. (2025). *Geothermal energy use, country update for the United Kingdom*. European Geothermal Congress 2025, Zurich, Switzerland; Coal Authority. (2025, March 17). *Mine water heat opportunity mapping for 10 cities in England*. Government of the United Kingdom.

GEOTHERMAL COSTS IN THE UK

Shallow Geothermal Deployment

Geothermal heat pump systems require a higher up-front investment than conventional heating systems: In the United States, these system costs are between $15,000 and $40,000 per home.[25] In the UK, sources indicate that up-front costs are roughly between £10,000 and £20,000.[26] However, they offer substantial long-term energy cost savings, government rebates, and long lifetimes, with additional costs often returned in energy savings in 5 to 10 years.[27] Thermal energy network capital costs are driven by network infrastructure costs, which can be significant (such as close to £12,000 per dwelling in modelled UK cases), but cost benefits come from economies of scale and high-density deployment.[28]

Scaling geothermal heat pumps and thermal energy networks can cut rate-payer energy payments by tens of billions nationally. In the United States, heat pumps can, on average, save more than US$500 per household.[29] Scaling ground source heat pumps could reduce winter peak electricity demand by up to 40 gigawatts, delivering an estimated US$4 billion per year in grid system savings.[30]

In the United States, deploying ground source heat pumps at scale could reduce peak winter demand by up to 40 gigawatts and create US$4 billion of annual grid system savings.

Cost Structures and Recent Technological Advancements in Deep Geothermal Deployment

The development of deep geothermal energy is often characterised by high up-front capital costs, which remain a key barrier to commercial deployment. These costs are largely driven by exploration and deep drilling, which are essential to confirm subsurface heat reservoirs but are both technically complex and financially risky.

Levelised costs represent the average discounted lifetime cost of constructing and operating a heat or power asset over its operational life. In the UK, levelised costs for geothermal technologies vary considerably due to differences in drilling depth, reservoir conditions, and the technologies deployed. Shallow ground source heat pump systems, particularly when integrated with underground thermal energy storage, currently achieve the lowest estimated levelised costs. Deep geothermal systems face higher costs, primarily due to greater up-front capital expenditures; however, they offer substantial potential for cost reduction as drilling costs fall with market growth and improved learning rates. With continued development and targeted support mechanisms, geothermal energy in the UK has the potential to reach cost parity with more mature European markets.[31]

Insights from more advanced geothermal markets show what is achievable. Emerging technologies—largely from the oil and gas sector—in directional drilling, AI-assisted site characterization, and advanced drilling fluids are reducing costs around the world. Recent results from Fervo Energy in the United States demonstrate significant cost improvements. Between 2022 and 2024, the costs for developing a well dropped by nearly half, and the time it took to drill a well fell by almost 70%.

Insights from more advanced geothermal markets show what is achievable. Emerging technologies—largely from the oil and gas sector—in directional drilling, artificial intelligence (AI)-assisted site characterisation, and advanced drilling fluids are reducing costs around the world.[32,33,34,35] Recent results from Fervo Energy in the United States demonstrate significant cost improvements. Between 2022 and 2024, the costs for developing a well dropped by nearly half, and the time it took to drill a well fell by almost 70%.[36,37]

Drilling is typically the single largest cost line in a geothermal project (often between around 40% and 60% of capital expenditures, depending on resource depth/temperature and success rates).[38] Major drivers are (i) depth and temperature (hard, abrasive formations; lost circulation); (ii) well design (diameter, casing strings, materials); (iii) rate of penetration and non-productive time; (iv) success rate (dry or underperforming wells); and (v) rig day rates and services tightly linked to the oil and gas cycle.

Low Operational Costs and Long-Term Competitiveness

In contrast with high capital costs, operating costs of geothermal plants are low because no fuel is required. Direct-use applications such as space heating, agriculture, and industrial drying can reduce fuel consumption by up to 80%, while overall operational costs fall by around 8% compared with conventional systems.[39] Globally, operations and maintenance costs for geothermal power plants typically range between US$9 and US$25 (£7–£18) per megawatt-hour, excluding well replacement drilling.[40] This predictable cost structure enhances geothermal projects' long-term economic viability.

Based on data published thus far, drilling and power plant components take up a large share of the costs for a geothermal power generation facility. While geothermal is capital intensive up front, it offers low and stable life cycle costs, positioning it as a firm renewable option that can complement the UK's solar- and wind-heavy system.

EXPANSION OF THE UK'S GEOTHERMAL INDUSTRY: OPPORTUNITIES AND BENEFITS

In any geothermal project, the resources—and their location—are key. As mentioned, the most promising opportunity in the UK is to use geothermal for heat processes. District heating networks are central to the UK government's energy security and decarbonisation strategies, with plans to supply 20% of UK heat demand by 2050 through an investment of £80 billion.[41]

As explained in detail in Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface Geology," one obvious starting point is the UK's National Health Service (NHS)—one of the world's largest public health systems—where large, always-on heat demand and public procurement can turn geothermal from promising into bankable.

National Health Service: A Key Opportunity

Hospitals and care facilities require constant, high-volume heat for space heating, hot water, and sterilisation. Supported by the UK's decarbonisation and energy security ambitions, hospitals are currently transitioning away from typical gas boilers and chillers to alternative renewable heating and cooling sources, including geothermal. Geothermal heat delivered either on site or via local heat networks offers predictable, low-carbon heat. Because geothermal supplies heat directly, it can also reduce winter peak pressure on the electricity system, which will become increasingly important as the UK's heat supply electrifies.

The UK government's £288 million Green Heat Network Fund has already awarded £22 million to the Langarth Deep Geothermal Heat Network in Cornwall. The project is expected to deliver around 50 gigawatts of heat per year to a new 3,800-unit development and to the Royal Cornwall Hospital starting this year.[42]

The NHS is also a key participant in programmes such as the Public Sector Decarbonisation Scheme, which has committed more than £1.8 billion in grant funding to decarbonise public sector buildings and reduce their emissions.[43] By being an anchor customer—committing early as a large, reliable heat user—NHS trusts can lower future costs and contribute to a resilient, low-carbon heat infrastructure and strengthen the economics of heat networks.

An indication of the scale of the NHS geothermal opportunity is illustrated in **Figure 2.3**. Project Innerspace has identified 301 NHS facilities located above Triassic aquifers, which represent promising deep geothermal targets. These aquifers offer examples of several viable geological and geothermal settings across the UK. Hospitals situated above sufficiently deep, hot, and permeable aquifer units are expected to have some of the strongest geothermal potential, although a full range of technologies—from GSHPs to deep geothermal systems—could offer low-carbon, reliable energy solutions for NHS facilities.

Shallow Geothermal Systems

Along with the NHS opportunity, minewater geothermal, low-temperature aquifer thermal energy storage, and expanded use of GSHPs are three strong options for residential and commercial heating and cooling that can also deliver meaningful grid benefits. Minewater systems can draw heat from abandoned mines that have filled with groundwater—a valuable opportunity for the near 6 million homes (about 25% of the UK's homes[44]) and many businesses located above former coalfields.

In parallel, aquifer thermal energy storage could supply roughly 61% of the UK's current heating demand and 79% of cooling demand,[45] which could significantly reduce peak loads (**Figure 2.4**). (See Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors," for more on this topic.)

NATIONAL HEALTH SERVICE (NHS) FACILITIES ACROSS THE UK

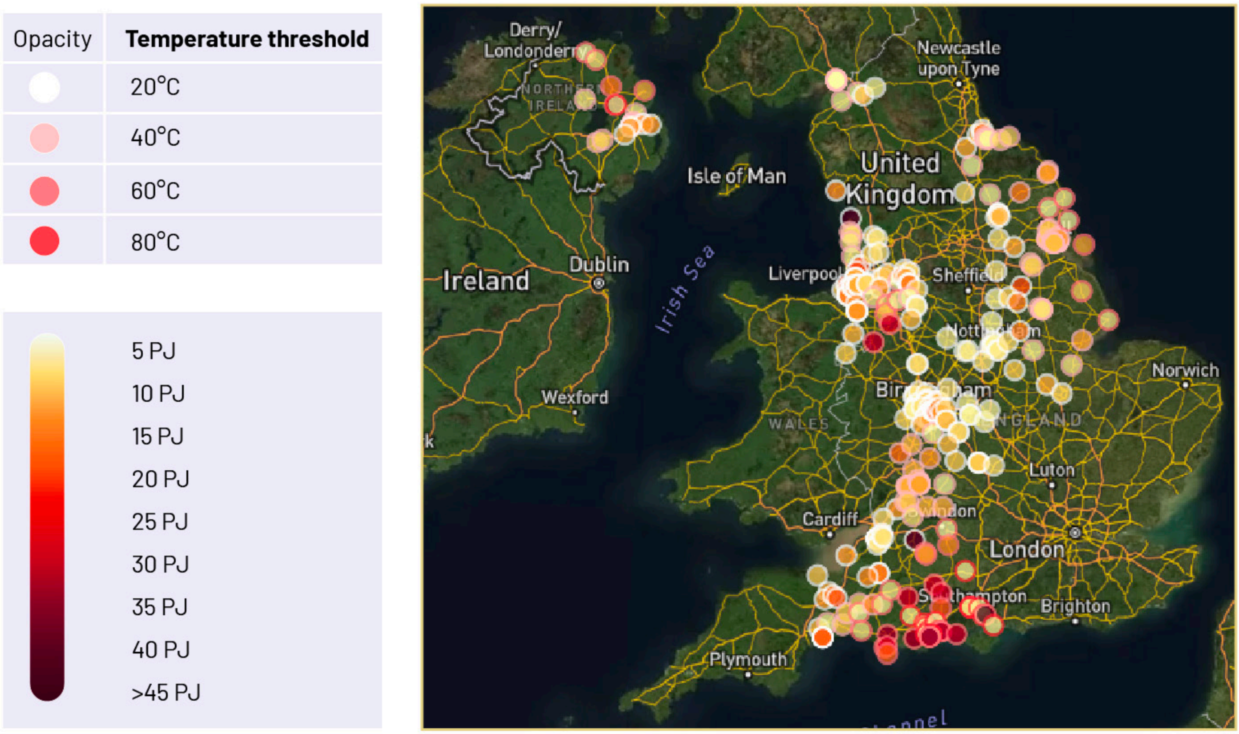


Figure 2.3: Project InnerSpace has mapped 301 National Health Service facilities that are situated over Triassic aquifers, a suitable geothermal target. Hospitals that lie over sufficiently deep (and hot) and permeable aquifer units are considered to have the greatest geothermal potential. 1 PJ (petajoule) = roughly 278 gigawatt-hours. Source: Project InnerSpace.

GSHPs are another scalable pathway because heat dominates building energy use, as about 80% of household energy goes to space heating, water heating, and cooking.[46] UK geothermal cost estimations highlight that GSHP systems used for combined heating and cooling benefit from reduced levelised costs because of greater system use and efficiency (relative to GSHP systems used for heating only or cooling only). That means lower bills.

Building district networks that can heat and cool, or that are coupled with thermal storage, can likewise reduce GSHP costs.[47] From a grid perspective, efficient heat pumps and networked geothermal systems reduce total electricity consumption per unit of heat delivered[48] and can lower peaks and reduce costs.[49]

These pathways—minewater, thermal energy storage, and GSHPs—represent a large technical opportunity. Countries such as France, Germany, and the Netherlands have developed policies to allow them to better tap into their geothermal heating opportunity, and these policies could be models for the UK (see Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential"). Even partial deployment of any of these solutions can reduce system costs and improve resilience.

Several research organisations and companies have secured millions in funding to explore geothermal energy and heating potential in England and elsewhere. (See Chapter 10, "A New Age of Innovation: The United Kingdom's Geothermal Start-Up Scene," for a detailed list.) Funding from the Green Heat Network Fund, the Public Sector Decarbonisation Scheme, and local pilot projects show growing governmental support.

The UK government recently announced a series of reforms intended to create "a more secure and more efficient energy system," in part through the development of a Strategic Spatial Energy Plan. Though the programme is still a work in progress, the government says it will include planning reforms and other efforts intended to encourage more renewable energy investment and development.[50]

Industrial geothermal heat can reduce reliance on gas-fired process heat, easing constraints on gas and power systems during cold spells when demand spikes across the economy.

The government's Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050 identify the eight most heat-intensive sectors as oil refining, chemicals, food and drink, glass, ceramics, cement, pulp and paper, and iron and steel.[51] While not explicitly mentioned in the Roadmaps, geothermal heat could be widely deployed across these industries, provided temperatures meet the required demand and the economic case is viable. Geothermal energy could also be used to supply baseload heating for greenhouses (as in the Eden Project, highlighted more in Chapter 7, "Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices"), crop drying facilities, aquaculture, and housing livestock. Industrial geothermal heat can reduce reliance on gas-fired process heat, easing constraints on gas and power systems during cold spells when demand spikes across the economy. (See Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors.")

SEASONAL OPERATION OF LT-ATES IN SUMMER AND WINTER

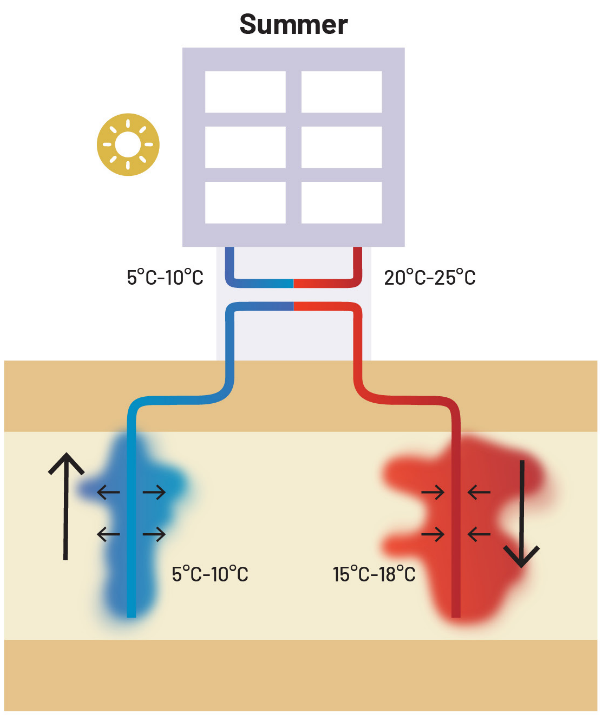


Figure 2.4: Seasonal operation of low-temperature aquifer thermal energy storage (LT-ATES) in summer (left) and winter (right). HP = heat pump. Source: Jackson, M. D., Regnier, G., & Staffell, I. (2024). [Aquifer thermal energy storage for low carbon heating and cooling in the United Kingdom: Current status and future prospects](). *Applied Energy, 376*, 124096.

Opportunities for Geothermally Cooled Data Centres

The rapid expansion of the UK's AI and data centre sector is driving unprecedented demand for cooling, which currently accounts for around 40% of data centre electricity use and is predicted to rise. Two of the government's AI Growth Zones—Culham, Oxfordshire, and the north-east's Northumberland and North Tyneside—also have thick sedimentary basins where geothermal cooling could be deployed and help reduce costs and energy demand.

Shallow aquifers and abandoned mines that have filled with groundwater can provide widespread low-carbon cooling and thermal storage. Using these resources would help reduce energy demand, peak loads, and emissions for large AI campuses. These same systems can also help turn a data centre from a "pure load" into a local heat asset: The low-grade waste heat rejected during cooling can be captured and upgraded (typically via heat pumps), then fed into nearby residential or municipal heating networks. In a geothermal heat-network context, that recovered heat can complement geothermal baseload—especially during shoulder seasons—helping balance supply and demand, improving overall network efficiency, and reducing the amount of new generation capacity needed to meet peak heating loads. What's more, there are more than 200 additional sites under government consideration with similar subsurface potential. (See Chapter 4 for more details and site-specific opportunities for geothermal data centre cooling.)

Opportunities in Deep Geothermal and Electricity Generation

Over the past few decades, the UK has made considerable efforts to decarbonise its electricity production primarily by shifting to renewable energy sources. In 2013, coal power made up 39.6% of electricity generation; by 2023, it was just 1%.[52] In 2020, for the first time, electricity generation came predominantly from renewable sources solar and wind. The following year, the largest overhaul to the UK's grid system began. The Great Grid Upgrade consists of 17 infrastructure projects across the country to increase the grid's clean energy capacity and transmit electricity more efficiently.[53]

Still, the largest single energy source today for the UK's electric grid is natural gas.[54] What's more, the transition away from fossil fuels in transportation, heating, and industrial use is expected to significantly increase electricity demand.[55]

Geothermal doesn't currently contribute meaningfully to electricity generation everywhere, but subsurface resources indicate that it could in some regions. Granite deposits such as the Cornubian Batholith in Cornwall and Devon show the best technical potential for electricity generation. Subsurface resources in sedimentary basins in Cheshire, Wessex, East Yorkshire, and Lincolnshire and across Northern Ireland—while modest—may also show some electricity generation potential as cost curves decrease and show strong potential for heat. (See Chapters 3 and 4 for detailed subsurface mapping and technical assessments.)

The Benefits of Geothermal for the UK's National Grid

The modern electricity grid is a delicate system that requires constant monitoring to balance electricity production against electricity demands. The UK's transmission infrastructure is extensive and interconnected with neighbouring countries, so energy can be exported and, as is largely the case with the UK, imported.[56]

Because geothermal resources can be used to generate electricity in some locations—and heat, regardless of weather conditions—it can offer various key direct and indirect advantages for the grid:

1. **Peak load management and load shaping for geothermal heat:** Shallow geothermal methods can store and directly supply heat to urban centres, reducing electricity demand for heating during winter peaks. By storing thermal energy with ground or water loops, geothermal systems can preserve energy during off-peak periods and deliver heating (or cooling) during peak hours, helping balance energy supply and demand and improve overall efficiency.[57] Use of geothermal heating flattens the load profile, reduces peak strain on the grid, and indirectly lowers costs associated with electricity generation,

transmission, and balancing (see "The Benefits of Geothermal Storage" for more information).

2. **Enhanced stability:** Geothermal power plants have a high capacity factor, typically in the range of 90% or more, meaning they operate near full output for most hours of the year.[58] As a firm, low-carbon baseload resource, geothermal provides consistent power to the grid, reducing reliance on fossil fuel-based generation during periods of peak demand and low renewable output.

3. **Improved resilience:** Unlike solar and wind, geothermal energy production remains largely unaffected by surface weather and can quickly return to operation after disruptions or extreme events. By prioritising investment in geothermal, regions prone to severe weather could significantly enhance grid resilience, reducing the likelihood of future outages, such as those that took place after severe windstorms in the UK in late 2024 and early 2025.

4. **Reduced transmission losses:** Locating geothermal deployments near demand centres minimises the distance electricity must travel, reducing energy losses. Additionally, geothermal is often structurally built close to energy demand (unlike solar and wind, which are often located where resources are strongest, such as offshore), which can alleviate local congestion and improve delivery efficiency. For example, curtailment of renewable energy in the UK (due to grid constraints and transmission bottlenecks) amounted to 5.8 terawatt-hours of wind energy in 2020 through 2021—enough to power 800,000 homes annually.[59] Locally embedded geothermal generation can help avoid similar inefficiencies.

5. **Transmission line capacity:** Geothermal plants produce steady, predictable output, allowing existing transmission lines to be used more efficiently and reducing the need for new infrastructure. An analysis by U.S. national labs (National Renewable Energy Laboratory and Oak Ridge National Laboratory) found that widespread deployment of geothermal heat pumps could reduce the need for new long-distance transmission lines by about 33% because these pumps reduce total electricity generation and peak demand compared with other pathways.[60] This deployment can lower system costs and ease congestion without requiring any changes to grid operations.

With the right policy support and financial mechanisms, developers can accelerate deployment of geothermal energy (see 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"). In the near term, targeted geothermal projects can provide meaningful grid support, resilience, and decarbonisation benefits at the community and city levels and, as momentum builds, unlock increasing national benefits over time.

In the near term, targeted geothermal projects can provide meaningful grid support, resilience, and decarbonisation benefits at the community and city levels and, as momentum builds, unlock increasing national benefits over time.

The Benefits of Geothermal Storage

As the UK relies more on wind and solar power for electricity generation, the share of intermittent power sources—available only when the sun shines or the wind blows—increases. As a result, energy storage will be necessary to maintain grid stability. The UK's National Energy System Operator estimates that overall electricity peak demand will almost double until 2050, with significant growth driven by new data centres used to power AI.[61]

Worldwide, hydroelectric storage provides most energy storage capacity today. There has also been a big expansion in the deployment of batteries for energy storage. Geothermal adds another option: underground thermal energy storage (UTES), which can capture and store waste heat in subsurface storage spaces such as aquifers, boreholes, and mines (see Chapter 1, "United Kingdom Underground: An Overview of Geothermal Technologies and

Applications," for details). In practice, UTES can be paired with heat networks and GSHP systems to store surplus heat—including summer heat rejected from buildings such as data centres, industrial waste heat, or during periods of solar and wind overproduction—and deliver it when needed in winter.

For the UK grid, shallow geothermal energy storage can have a "whole system" impact. UTES shifts energy use away from peak hours and seasons, reducing peak generation costs and lowering strain on transmission and distribution networks. By storing heat when renewable electricity is plentiful and cheap, and using it later to meet heating demand during peak periods, UTES can reduce winter peak electricity loads that would otherwise rise as heat electrifies. UTES also helps absorb periods of excess renewable output—turning potential curtailment into usable thermal energy—while improving resilience by keeping critical heat services running with less dependence on real-time grid conditions.

UTES could be a good option for locations in areas with significant wind production and sedimentary basins, such as North East Lincolnshire.

CONCLUSION

The UK's geothermal opportunity is fundamentally a grid opportunity: Scaling geothermal heat can change the shape of electricity demand, while targeted geothermal power can add firm, weather-independent capacity in select locations. By supplying heat directly—through aquifer thermal energy storage, ground source heat pumps, minewater systems, heat networks, and direct heat from deep geothermal wells—and adding targeted geothermal power where resources allow, geothermal can ease the operational and infrastructure pressures created by rising electrification and an increasingly wind- and solar-heavy grid.

Going big on geothermal heat helps the grid in three practical ways. First, it reduces peak electricity demand, especially in winter, by shifting heating load off the power system and into direct thermal supply. Second, when paired with thermal storage in the ground or water loops, geothermal systems can absorb energy during low-demand periods and deliver heat when needed—flattening load profiles, reducing peak strain, and supporting system balancing as variable renewables expand. Third, geothermal's proximity to demand centres can reduce congestion and transmission losses and—by lowering overall and peak electricity needs—help limit the scale of new long-distance transmission required under other decarbonisation pathways.

Geothermal can become a cornerstone of a more resilient, lower-cost energy system—not only by decarbonising heat but also by making the electricity grid easier to operate and less exposed to peaks and constraints and lowering costs for consumers.

Targeted geothermal power adds a complementary benefit: firm, weather-independent generation with high capacity factors,[62,63,64] which strengthens grid stability and resilience when wind and solar output is low. While geothermal is not likely to dominate UK electricity supply, it can be a strategically valuable option in specific locations—especially where it can be co-located with large loads and integrated into heat-and-power configurations.

In summary, geothermal heating and electricity can accomplish several goals:

- Lower peak strain on the grid, particularly in the winter.
- Improve energy balance in a renewables-heavy system.
- Deliver energy more efficiently.
- Provide dependable clean capacity.

Geothermal can become a cornerstone of a more resilient, lower-cost energy system—not only by decarbonising heat but also by making the electricity grid easier to operate and less exposed to peaks and constraints and lowering costs for consumers.

CHAPTER REFERENCES

1 Beazleigh, E. J. (2025). Chapter 4: Natural gas. In Department for Energy Security and Net Zero (Ed.), *Digest of UK energy statistics (DUKES): Natural gas*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/688a0938a11f85999440922e/DUKES_2025_Chapter_4.pdf

2 Martin, V. (2025). Chapter 5: Electricity. In Department for Energy Security and Net Zero (Ed.), *Digest of UK energy statistics (DUKES): Electricity*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/688a286564785256757390 51/DUKES_2025_Chapter_5.pdf

3 National Energy System Operator. (2025, January 14). *Britain's energy explained: 2025 review*. https://www.neso.energy/news/britains-energy-explained-2025-review#:~:text=Wind%20was%20the%20largest%20source,of%20our%20electricity%20during%202025. The total UK electricity generation value has been estimated by dividing the published renewable generation value by the reported renewable share (that is, 127 terawatt-hours divided by 44%).

4 National Energy System Operator. (n.d.). *2035: Key challenges*. https://www.neso.energy/document/250156/download#:~:text=By%202035%2C%20according%20to%20our,to%20electricity%20rather%20than%20hydrogen

5 This number is inferred from page 102 of the *Warm Homes Plan*, which reports district heating provision as a share of total UK heat demand. Department for Energy Security and Net Zero. (2026). *Warm homes plan*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/696f8a3ec0f4afaa9536a0c4/warm-homes-plan-standard-print.pdf

6 See Chapter 5 in Department for Energy Security and Net Zero, *Warm homes plan*, 2026.

7 Kavan, M. (n.d.). *How different households use energy and how much it costs them*. Nesta. https://www.nesta.org.uk/project/finding-ways-to-deliver-cheaper-electricity-by-rebalancing-levies/how-different-households-use-energy/

8 Khosla, R., & Lizana, J. (2021, December 16). *UK net zero strategies are overlooking something vital: How to cool buildings amid rising temperatures*. The Conversation. https://theconversation.com/uk-net-zero-strategies-are-overlooking-something-vital-how-to-cool-buildings-amid-rising-temperatures-172080

9 Staffell, I., Pfenninger, S., & Johnson, N. (2023). A global model of hourly space heating and cooling demand at multiple spatial scales. *Nature Energy*, *8*, 1328–1344. https://www.nature.com/articles/s41560-023-01341-5

10 Dunning, H. (2023, September 14). *London has the fastest increase in cooling demand in the world, shows new model*. Imperial College London. https://www.imperial.ac.uk/news/247593/london-fastest-increase-cooling-demand-world/#:~:text=Science-,London%20has%20the%20fastest%20increase%20in%20cooling,the%20world%2C%20shows%20new%20model&text=A%20model%20to%20map%20energy,more%20common%20and%20more%20intense.&text=Countries%20like%20the%20UK%20are,entire%20electricity%20demand%20of%20Switzerland

11 UK Parliament. (2021, September 15). *Geothermal energy*. Hansard. https://hansard.parliament.uk/commons/2021-09-15/debates/B8BE6909-6010-4331-A03B-A9FE856712A6/GeothermalEnergy

12 Government Office for Science. (2024). *Future of the subsurface: Geothermal energy generation in the UK (annex)*. Government of the United Kingdom. https://www.gov.uk/government/publications/future-of-the-subsurface-report/future-of-the-subsurface-geothermal-energy-generation-in-the-uk-annex

13 Shepheard, M. (2020, April 20). *UK net zero target*. Institute for Government. https://www.instituteforgovernment.org.uk/article/explainer/uk-net-zero-target

14 Morton, B., & Mason, H. (2023, November 10). *The road to decarbonisation of heat in the UK*. DLA Piper. https://www.dlapiper.com/en/insights/publications/energy-act/the-road-to-decarbonisation-of-heat-in-the-uk

15 Climate Change Committee. (2025). *Progress in reducing emissions: 2025 report to Parliament*. https://www.theccc.org.uk/publication/progress-in-reducing-emissions-2025-report-to-parliament/

16 Department for Energy Security and Net Zero & Department for Business, Energy and Industrial Strategy. (2023). *Heat and building strategy*. Government of the United Kingdom. https://www.gov.uk/government/publications/heat-and-buildings-strategy/heat-and-building-strategy-accessible-webpage

17 Office of Policy. (2024, February 14). *For most Americans, a heat pump can lower bills right now*. U.S. Department of Energy. https://www.energy.gov/policy/articles/most-americans-heat-pump-can-lower-bills-right-now

18 Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS One, 17*(7), e0270155. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0270155

19 Jaeger, J., McLaughlin, K., Bird, L., & Hausker, K. (2024, December 10). *Next-generation geothermal can help unlock 100% clean power*. World Resources Institute. https://www.wri.org/insights/next-generation-geothermal-energy-explained

20 Bracke, R., & Huenges, E. (2022, February 2). *Shaping a successful energy transition* [Press release]. Fraunhofer IEG. https://www.ieg.fraunhofer.de/de/presse/pressemitteilungen/2022/erfolgreiche-waermewende-gestalten.html

21 Mullan, K. (2023). *Dig deep: Opportunities to level up through deep geothermal heat and energy on the way to net zero*. https://www.drkieranmullan.org.uk/sites/www.drkieranmullan.org.uk/files/2024-11/Dig%20Deep%20June%202023.pdf

22 Birkby, J. (2012). *Geothermal energy in Montana: A consumer's guide*. Montana Department of Environmental Quality. https://deq.mt.gov/files/Energy/EnergizeMT/Renewables/Geothermal%20Pub/GeothermalConsumer'sGuide2012%20.pdf

23 IEA Geothermal. (n.d.). *United Kingdom*. https://www.iea-gia.org/our-members/united-kingdom

24 Department for Energy Security and Net Zero. (2025, December 4). *Phase 4 Public Sector Decarbonisation Scheme: Project summaries*. Government of the United Kingdom. https://www.gov.uk/government/publications/public-sector-decarbonisation-scheme-phase-4/phase-4-public-sector-decarbonisation-scheme-project-summaries

25 Hu, S. (2024, December 3). *Geothermal energy: The advantages, the challenges, and the potential*. Natural Resources Defense Council. https://www.nrdc.org/stories/geothermal-energy-advantages-challenges-and-potential

26 Maggie. (2026, January 6). *Air source vs. ground source heat pumps: A UK homeowner's comparison guide*. Megawave Energy Solutions. https://hub.theheatpumps.co.uk/air-source-vs-ground-source-heat-pumps-a-uk-homeowners-comparison-guide

27 U.S. Department of Energy. (n.d.). *Geothermal heat pumps*. https://www.energy.gov/energysaver/geothermal-heat-pumps

28 Pans, M. A., Claudio, G., & Eames, P. C. (2024). Theoretical cost and energy optimisation of a 4th generation net-zero district heating system with different thermal energy storage technologies. *Sustainable Cities and Society, 100*, 105064. https://www.sciencedirect.com/science/article/pii/S2210670723006741

29 Bui, V. (2023, May 30). *Pump up your savings with heat pumps*. U.S. Department of Energy. https://www.energy.gov/articles/pump-your-savings-heat-pumps

30 Gertler, C. G., Steeves, T. M., & Wang, D. T. (2025). *Pathways to commercial liftoff: Geothermal heating and cooling*. U.S. Department of Energy. https://igshpa.org/wp-content/uploads/LIFTOFF_DOE_Geothermal_HC.pdf

31 Arup. (2025). *UK geothermal review and cost estimations*. Department for Energy Security and Net Zero, Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/689472ada6eb81a3f9b2e1fb/geothermal-energy-review.pdf

32 Barth, A., & Wood, C, (2025). *Is geothermal energy ready to make its mark in the US power mix?* McKinsey. https://www.mckinsey.com.br/industries/electric-power-and-natural-gas/our-insights/is-geothermal-energy-ready-to-make-its-mark-in-the-us-power-mix

33 National Renewable Energy Laboratory (NREL). (2022). *Annual technology baseline: Geothermal*. https://atb.nrel.gov/electricity/2023/geothermal
34 Robins, J. C., Kesseli, D., Witter, E., & Rhodes, G. (2022). *2022 GETEM geothermal drilling cost curve update*. 2022 Geothermal Rising Conference. Reno, Nevada. https://docs.nrel.gov/docs/fy23osti/82771.pdf
35 Geothermal Technologies Office. (2019). *GeoVision: Harnessing the heat beneath our feet*. U.S. Department of Energy. https://www.energy.gov/sites/default/files/2019/06/f63/GeoVision-full-report-opt.pdf
36 Law, S. (2024, July 10). *We're going underground: New advent for geothermal drilling.* Cleantech Group. https://cleantech.com/were-going-underground-new-advent-for-geothermal-drilling/
37 Seligman, A., & Virone, A. (2025, September 10). *What five key trends in enhanced geothermal mean for the EU*. Clean Air Task Force. https://www.catf.us/2025/09/what-five-key-trends-in-enhanced-geothermal-mean-for-the-eu/
38 Akindipe, D., & Twitter, E. (2025). 2025 geothermal drilling cost curves update. In *Proceedings, 50th Workshop on Geothermal Reservoir Engineering*. Stanford, CA, United States. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2025/Akindipe.pdf
39 U.S. Department of Energy. (n.d.). *Guide to tribal energy development: Geothermal*. https://www.energy.gov/indianenergy/tribal-energy-guide/geothermal
40 International Energy Agency (IEA). (2021). *Technology roadmap: Geothermal heat and power*. https://iea.blob.core.windows.net/assets/f108d75f-302d-42ca-9542-458eea569f5d/Geothermal_Roadmap.pdf
41 Department for Energy Security and Net Zero. (2024). *UK heat networks: Market overview*. Government of the United Kingdom. https://www.gov.uk/government/publications/uk-heat-networks-market-overview/uk-heat-networks-market-overview-accessible-webpage
42 Triple Point Heat Networks. (n.d.). *Green Heat Network Fund awards over £91 million to decarbonise buildings across the country*. https://tp-heatnetworks.org/green-heat-network-fund-awards-over-91-million-to-decarbonise-buildings-across-the-country/
43 Department for Energy Security and Net Zero. (2024). *Public Sector Decarbonisation Scheme: Phase 3c summary report*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/673f0169ad6a5d7d2b1b0978/phase-3c-public-sector-decarbonisation-scheme-summary-report.pdf
44 Coal Authority. (2024, January 23). *Project explores potential demand for mine water heat* [Press release]. Government of the United Kingdom. https://www.gov.uk/government/news/project-explores-potential-demand-for-mine-water-heat
45 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://www.sciencedirect.com/science/article/pii/S030626192401479X
46 Peñasco, C. (2024). From policy to practice: The role of national policy instruments and social barriers in UK energy efficiency adoption in households. *Energy Policy, 194*, 114308. https://www.sciencedirect.com/science/article/pii/S0301421524003288
47 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
48 International Energy Agency (IEA). (2022). *The future of heat pumps: Executive summary*. https://www.iea.org/reports/the-future-of-heat-pumps/executive-summary
49 Liu, X., Ho, J., Winick, J., Porse, S., Lian, J., Wang, X., Liu, W., Malhotra, M., Li, Y., & Anand, J. (2023). *Grid cost and total emissions reductions through mass deployment of geothermal heat pumps for building and heating cooling electrification in the United States*. U.S. Department of Energy, Office of Scientific and Technical Information. https://www.osti.gov/biblio/2224191

50 Department for Energy Security and Net Zero & Miliband, E. (2025, July 10). *Government sets out reforms to create a fair, secure, affordable and efficient electricity system* [Press release]. Government of the United Kingdom. https://www.gov.uk/government/news/government-sets-out-reforms-to-create-a-fair-secure-affordable-and-efficient-electricity-system

51 Department of Energy and Climate Change & Department for Business, Innovation and Skills. (2015). *Industrial decarbonisation and energy efficiency roadmaps to 2050*. Government of the United Kingdom. https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

52 National Grid. (2024, January 17). *How much of the UK's energy is renewable?* https://www.nationalgrid.com/stories/energy-explained/how-much-uks-energy-renewable#:~:text=Breaking%20records:%20The%20UK%E2%80%99s%20renewable%20energy%20in%20numbers&text=We%E2%80%99ve%20reduced%20the%20involvement,achieved%20on%2018%20September%202023

53 National Grid. (2022, August 17). *How will our electricity supply change in the future?* https://www.nationalgrid.com/stories/energy-explained/how-will-our-electricity-supply-change-future#:~:text=Why%20will%20we%20use%20more,more%20than%20double%20by%202050

54 National Grid, 2024.

55 Daly, E., Finkel, V. Kar, J., & Pani, M. (2022, February 10). *Facing the future: Net zero and the UK electricity sector*. McKinsey. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/facing-the-future-net-zero-and-the-uk-electricity-sector

56 Department for Energy Security and Net Zero. (2025). *Statutory security of supply report: 2025*. Government of the United Kingdom. https://www.gov.uk/government/publications/statutory-security-of-supply-report-2025/statutory-security-of-supply-report-2025

57 Saleem, A., Ambreen, T., & Ugalde-Loo, C. E. (2024). Energy storage-integrated ground-source heat pumps for heating and cooling applications: A systematic review. *Journal of Energy Storage, 102*(Part B), 114097. https://www.sciencedirect.com/science/article/pii/S2352152X24036831

58 Geothermal Technologies Office. (n.d.). *Geothermal FAQs*. U.S. Department of Energy. https://www.energy.gov/eere/geothermal/geothermal-faqs

59 Matson, C., & Knighton, J. (2022). *Renewable curtailment and the role of long duration storage*. Lane Clark & Peacock LLP. https://www.drax.com/wp-content/uploads/2022/06/Drax-LCP-Renewable-curtailment-report-1.pdf

60 MacGregor, K. (2024, January 26). *New analysis highlights geothermal heat pumps as key opportunity in switch to clean energy*. National Laboratory of the Rockies. https://www.nrel.gov/news/detail/program/2024/new-analysis-highlights-geothermal-heat-pumps-as-key-opportunity-in-switch-to-clean-energy

61 National Energy System Operator. (2025). *Future energy scenarios: Pathways to net zero*. https://www.neso.energy/document/364541/download

62 Arup, 2025.

63 National Laboratory of the Rockies. (2025, December 7). *CREST: Cost of renewable energy spreadsheet tool*. U.S. Department of Energy. https://www.nrel.gov/analysis/crest

64 Office of Critical Minerals and Energy Innovation. (2022). *Chapter 2: Geothermal takes the stage*. U.S. Department of Energy. https://www.energy.gov/cmei/articles/chapter-2-geothermal-takes-stage

Chapter 3

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

David Banks and Gioia Falcone, University of Glasgow; Helen Doran, Project InnerSpace; Mark Ireland, Newcastle University; Jon Gluyas, Durham University and National Geothermal Centre; Matthew Jackson, Imperial College; Charlotte Adams, National Geothermal Centre; and Peter Ledingham; technical review by Cathy Hollis, University of Manchester

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

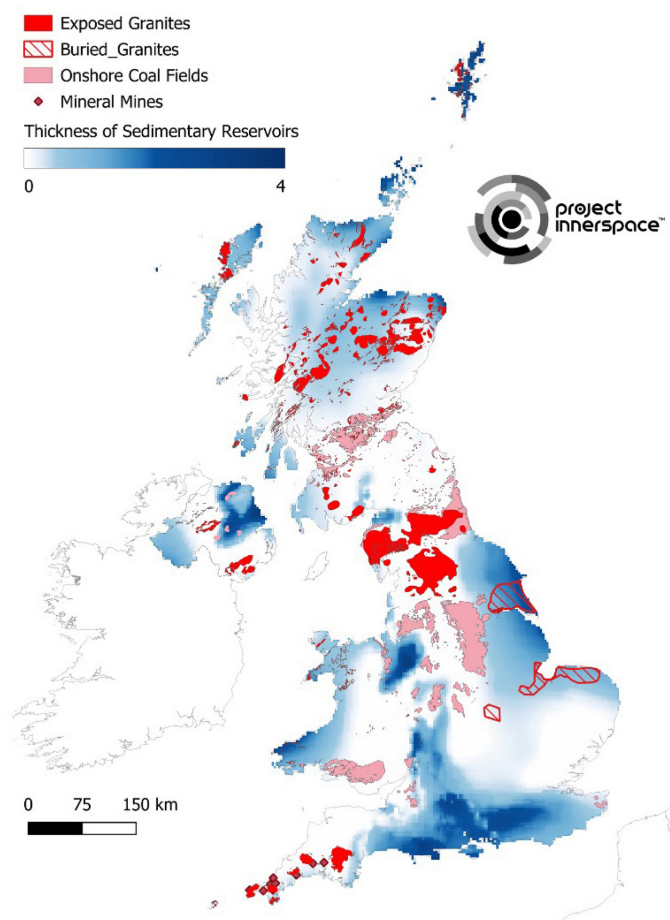


Figure 3.1: Distribution of key geological settings relevant to UK geothermal potential, showing the extent and depth of sedimentary reservoirs, the locations of exposed granites and buried granites, and areas of historic or active mining. In the southwest, the red granite areas are the most likely option 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

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

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

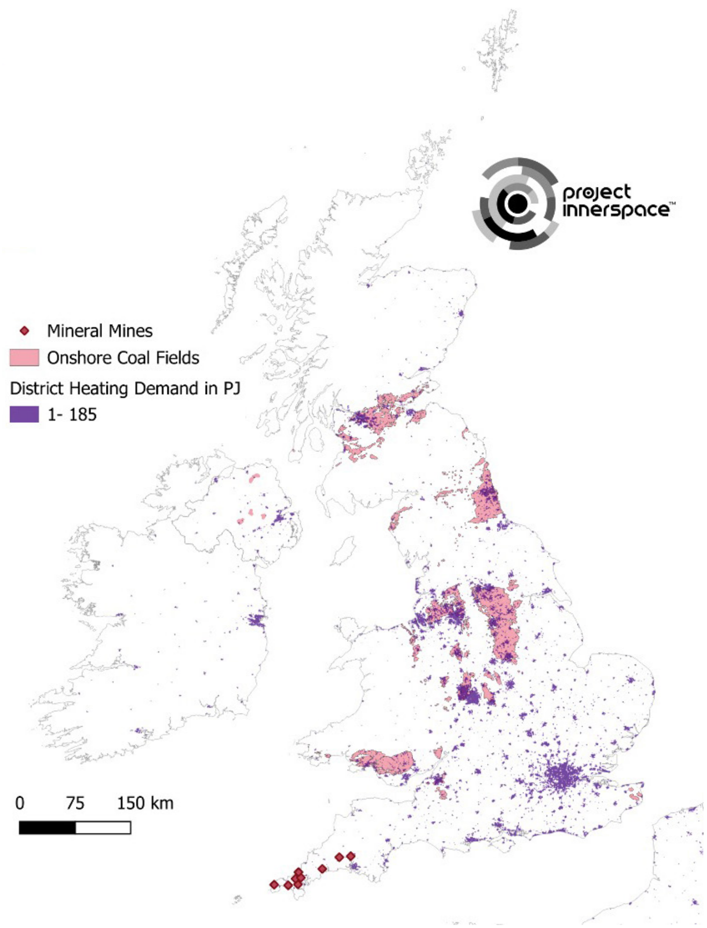


Figure 3.2: Distribution of onshore coalfields, mineral mines, and district heating demand across the United Kingdom. Areas shaded in pink indicate known onshore coalfields, while red diamonds mark the locations of active or historical mineral mines. Purple dots show spatial variation in district heating 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

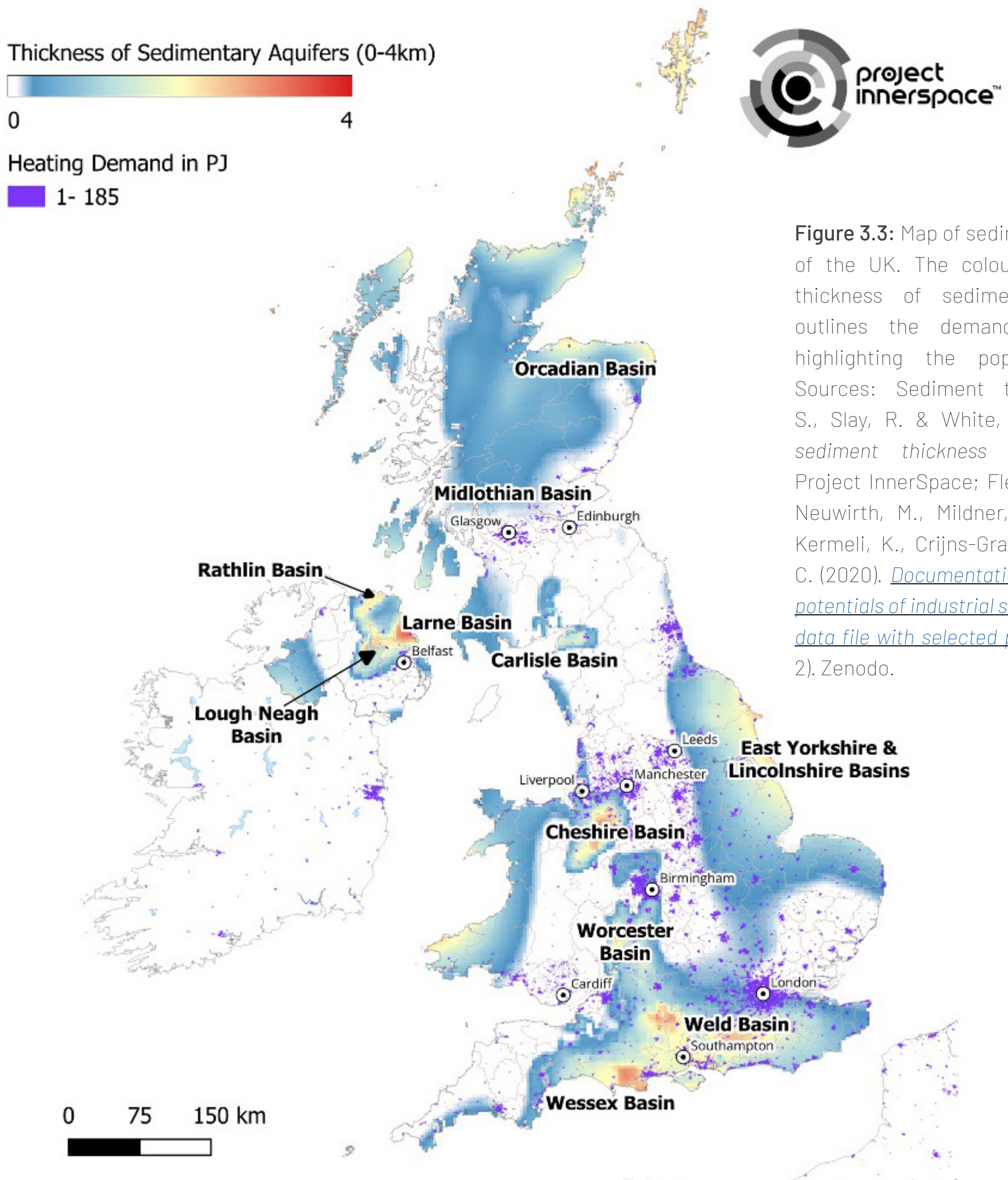


Figure 3.3: Map of sedimentary thickness of the UK. The colours represent the thickness of sediments, the purple outlines the demand in petajoules, highlighting the population centres. Sources: Sediment thickness: Holdt, S., Slay, R. & White, N. (2025). *Global sediment thickness* (in preparation). Project 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

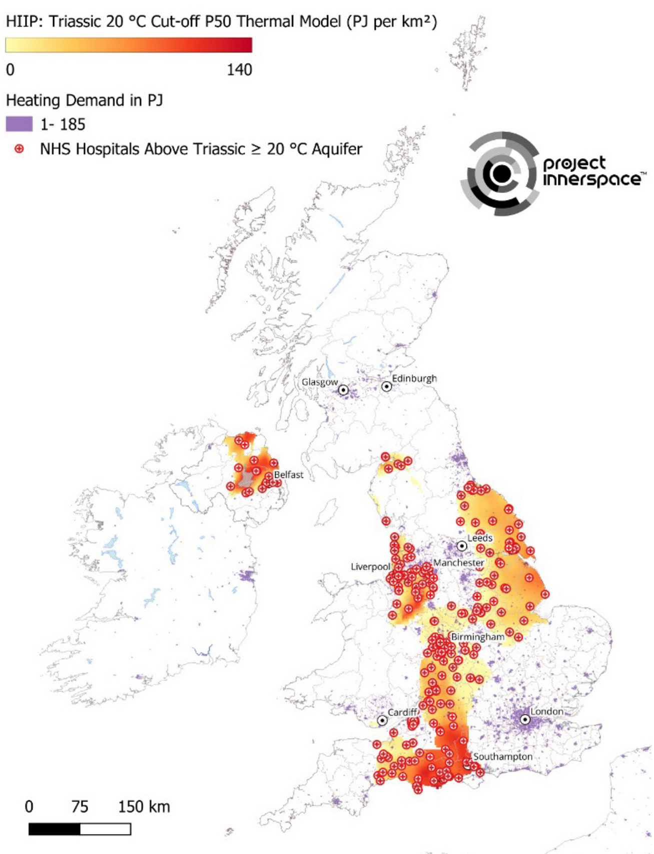


Figure 3.4: Geothermal resource potential in Triassic reservoirs beneath National Health Service (NHS) facilities ≥20°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace; Fleiter, T., Manz, P., Neuwirth, 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

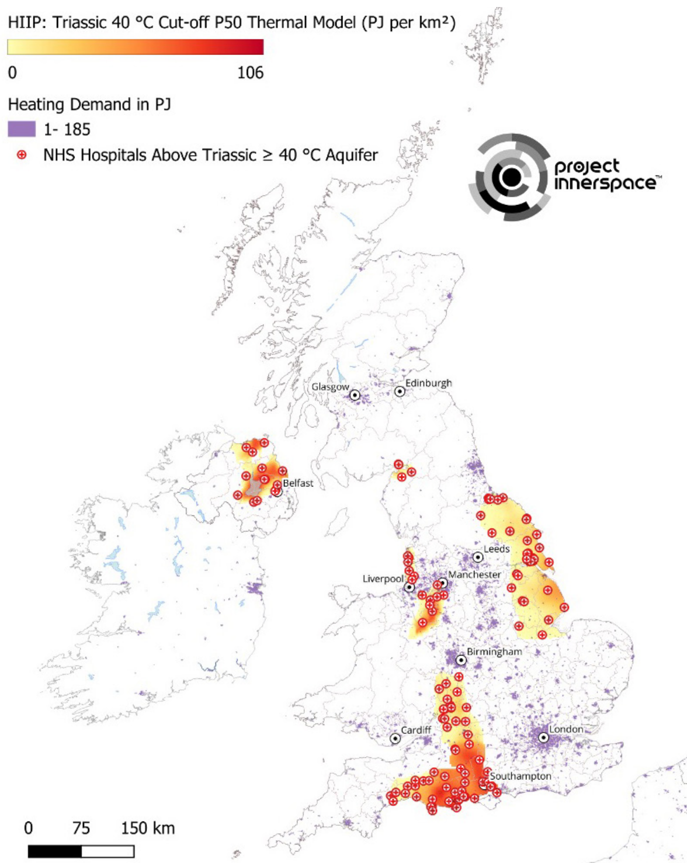


Figure 3.5: Geothermal resource potential in Triassic reservoirs beneath National Health Service (NHS) facilities ≥40°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., 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

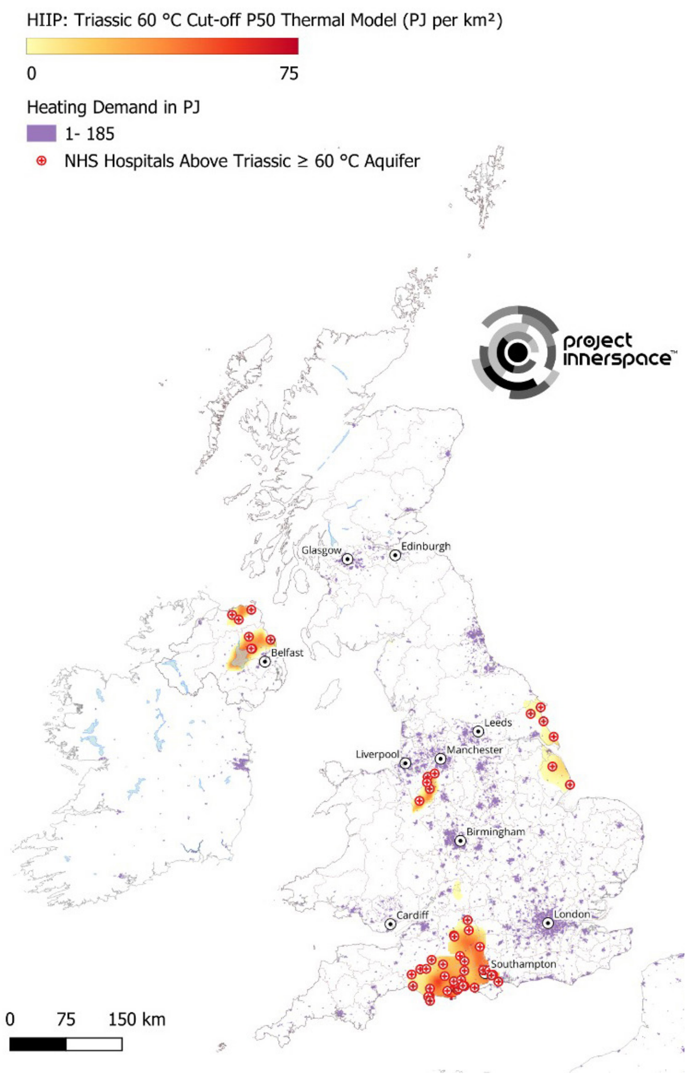
Methodology

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

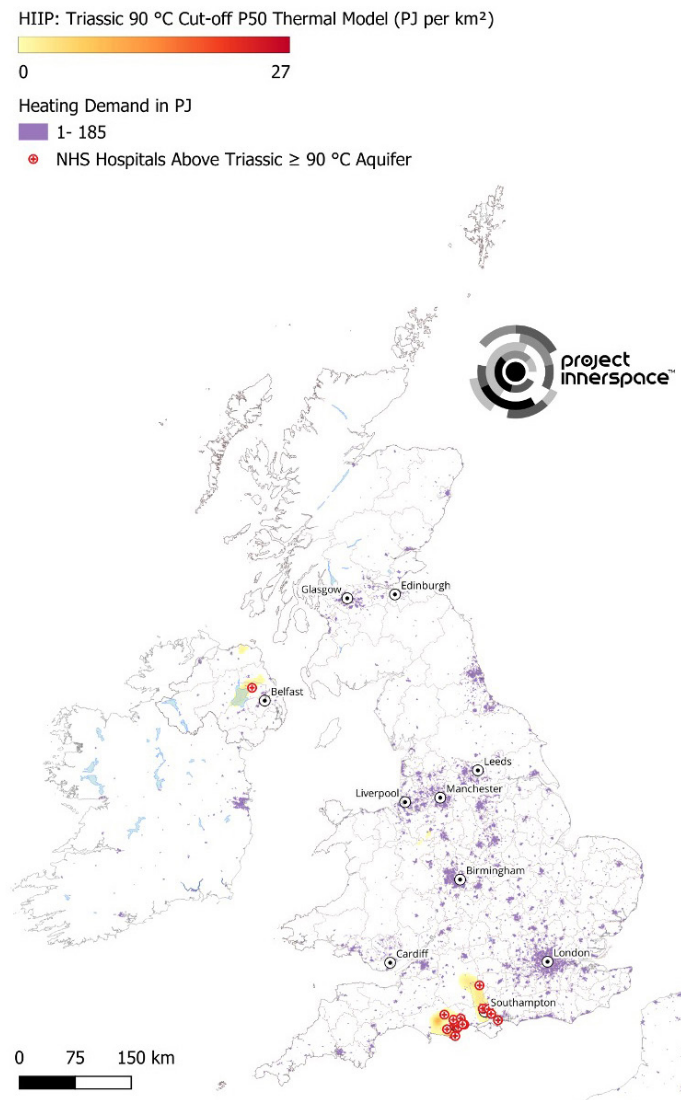
GEOTHERMAL RESOURCE POTENTIAL BENEATH NHS FACILITIES, ≥60°C

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

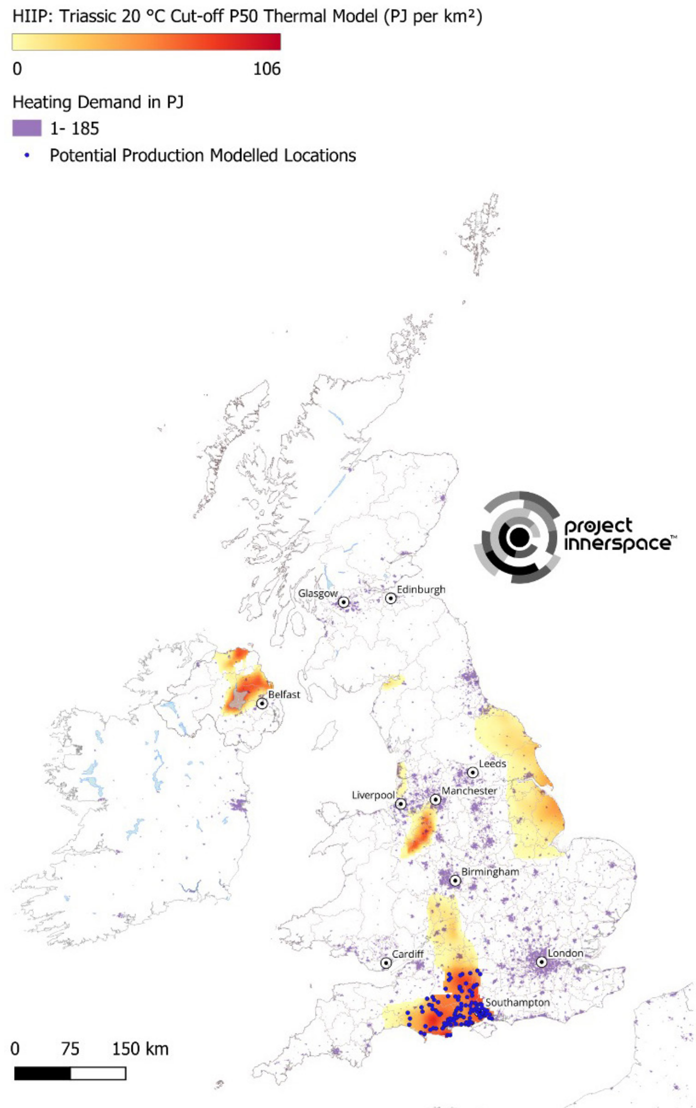


Figure 3.8: Geothermal resource potential in Triassic reservoirs ≥20°C The map shows HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*; Fleiter, T., Manz, P., Neuwirth, M., Mildner, F., Persson, U., Kermeli, K., Crijns-Graus, W., & 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

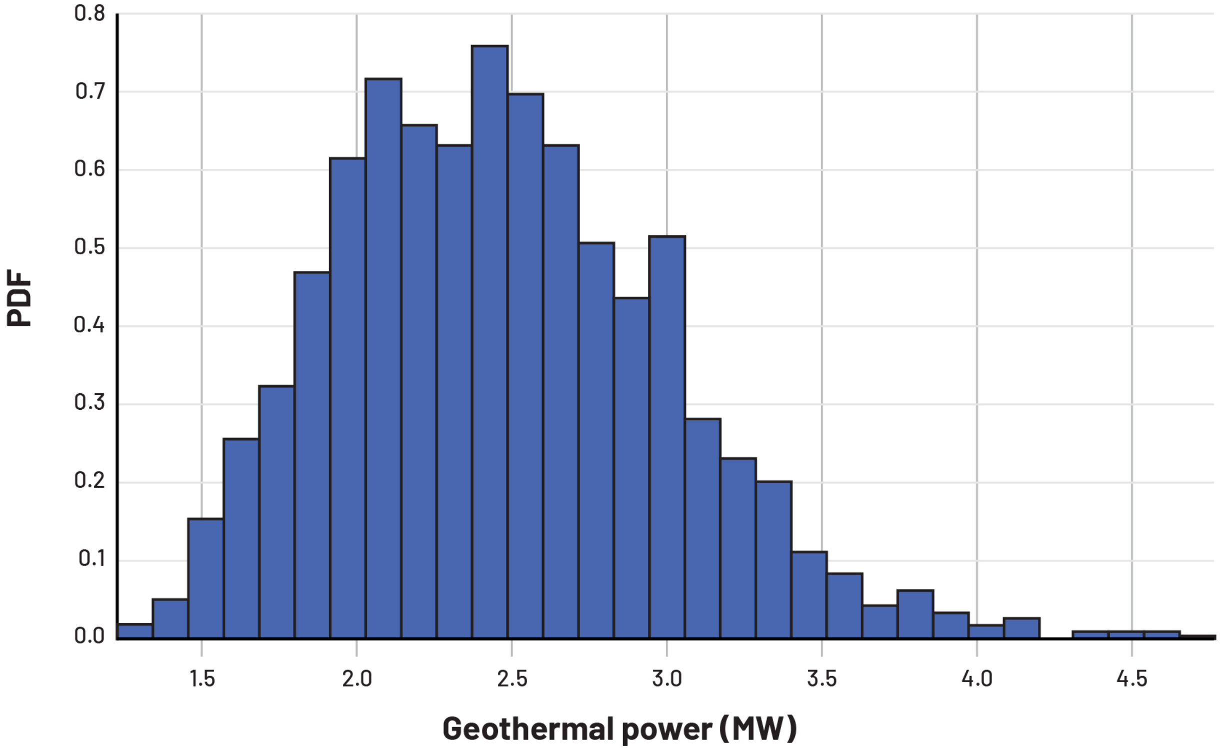


Figure 3.9: Probability distribution of geothermal capacity of conceptual development within the Bournemouth built-up area. Source: Ireland, M., Doran, H. & Falcone, G. (2025). *Geothermal energy potential of the Triassic Sandstone reservoirs in the Wessex Basin*. Project InnerSpace.

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

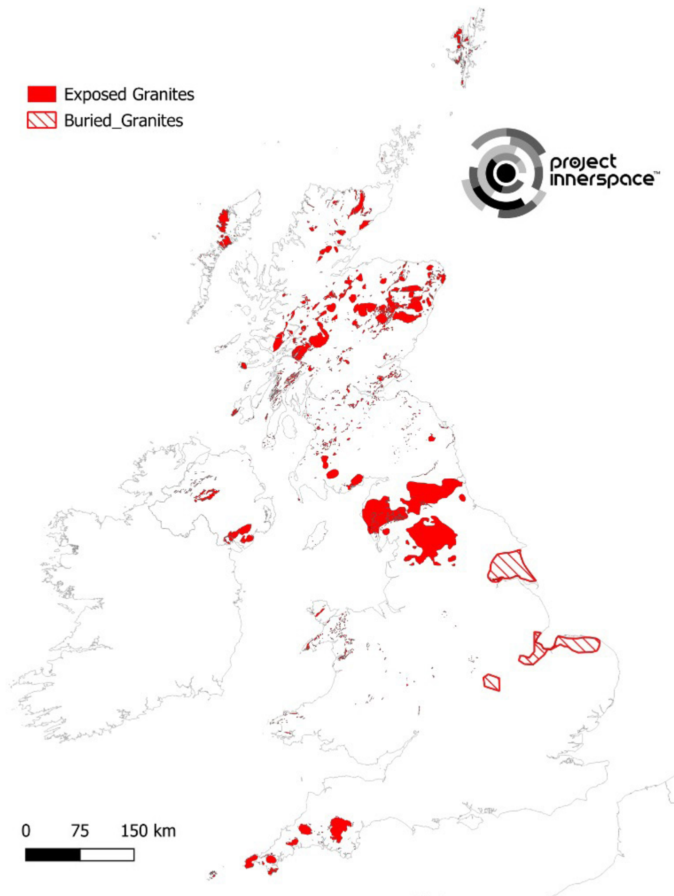


Figure 3.10: Distribution of granitic intrusions across the UK. Granites shown include key geothermal targets such as the Cornubian Batholith, Weardale Granite, Mourne Mountains, and Caledonian granites of Scotland. Source: Map produced by Project InnerSpace. Exposed and Buried Granites from BGS (625k_V5_Geology_UK_EPSG27700); 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.

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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

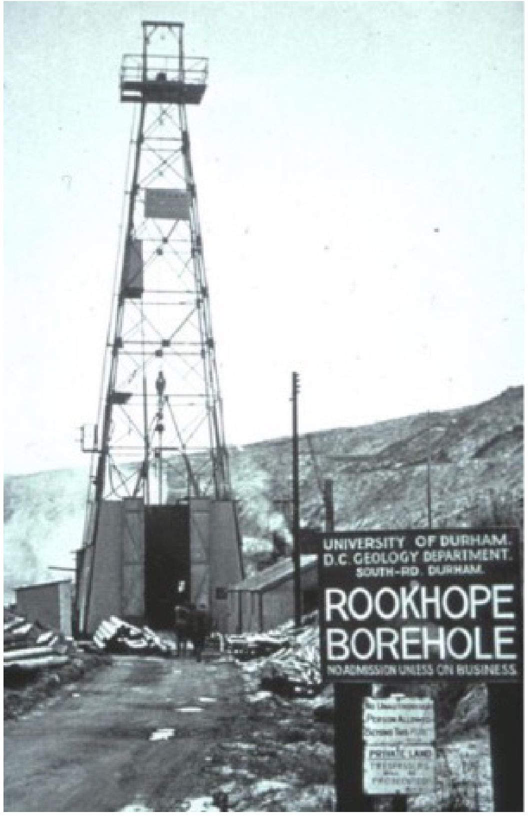


Figure 3.11: The UK's first geothermal exploration well. The well was drilled in 1961 in Rookhope in Weardale, County Durham. It proved the presence of hot granite, which until the well was drilled has been a speculative intrusion. Source: Photograph supplied by Durham University.

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

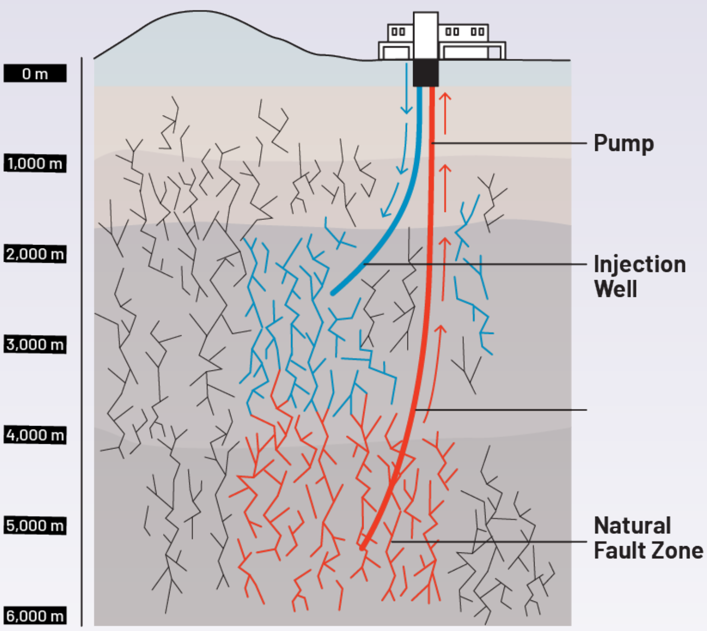


Figure 3.12: Schematic diagram of the geothermal doublet design at United Downs. The production well was drilled to a measured depth of 5,275 m and the injection to a measured depth of 2,393 m. Source: Olver, T., & Law, R. (2025). The United Downs Geothermal Power Plant, Cornwall, UK: Combining the generation 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 × depth in kilometres).*

DEPTH TO TOP OF TRIASSIC SANDSTONE GROUP ACROSS THE UK

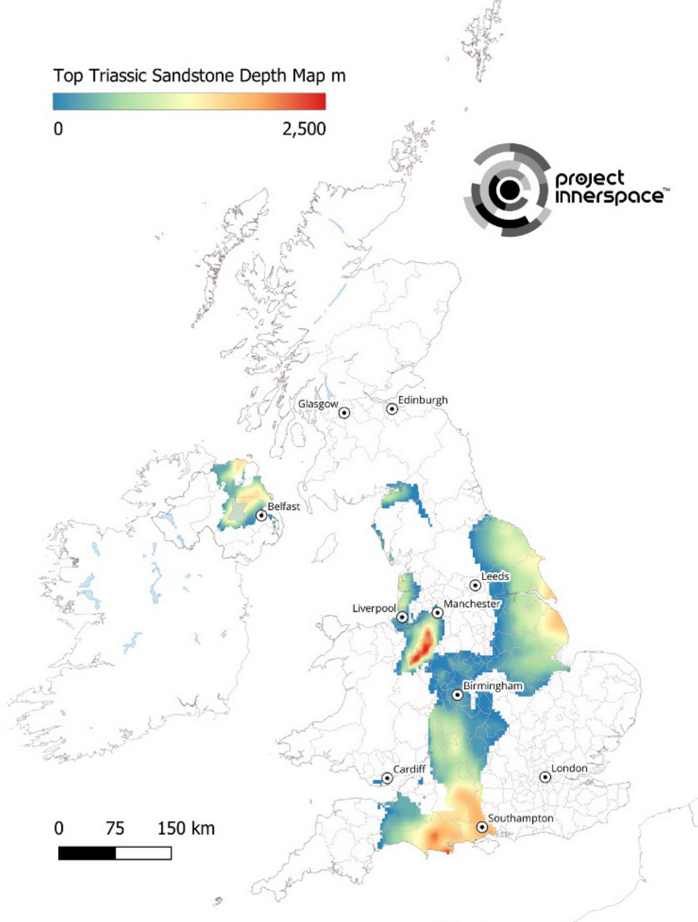


Figure 3.A.1: Depth to Top of the Triassic Sandstone Group across the UK. This map shows the estimated depth (in metres) to the top of the Sherwood Sandstone Group, one of the principal geothermal aquifers in the UK. Depths range from surface outcrop to more than 2,500 m (dark red). Sources: Data compiled 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

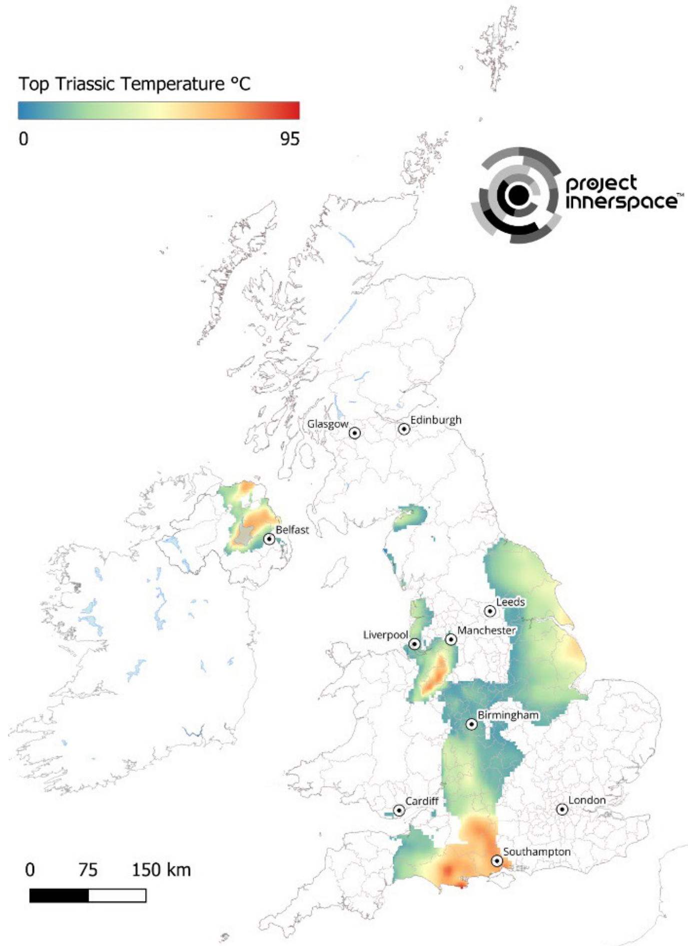


Figure 3.A.2: This map displays the modelled temperature distribution at the top of the Triassic Sandstone Group across the UK, with values ranging from 0°C (blue) to 95°C (red). Source: Temperatures were calculated using Doran, H., & Matt, V. (2025). *Global lithosphere thermal model*. Project InnerSpace.

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]

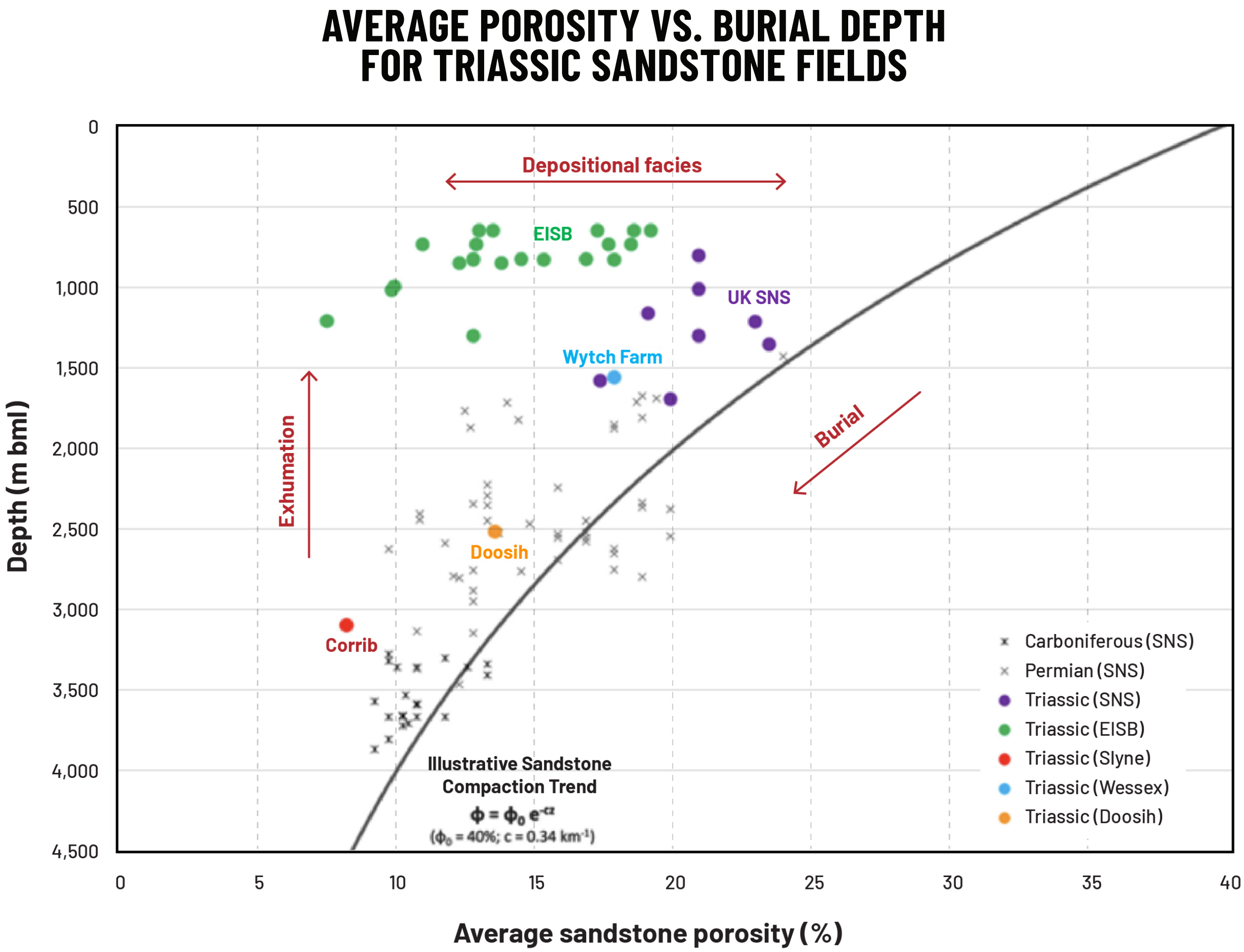


Figure 3.A.3: Average porosity vs burial depth for Triassic sandstone fields in UK and Ireland. Source: English, K. L., English, J. M., Moscardini, R., Haughton, P. D. W., Raine, R. J., & Cooper, M. (2024). Review of Triassic Sherwood Sandstone Group reservoirs of Ireland and Great Britain and their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

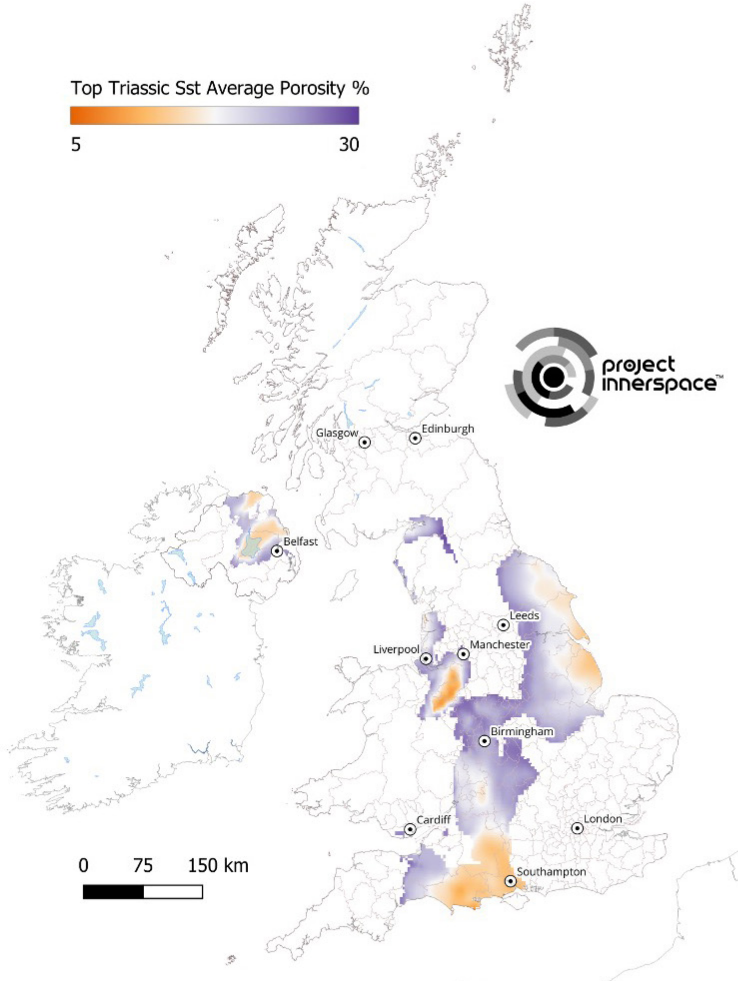


Figure 3.A.4: This map illustrates spatial variation in average porosity across the Triassic Sandstone, with values ranging from 5% (orange) to 30% (purple). Source: English, K. L., English, J. M., Moscardini, R., Haughton, P. D. W., Raine, R. J., & Cooper, M. (2024). Review of Triassic Sherwood Sandstone 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 × 10^{10} × 4180 × 62.8 ≈ 2.7 × 10^{15} J

Rock Energy

Q_rock = 2.52 × 10^{11} × 790 × 62.8 ≈ 1.25 × 10^{16} J

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

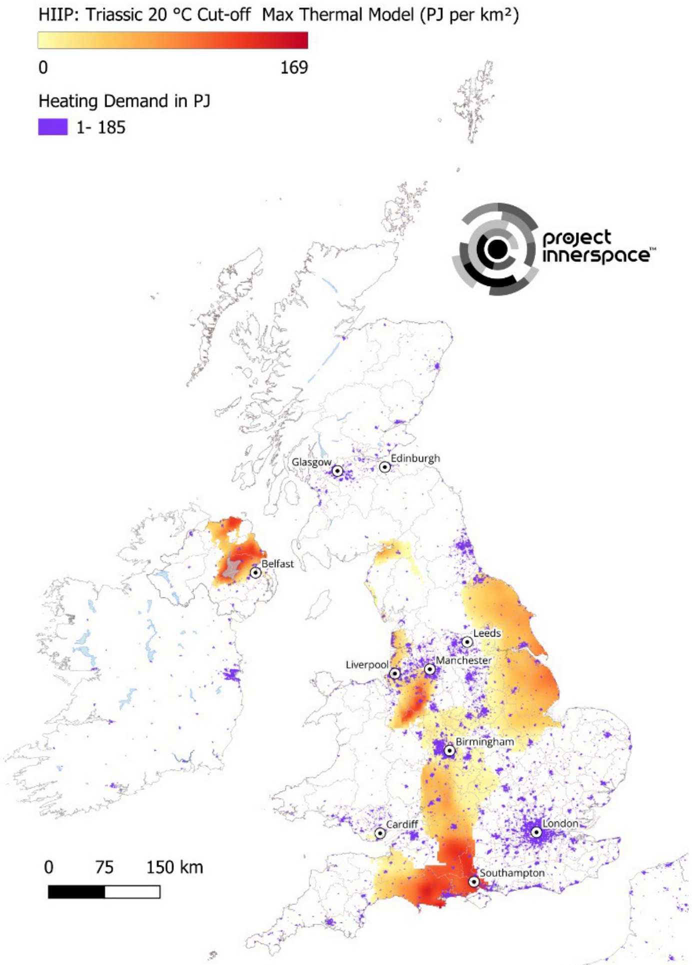


Figure 3.A.5: Geothermal resource potential in Triassic reservoirs ≥20°C using the Max thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.

Total Thermal Energy

Q_total = Q_water + Q_rock = 2.7 × 10^{15} + 1.25 × 10^{16} = 1.52 × 10^{16} J

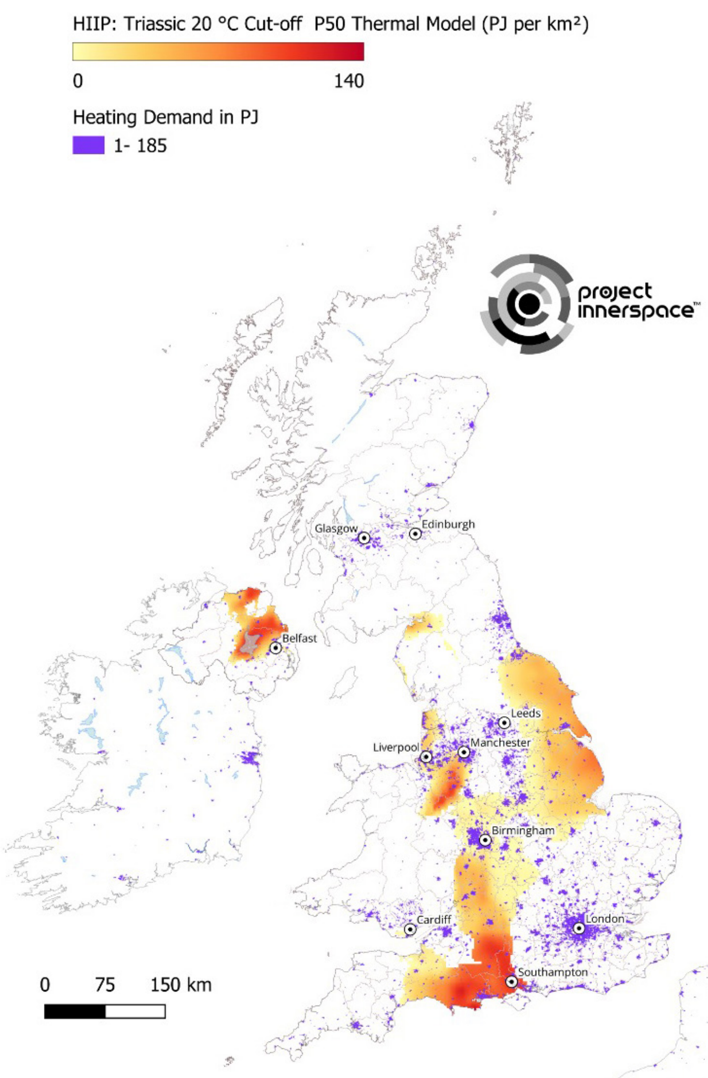
Convert to Petajoules (PJ)

1 PJ = 10^{15} J
Q_total ≈ 15.2 PJ/km^2

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

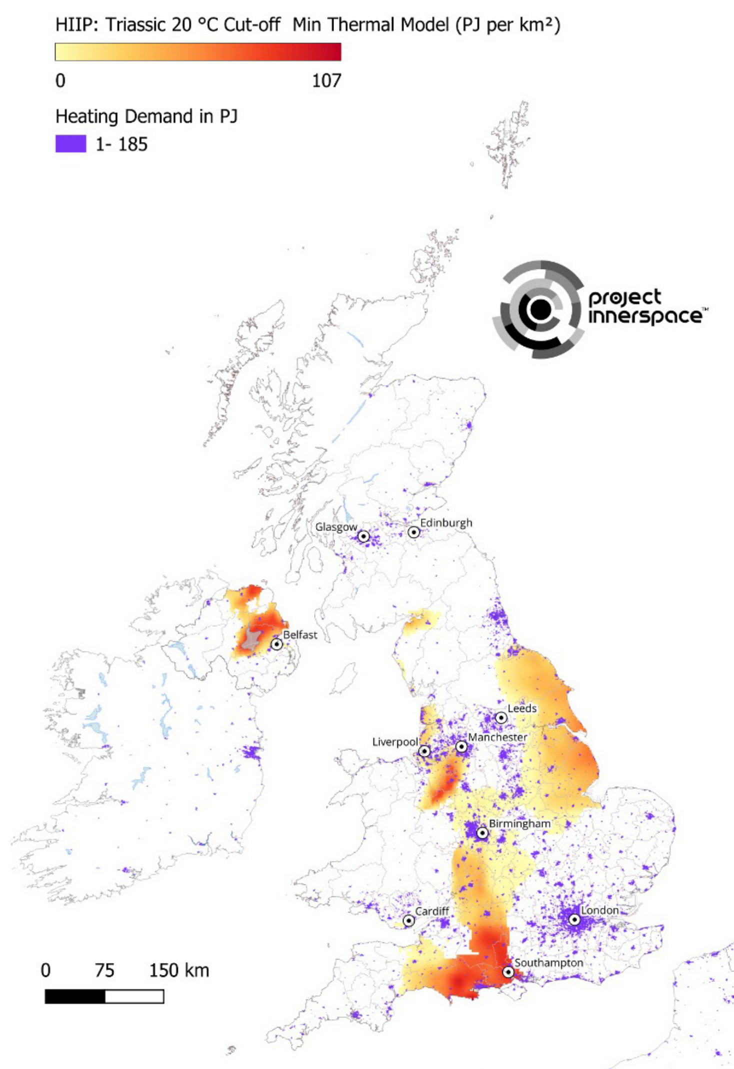
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥20°C USING P50 THERMAL MODEL

Figure 3.A.6: Geothermal resource potential in Triassic reservoirs ≥20°C using the P50 thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



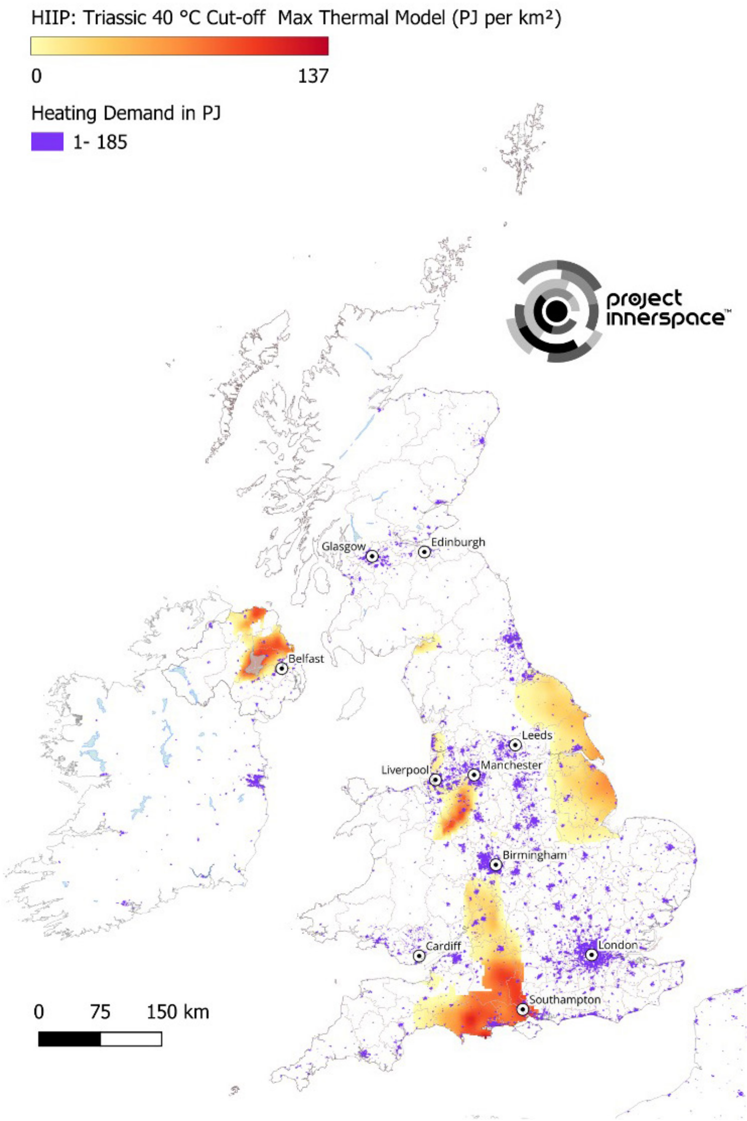
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥20°C USING MIN THERMAL MODEL

Figure 3.A.7: Geothermal resource potential in Triassic reservoirs ≥20°C using the Min thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



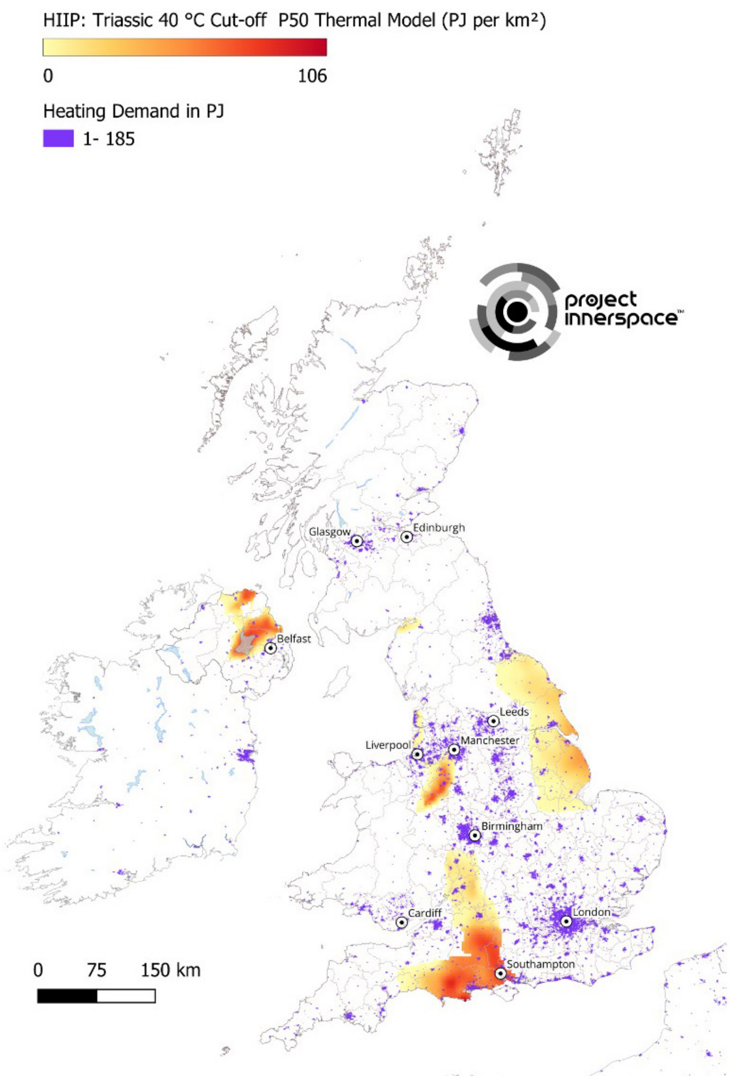
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥40°C USING MAX THERMAL MODEL

Figure 3.A.8: Geothermal resource potential in Triassic reservoirs ≥40°C using the Max thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



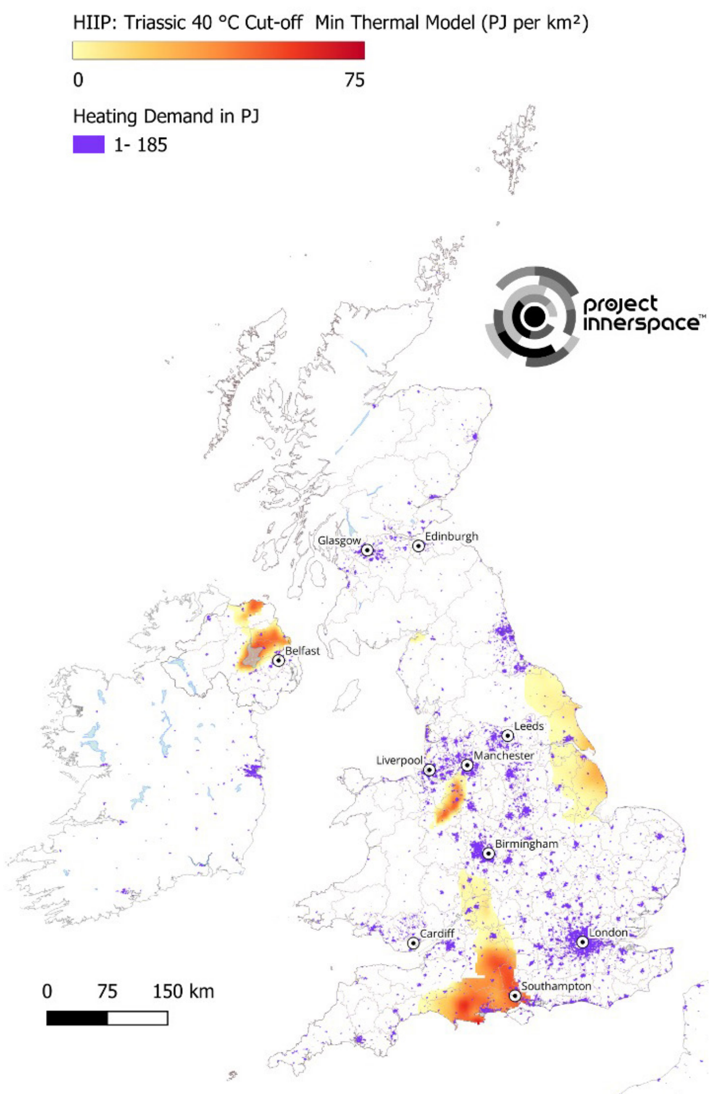
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥40°C USING P50 THERMAL MODEL

Figure 3.A.9: Geothermal resource potential in Triassic reservoirs ≥40°C using the P50 thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.



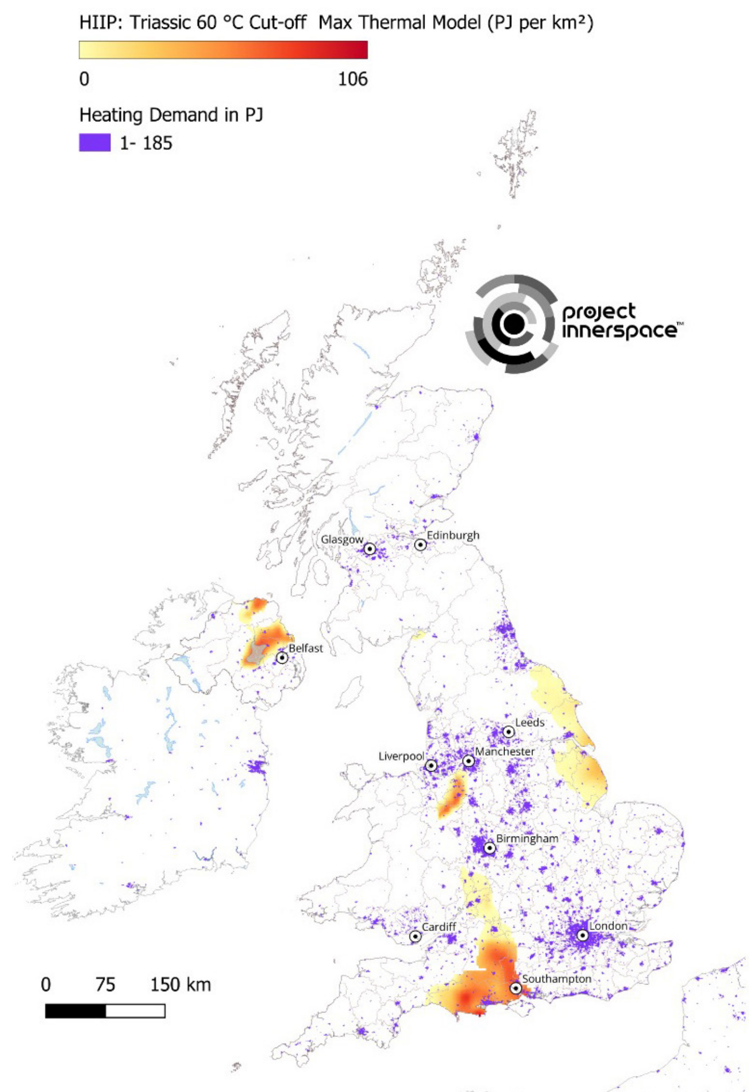
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥40°C USING MIN THERMAL MODEL

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.



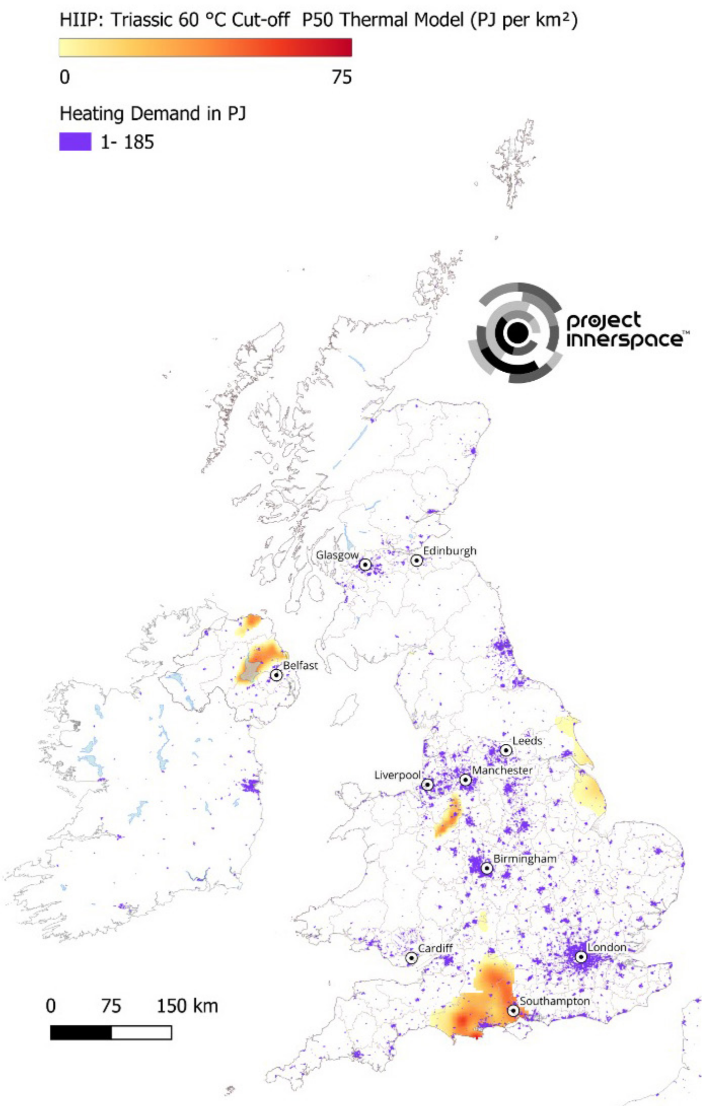
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥60°C USING MAX THERMAL MODEL

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.



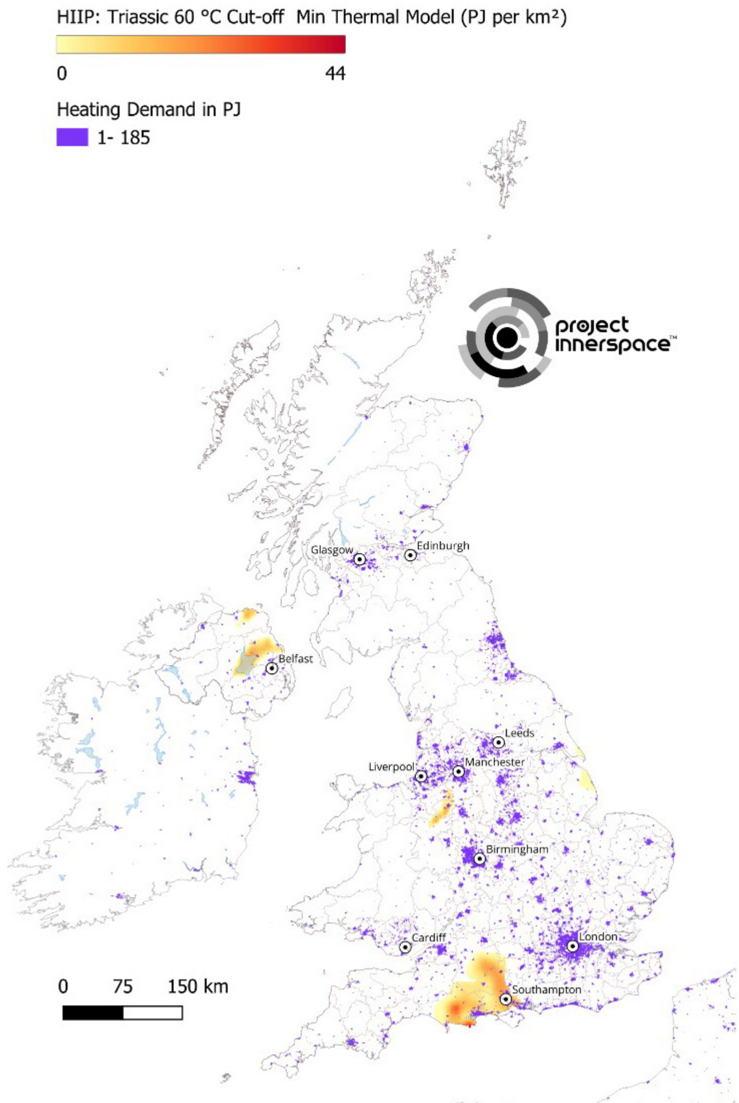
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥60°C USING P50 THERMAL MODEL

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.



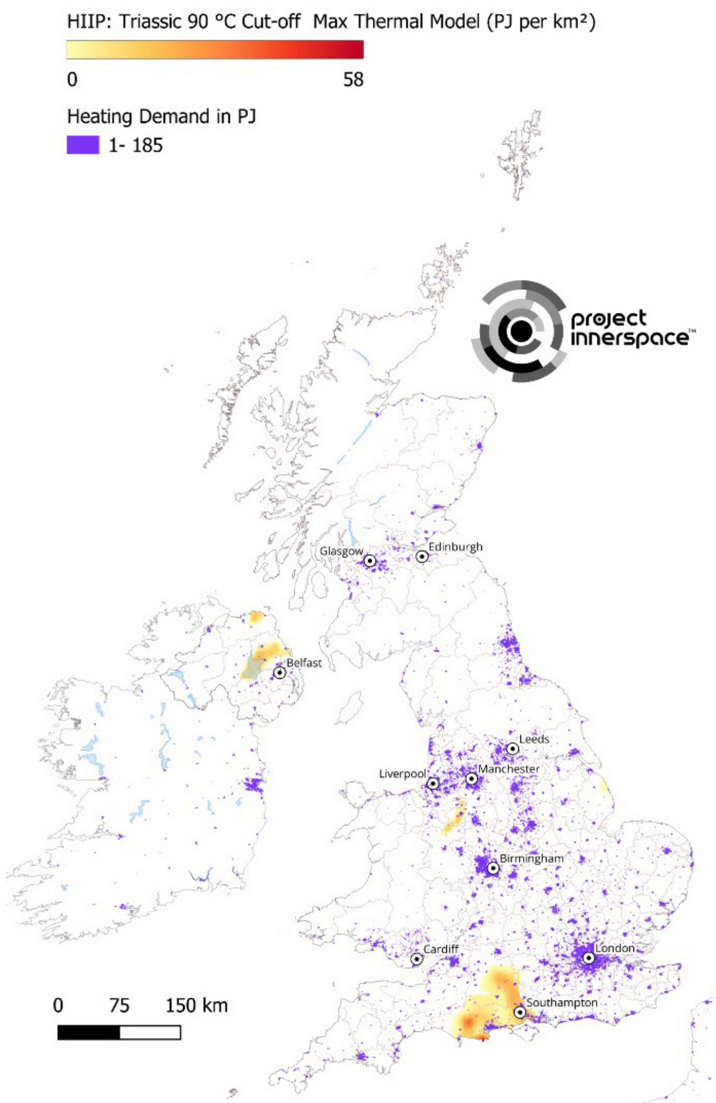
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥60°C USING MIN THERMAL MODEL

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.



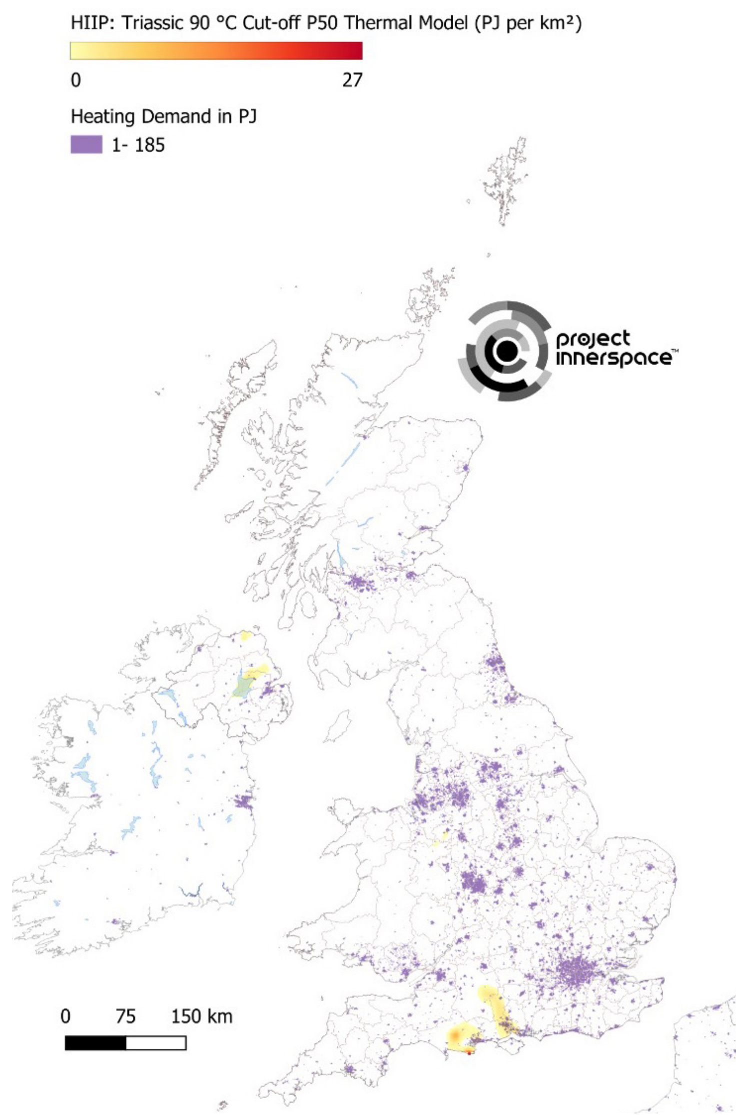
GEOTHERMAL RESOURCE POTENTIAL IN TRIASSIC RESERVOIRS ≥90°C USING MAX THERMAL MODEL

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.

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

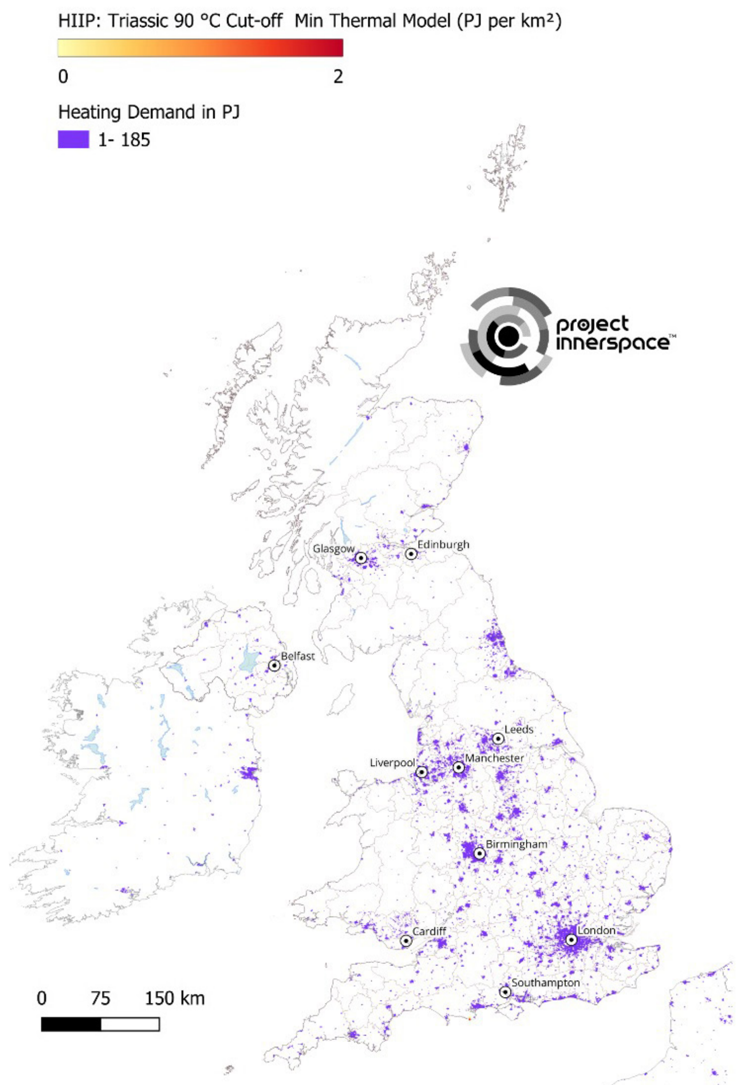


Figure 3.A.16: Geothermal resource potential in Triassic reservoirs ≥90°C using the Min thermal model. The maps show HiP estimates in PJ/km^2. Source: Doran, H. (2025). *Geothermal resource potential (PJ) in the UK Triassic reservoirs*. Project InnerSpace.

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-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

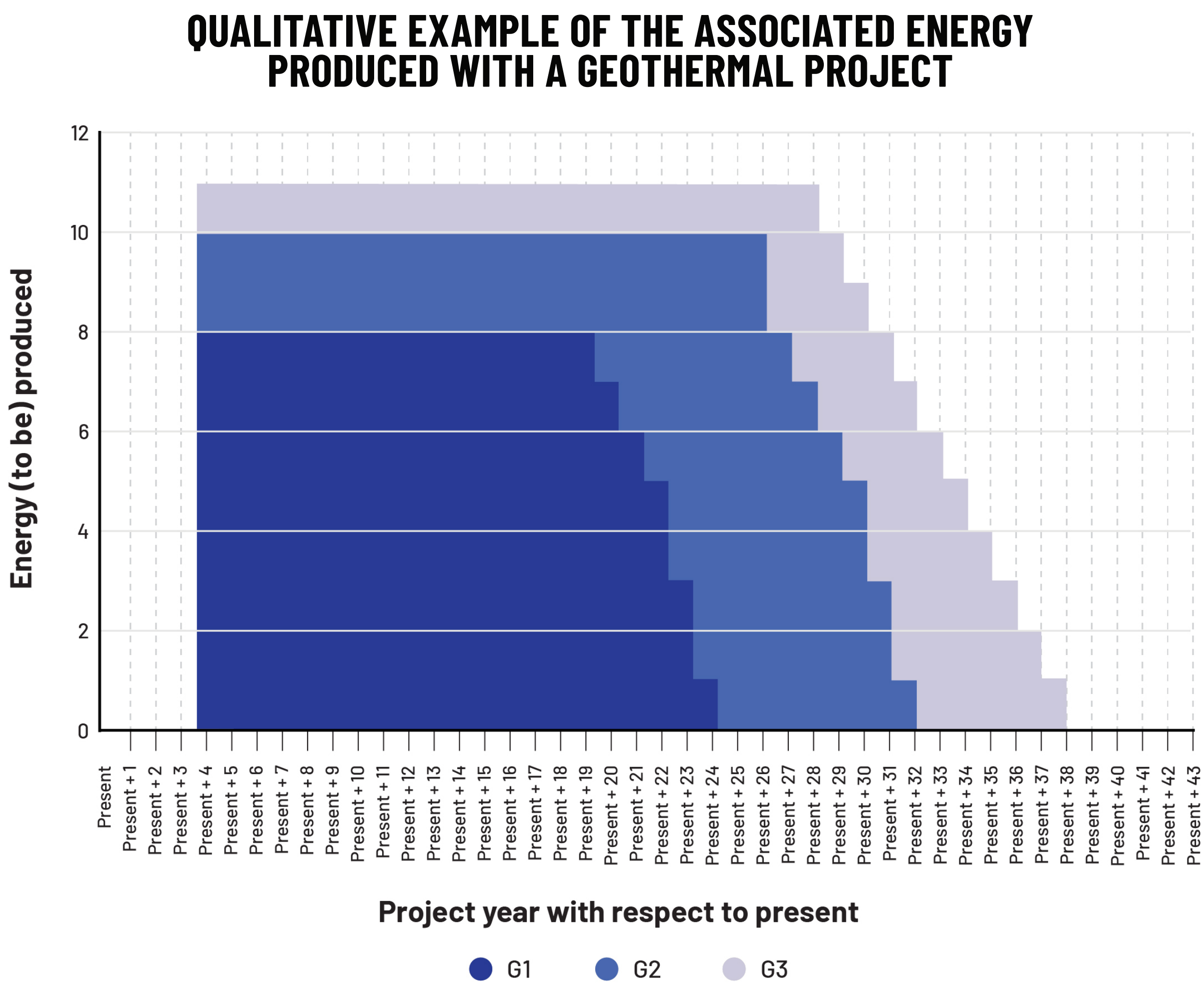


Figure 3.B.2: Qualitative example of the associated with a geothermal energy project. G1 = high confidence in the estimated quantities of a resource; G3 = lower confidence in the estimated quantities of a resource. Source: adapted from various training materials jointly produced by the United Nations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

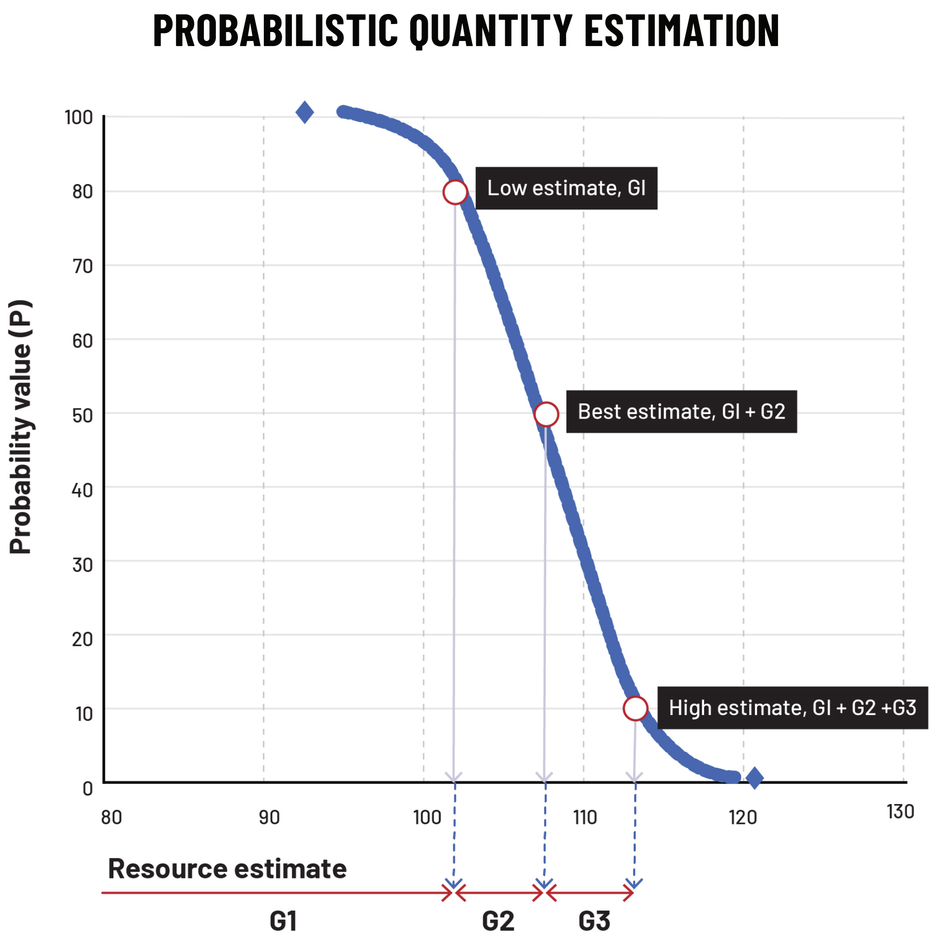


Figure 3.B.3: Example of probabilistic quantity estimation with corresponding G1, G1+G2, and G1+G2+G3 range of uncertainty. G1 = high confidence in the estimated quantities of a resource; G3 = lower confidence in the estimated quantities of a resource. Source: adapted from various training materials 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.

Chapter 4

Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors

Matthew Jackson, Imperial College; David Banks and Gioia Falcone, University of Glasgow; Mark Ireland, Newcastle University; Jon Gluyas, Durham University and National Geothermal Centre; and Helen Doran, Project InnerSpace

Geothermal heating and cooling from shallow systems, minewater networks, and deep aquifers already provide clean, low-cost, reliable energy for UK homes, hospitals, and campuses. But these resources could be used much more widely. Aquifer thermal energy storage alone could meet more than 60% of heating and nearly 80% of cooling demand. Expanding these methods could make geothermal a cornerstone of the UK's heat system.

The United Kingdom already has working, world-class examples of geothermal heating and cooling that are cutting carbon, saving money, and protecting heritage—proving that the technology is ready to scale now. From Bath's Roman springs heating historic landmarks to Southampton's pioneering district network, Gateshead's minewater schemes revitalising coalfield communities, and London's aquifer storage enabling low-carbon heating and cooling, geothermal is delivering reliable, cost-competitive energy across diverse settings. Shallow systems are already cheaper than wind and solar, while deep projects unlock massive long-term capacity, showing geothermal can compete head-to-head with mainstream renewables. The common success

This chapter has been developed through contributions from a wide range of authors, each responsible for specific sections. **Matthew Jackson** prepared the aquifer thermal energy storage and Wandsworth case study. **David Banks** prepared the section on shallow geothermal. **Helen Doran, Mark Ireland, Jon Gluyas**, and **Gioia Falcone** contributed to the Southampton and Bath case studies. **Helen Doran** performed the analysis and prepared the section on geological cooling and storage for the UK's AI Growth Zones. Editorial responsibilities were coordinated by **Helen Doran**, **Mark Ireland**, and **Jon Gluyas**.

factors—strong governance, public–private partnerships, and integration with complementary heat sources—make these projects not just technically feasible, but economically bankable as well. Geothermal heat is not a future ambition but a proven solution. Collectively, these case studies highlight that geothermal innovation is already embedded in the UK's energy transition. Scaling these models nationwide will slash emissions, tackle fuel poverty, enhance energy security, and turn Britain's geology and industrial legacy into a cornerstone of its transition to renewable and sustainable energy. This chapter outlines immediately deployable, scalable opportunities for heating (and cooling) across the UK.

In terms of heat applications, shallow geothermal technologies offer the lowest levelised costs of heat among geothermal options, primarily due to their maturity, established supply chains, lower construction costs, and strong contractor competition. For heating-only applications, shallow systems typically deliver heat at between £18 and £56 per megawatt-hour[1] (assuming an Nth-of-a-Kind [NOAK] project starts in 2024), with costs falling further when systems are designed to provide both heating and cooling, a particularly advantageous setup in buildings like hospitals. These systems' lower risk profile allows for a reduced hurdle rate (around 7.5% compared with 10.1% for deep geothermal), though higher assumptions would increase costs—for example, a shallow minewater network could rise from £30 per megawatt-hour to £36 per megawatt-hour[2] if the hurdle rate increased to 10%. While shallow systems avoid the high drilling costs associated with deep geothermal, they do require additional investment in heat pumps to raise extracted temperatures to usable levels.

Deep geothermal options for heat (including new deep doublets and repurposed oil and gas wells) are more expensive up front: Doublets range from roughly £84 to £172 per megawatt-hour, while repurposed wells cost between £55 and £100 per megawatt-hour. However, doublets deliver much higher heat output and are widely proven in Europe (see Chapter 3's section titled "Modelling Future Production Scenarios for the Wessex Basin"). Costs for deep systems reflect project risk. For instance, a higher hurdle rate during the drilling phase can push a deep doublet from about £126 to £264 per megawatt-hour, whereas reducing risks can improve cost-effectiveness.

SHALLOW GEOTHERMAL SYSTEMS

There is no formal definition of "shallow" geothermal in the United Kingdom, but a working definition might include systems shallower than 300 metres (also the upper defined limit for "deep level land" in the Infrastructure Act 2015):[3]

- **Thermal extraction systems**, which transfer heat or cooling from the subsurface but do not store energy (**Figure 4.1a, b**).
- **Underground thermal energy storage systems**, in which heat or cooling is stored for later use (**Figure 4.1c–e**).

Both categories can be configured as either closed-loop or open-loop systems. In closed-loop systems (**Figure 4.1a, d)**, a heat transfer fluid circulates within sealed pipes or boreholes, exchanging heat with the surrounding soil or rock. In open-loop systems (**Figure 4.1b, c, and e**), groundwater is pumped from and returned to the subsurface via one or more boreholes, enabling direct extraction or storage of thermal energy.

Heating and cooling systems that use the ground to supply energy to a heat pump are often called ground source heat pump (GSHP) or ground source heating and cooling (GSHC) systems. Open-loop systems are sometimes referred to as groundwater heat pump (GWHP) or groundwater heating and cooling (GWHC) systems. In this report, GWHP is used to refer to systems that supply heating or cooling only, and GWHC is used when they provide both.

There are several main approaches to extracting heat from the shallow subsurface:

1. A groundwater-based "**open-loop**" GSHC system: If a permeable aquifer horizon is present in the shallow subsurface, a water well can be drilled. Groundwater can be pumped from the well and passed through a heat pump system, which extracts heat from the water. Note that the "thermally spent" water must be disposed of responsibly. To conserve water resources, environmental authorities will normally insist that this water is returned to the aquifer via a reinjection well (see "Underground Thermal Energy Storage in the UK, with a Focus on Aquifer Thermal Energy Storage"). A special class of

GROUND SOURCE AND UNDERGROUND THERMAL ENERGY STORAGE SYSTEMS

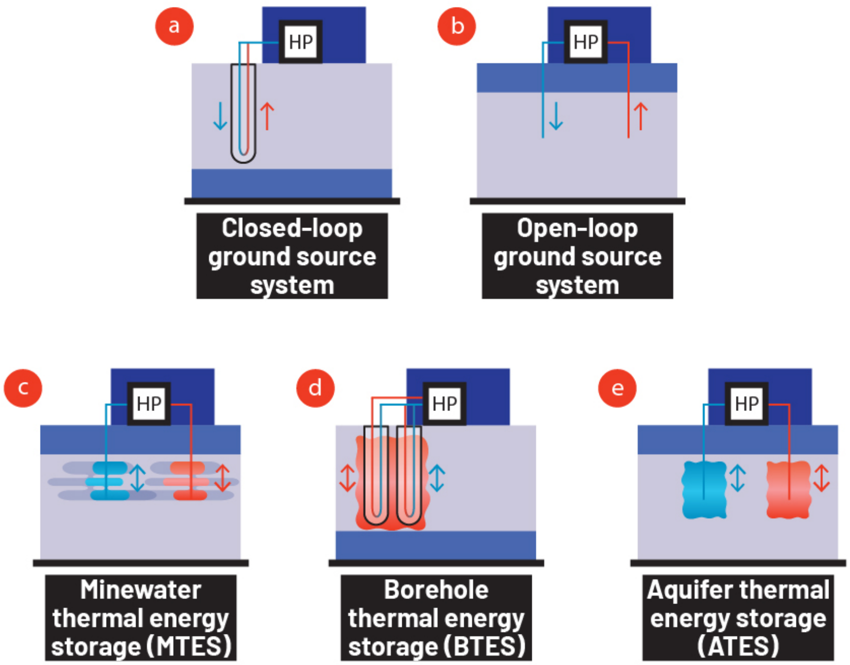


Figure 4.1: Schematics illustrating (a, b) ground source and (c, d, e) underground thermal energy storage systems for low-carbon heating and/or cooling. Source: Modified from Jackson, M. D., Regnier, G., & Staffell, I. (2024). Aquifer thermal energy storage for low carbon heating and cooling in the United Kingdom: Current status and future prospects. *Applied Energy*, *376*, 124096.

open-loop system is one in which water is pumped from flooded, abandoned mines for the purpose of heating or cooling (see "Minewater Geothermal Energy in the UK").

2. A shallow, **horizontal closed-loop** system: In this system, one or more loops of polyethylene pipe are buried between 1.2 metres and 2 metres deep in soil trenches. A heat transfer fluid (a solution of glycol or alcohol) circulates through the pipes, collecting heat from the soil and returning it to a heat pump, where heat is extracted before the fluid is recirculated. This may not sound like "geothermal," and indeed, much of the heat from such systems is derived from solar energy being absorbed by the soil. But the heat is stored in the ground and, as such, represents the "shallowest" end of the geothermal spectrum.
3. A **vertical closed-loop** system or borehole heat exchanger (BHE): In this system, a borehole is drilled (often to between 60 metres and 250 metres deep) and a loop (U-tube) of polyethylene pipe is installed. Heat transfer fluid is circulated around the loop, absorbing heat from the rocks in the borehole wall and delivering it back to the heat pump. Around 250 metres deep and below, U-tubes become hydraulically inefficient and coaxial circulation systems can be used in deeper borehole heat exchangers.[4]

While most shallow geothermal systems are designed for heating, they are inherently reversible and can be operated to reject waste heat and provide cooling. In some geological settings, it is also possible to store surplus heat generated in summer for recovery during the winter (see "Underground Thermal Energy Storage in the UK, with a Focus on Aquifer Thermal Energy Storage").

Ground Source Heat Pumps

The shallow GSHP sector is the one area of geothermal that has, to date, enjoyed significant uptake in the UK. It also has a historic pedigree: The world's first GSHP was used to freeze ground during shaft excavation in Swansea in 1862;[5] probably the world's first groundwater-sourced domestic heat pump was installed in Perthshire, Scotland, in the mid-1920s.[6,7] Much of the pioneering experimental work on ground heat exchangers was carried out by Miriam Griffith and John Sumner in the United Kingdom from the 1950s through the 1970s.[8,9,10] The UK has a particularly active Ground Source Heat Pump Association (GSHPA)[11] that produces standards for the construction of GSHP systems.[12]

THERMODYNAMICS OF GEOTHERMAL HEAT ENGINES, HEAT PUMPS, AND DIRECT-USE SYSTEMS

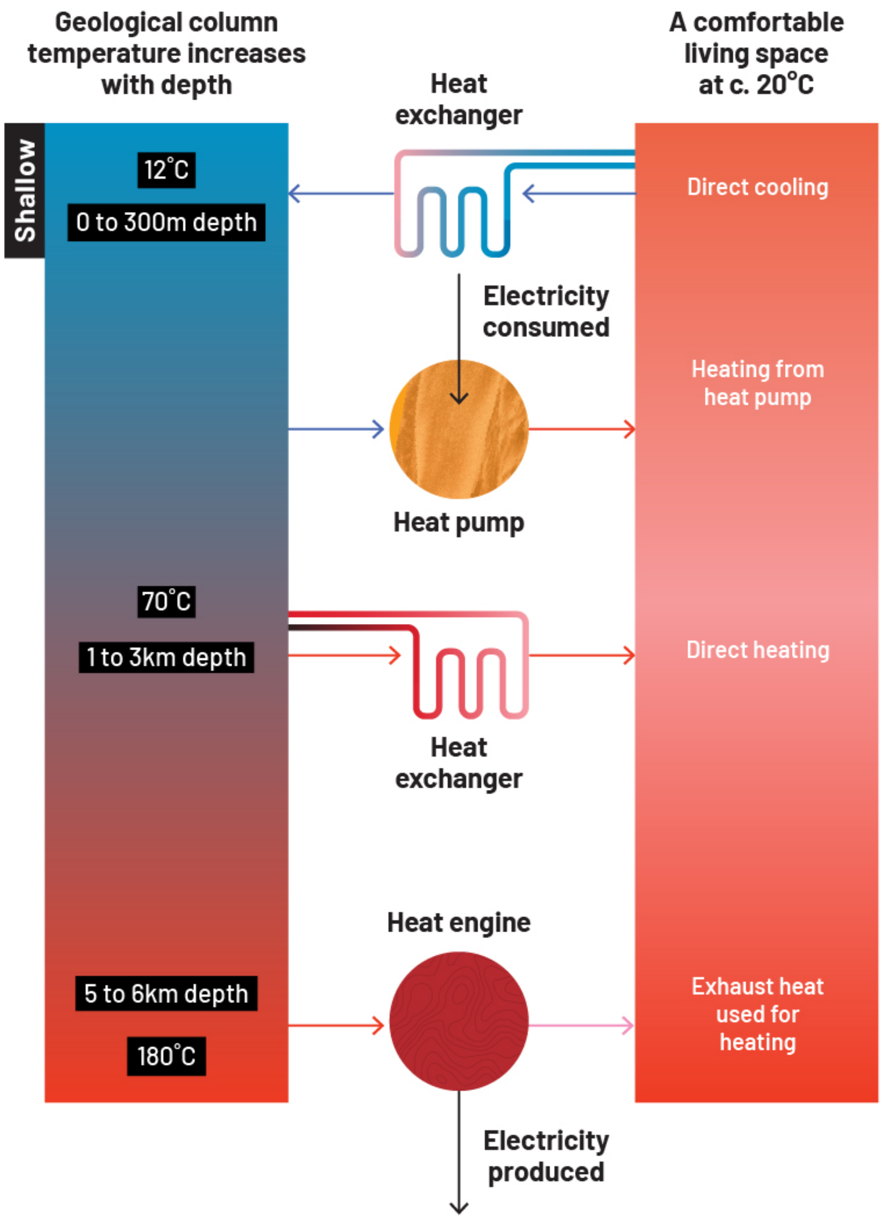


Figure 4.2: The simplified thermodynamics of geothermal heat engines, heat pumps, and direct-use systems. Source: David Banks.

The Heat Pump

In deep geothermal boreholes drilled in rocks with a high geothermal gradient (such as United Downs in Cornwall), it may be possible to extract hot fluids at temperatures high enough to generate electricity. In thermodynamic terms, the high-temperature heat flows through a heat engine to a lower-temperature exhaust. In the engine, heat is converted to mechanical work (turbine) and then to electricity (**Figure 4.2**).

In medium-depth geothermal prospects (such as the deep Triassic, Sherwood Sandstone), it is possible to extract fluids that are not hot enough for viable electricity generation but that can provide heat, via direct heat exchange, to a consumer such as a district heat network, large user (for instance, warehouse or hospital), or agricultural enterprise.

At shallow depths, temperatures in the UK are seldom warm enough for such direct use. To be able to extract heat from cool ground, the thermodynamic opposite of a heat engine is required—that is, a heat pump. A heat pump uses electricity to perform mechanical work (a compressor) to transfer heat from a low-temperature source (the ground) to a high-temperature sink (a heating system). Provided the electricity used is low carbon and relatively cheap, shallow geothermal prospects are attractive because the capital costs, risks, and uncertainties of deep drilling are avoided. A shallow geothermal system that uses a heat pump is often called a GSHP system. The efficiency of such systems is described in terms of coefficient of performance (COP), or the ratio of heating output to the electrical energy consumed. A COP of 2 for a heat pump means that it produces twice as much heat as the amount of electrical energy it consumes, but heat pumps are typically designed to be more efficient than this, so one will often aim for a COP of at least 3 for a GSHP.[13,14]

Although shallow groundwater and rocks usually require a heat pump to provide heating to a customer, they are cool enough to provide direct cooling.

Where Can Shallow GSHPs Be Developed?

Shallow GSHPs can be developed almost anywhere in the United Kingdom, subject to meeting the licensing and permitting requirements of the relevant regulatory authority (see, for example, the Environment Agency's guidance on permitting closed-loop[15] and open-loop[16] systems in England). Open-loop groundwater-based GSHC systems require an aquifer that will yield the required quantity of water. Horizontal closed-loop GSHPs can be developed where there is sufficient land area that can be excavated to at least 1.2 metres deep and is likely to remain undisturbed for the foreseeable future.

Vertical borehole GSHC systems can be developed in almost any ground condition and underlying rock type. The more quartz-rich and compact the rock is, the better the thermal conductivity of the ground (quartzites, sandstones, and granites are particularly attractive). Dry porous rocks or sediments will have low thermal conductivity. Environments that can be problematic for BHE construction include locations underlain by shallow mine workings or caves, areas with artesian groundwater head (pressure that causes groundwater to rise above the top of the aquifer or surface), lithologies where soluble evaporite minerals (for example, salt and anhydrite) are present, or lithologies where there is risk of petroleum or gas presence. The British Geological Survey (BGS) has a screening tool for evaluating the suitability of geology for both open- and closed-loop solutions.[17,18]

Shallow Geothermal Systems in the UK

By 2021, according to an estimate reported by the Environment Agency, around 43,700 GSHP units had been sold for installation in the UK, probably representing between 30,000 and 38,000 GSHC systems (a system may use more than one heat pump).[19] The vast majority of these are closed-loop, modestly sized domestic systems.

Since the introduction of the government's Boiler Upgrade Scheme subsidy in 2022, however, sales of domestic GSHP systems for retrofit have declined significantly because the current subsidy of £7,500 typically covers more than half the cost of an air source heat pump installation but only a small fraction of the cost of a GSHP system, disincentivising prospective GSHP investors.

The long-awaited introduction of the Future Homes Standard is anticipated to force all new homes to be equipped with non-fossil-fuel heating.[20] This requirement should provide a boost to the domestic GSHP sector, given the former and current government's intentions to build 300,000 new dwellings per year.[21] The standard will also drive continuing improvements in the efficient thermal construction of homes, allowing them to be effectively heated by low-temperature hydronic emitter systems (which are well suited to heat pumps), rather than the high-temperature radiator systems installed in poorly insulated houses during the "coal age" and "gas age."

Rebalancing environmental and social levies on electricity towards gas would narrow the "spark gap" between electricity and gas prices and would therefore also incentivise operation of heat pumps.[22]

The commercial, industrial, and public GSHC sector is more buoyant than the domestic sector, with between 500 and 1,000 smaller (<100 kilowatts) and between 60 and 80 larger (>100 kilowatts) non-domestic GSHC systems installed per year in the United Kingdom as of 2023.[23]

Almost all groundwater-sourced open-loop GSHC systems require an abstraction licence from the regulatory agency (the Environment Agency [EA] in England). As of 2023, the number of such systems was still relatively low. There were 149 EA groundwater abstraction licences listing "heat pump" as a usage (median heat transfer capacity estimated as around 208 kilowatts) in England and 174 groundwater licences listing "low-loss" or non-evaporative cooling as a use (of which three also listed "heat pump").[24]

Distribution

Most (but not all) modestly sized, retrofitted GSHP systems in the UK will be registered with the Microgeneration Certification Scheme (MCS), which has a database of installations. The largest densities (relative to number of households) of MCS-accredited GSHP installations in the UK (of which the majority are domestic, retrofit, closed-loop installations) are in Cornwall, northern Scotland, central Wales, and Shropshire. The uptake of GSHPs has generally been low in the main urban areas (**Figure 4.3**).

The highest numbers of EA groundwater-sourced open-loop heat pump abstraction licences are located in the Thames region. Those for "low-loss" or non-evaporative cooling are in the northeast, northwest, and Midlands of England and are used in the metals, machinery, electronics, chemicals, and food and drink industries.[25]

Networking Shallow Geothermal

Shallow geothermal lends itself to incorporation within fourth- and fifth-generation district heating and cooling networks (DHCNs). In fourth-generation systems, an array of GSHPs are typically installed in an energy centre and coupled to an open-loop well doublet or vertical or horizontal subsurface heat exchangers.[26] The heat pumps in the energy centre then distribute low-temperature waterborne heat (often at between 50°C and 60°C) around a district heating network. The client properties extract heat from the network via heat interface units (effectively heat exchangers). All variants of shallow geothermal can be connected to such networks.

Several versions of this currently exist, though some have struggled with operational costs. At North Aston Farm Estates, near Bicester, Oxfordshire, a GSHP network was installed to serve 27 properties in a village. The energy centre is supported by an array of horizontal

DISTRIBUTION OF GSHP INSTALLATIONS IN THE UK, BY LOCAL AUTHORITY AREA

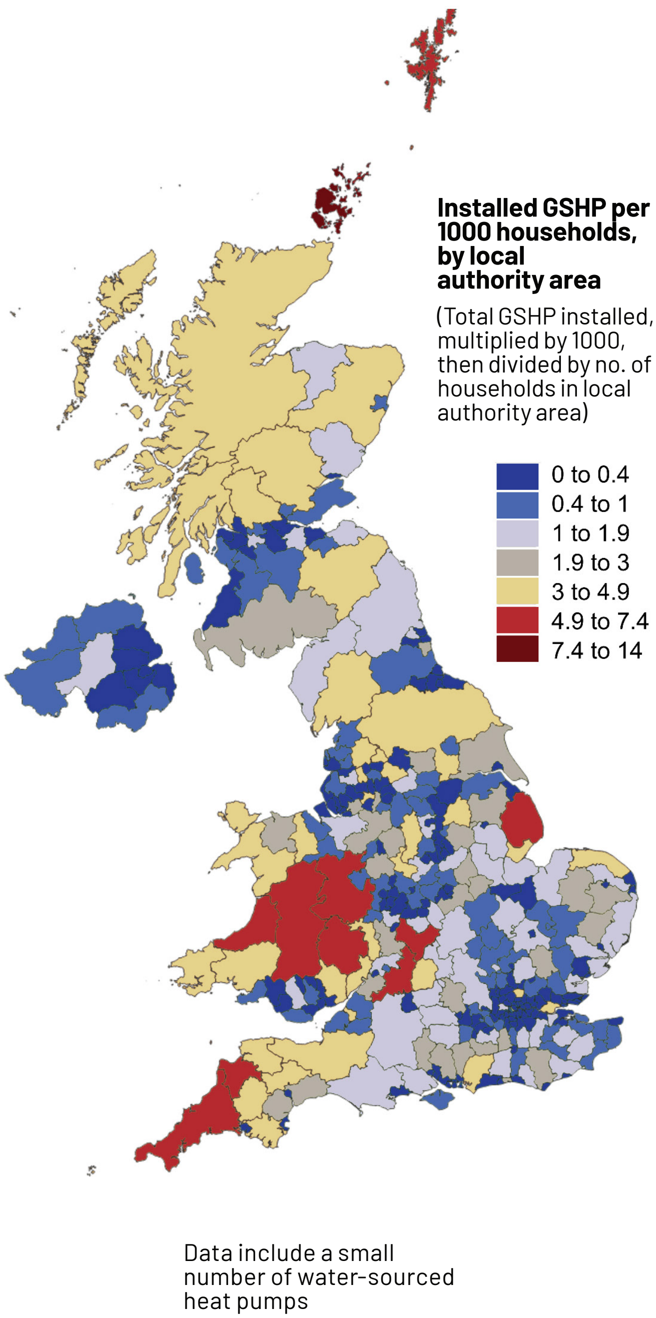


Figure 4.3: Distribution of MCS-accredited ground source heat pump installations in the UK as of July 2025, by local authority area. A total of 33,256 systems had been installed under the MCS scheme as of that date. GSHP = ground source heat pump. Source: Microgeneration Certification Scheme (MCS). (n.d.). *MCS data dashboard*.

ground loops installed beneath a large field. The system reportedly functions well, although the electricity costs associated with heat and circulation pumps have proved challenging, leading to a recent application to construct a solar photovoltaics farm to support the system.[27] A closed-loop BHE-based GSHP network—comprising 28 boreholes to 100 metres deep and three 40 kilowatt heat pumps—was installed in 2012 to serve 18 flats at Hartshorne, South Derbyshire, with a flow temperature of 55°C, although identification of a financial model to cover operational costs has proved challenging.[28,29] Finally, at Wandsworth Riverside (see "Use Cases and Deployment Examples" and the case study in this chapter) in London, more than 1 megawatt of heating and cooling capacity was installed in 2013 to support a network supplying 504 apartments and commercial and leisure space, based on an open-loop system abstracting and reinjecting chalk groundwater from eight 120 metre deep drilled wells.[30]

A fifth-generation DHCN overcomes some of the potential disadvantages of fourth (and earlier) generations.[31] They have no centralised energy centre. Instead, a network of heat transfer fluid is directly coupled to the ground, such as via a number of BHEs, which can be in a central array or distributed around the network (**Figure 4.4**). The heat transfer fluid circulates throughout the network at near-ambient temperature (5°C–30°C), and the pipes thus require no insulation. Client properties have their own heat pumps, extracting heat from—or rejecting surplus heat to—the ambient loop and delivering heating or cooling at a temperature determined by the client.

One advantage of these ambient networks is they are typically largely self-regulating, meaning the management, maintenance, and financial models for fifth-generation DHCNs are far simpler than for fourth-generation ones, as clients own heat pumps and are responsible for the electricity required to run them. Communal or utility

FIFTH-GENERATION DISTRICT HEATING AND COOLING NETWORK

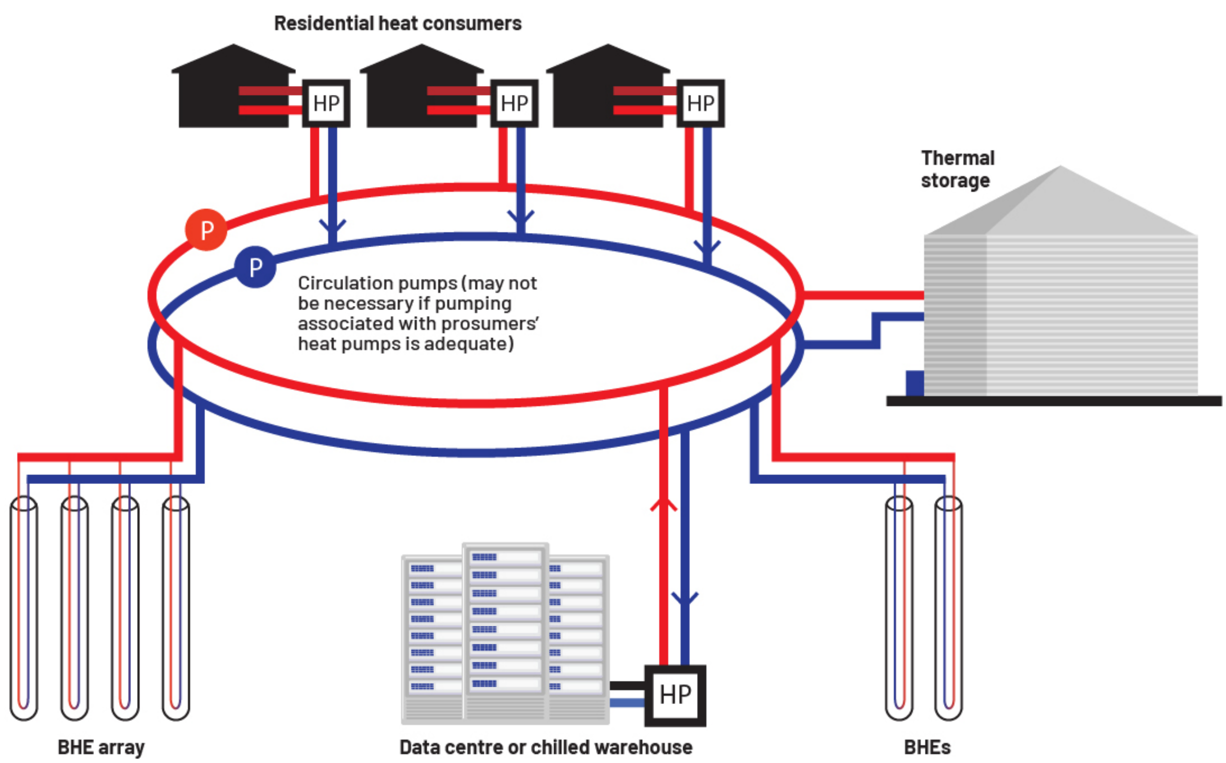


Figure 4.4: Schematic diagram of a fifth-generation district heating and cooling network, coupled to shallow geothermal BHEs, heating and cooling clients, and thermal storage. BHE = borehole heat exchanger; HP = heat pump. Source: David Banks, personal communications, 2025.

responsibility is thus restricted to the ambient loop and geological collectors themselves and could be financed via a simple standing change. There are early examples of large fifth-generation DHCNs globally, such as the minewater-coupled network in Heerlen, the Netherlands.[32] The concept is relatively new to the UK, but the company Kensa has pioneered a BHE-based ambient loop approach in their Heating the Streets project at Stithians, Cornwall.[33] This couples 96 dwellings (each with their own small heat pump), via an ambient loop, to 102 closed-loop BHEs (11,319 drilled metres) in the Carnmenellis Granite.

Along with residential applications, shallow geothermal is also well suited to campus-type building clusters (such as at universities and hospitals). At Cheltenham and Gloucester College, two campuses are each supported by around 400 kilowatts of heat pump capacity and a ground array of 40 boreholes to an average of 200 metres deep.[34]

Heat Pump Case Study: Roman Baths Hot Spring Water Heat Recovery System, Bath

Bath sits atop the UK's only truly hot springs, used for more than two millennia and still rising at approximately 45°C to 46 °C beneath the Roman Baths.[35] Today, the city is harnessing this resource through non-contact heat recovery to decarbonise landmark buildings while safeguarding archaeology and water quality (**Figure 4.5**). The programme centres on two complementary schemes: (i) Roman Baths and Pump Room heat recovery, and (ii) the Bath Abbey Footprint project, which captures heat from the adjacent Great Roman Drain.

Roman Baths and Pump Room Heat Recovery

The Roman Baths and Pump Room project captures low-grade heat from the King's Bath via 16 stainless-steel energy exchange blades installed within the spring

BATH ABBEY, UNITED KINGDOM

Figure 4.5: Bath Abbey stands above the Great Roman Drain, where a modern, non-invasive heat recovery system captures geothermal heat from spring water flowing beneath York Street to provide low-carbon heating for the Abbey. Adjacent, the Roman Baths demonstrate nearly two millennia of continuous geothermal use, with the Great Bath still fed by warm, mineral-rich waters rising from deep geological formations below Bath.

chamber. A new plant room beneath Stall Street integrates pumps, heat exchangers, and controls, transferring recovered energy into the heating circuits of the Roman Baths, the Pump Room, and the Clore Learning Centre.[36]

This closed-loop system avoids direct contact with the spring water, preserving both water quality and archaeological integrity. With an estimated thermal capacity of approximately 100 kilowatts, the installation supplies up to two-thirds of annual heating demand for the served buildings, with output temperatures reaching around 75°C for the Roman Baths and approximately 55°C for the Clore Learning Centre. [37]

Bath Abbey Footprint Project

As part of the £19.3 million Footprint project, Bath Abbey has installed a complementary heat recovery system within the Great Roman Drain, located beneath York Street. Here, 10 custom-built EnergyBlade® heat exchangers extract heat from spring water flowing towards the River Avon.[38] The recovered energy feeds two Ecoforest heat pumps (ecoGEO HP 25–100 kW units), which upgrade the temperature to supply year-round underfloor heating throughout the Abbey and associated facilities.[39]

To ensure heritage protection, the system operates entirely non-invasively: The spring water remains isolated from the heating circuits, preventing biological or chemical impacts while maintaining the Abbey's historical character.

Performance, Carbon Savings, and Resilience

Together, these schemes provide reliable baseload heating to some of Bath's most significant heritage sites. The Roman Baths system supplies up to two-thirds of annual heating demand for its connected buildings, while the Abbey's Footprint project enables year-round underfloor heating powered almost entirely by renewable energy.[40,41]

By replacing gas-fired heating, the combined projects significantly reduce operational carbon emissions and contribute directly to Bath & North East Somerset Council's climate goals. System resilience is supported through hybrid integration with existing boilers for peak load; redundancy in plantroom design; and continuous monitoring of flow rates, temperatures, and hydraulic performance.

Lessons for Policymakers and Investors

For policymakers and investors, the Bath schemes highlight the potential of geothermal heat recovery in sensitive heritage contexts. They demonstrate that such systems can be successfully deployed within a United Nations Educational, Scientific, and Cultural (UNESCO) World Heritage setting without compromising cultural assets.[42] The use of non-contact engineering ensures that the spring water remains isolated from the heating circuits, avoiding contamination and protecting fragile archaeological environments.[43] The projects also showcase modular scalability, with multiple small-scale systems acting as anchor loads that could be integrated into larger district heating frameworks in the future. By displacing fossil-fuel-based heating, the schemes directly support Bath & North East Somerset Council's renewable energy ambitions, aligning closely with regional and national climate policy goals.

UNDERGROUND THERMAL ENERGY STORAGE IN THE UK, WITH A FOCUS ON AQUIFER THERMAL ENERGY STORAGE

Concept and Mechanism

Underground thermal energy storage (UTES) involves the capture, storage, and reuse of heat in the subsurface. Waste heat captured from buildings, industrial processes, or excess renewable energy generation in the summer can be stored and used for heating in the winter.[44] Conversely, waste cool can be captured and stored to provide cooling in the summer. Thermal energy is transported from the subsurface using boreholes and a carrier fluid and from the carrier fluid to a working fluid on the building side via a heat exchanger. The temperature of the working fluid can be increased or decreased as required using a heat pump (see "Ground Source Heat Pumps").

Aquifer thermal energy storage (ATES) is a type of open-loop UTES that stores warmed or cooled groundwater in naturally porous, permeable underground rocks and uses this groundwater to provide low-carbon heating and cooling (**Figure 4.1e**). In this chapter, we primarily consider low-temperature ATES (LT-ATES) systems in which storage temperatures are typically between around 15°C and 20°C at the warm wells and between 5°C and 10°C at the cold wells, both because these systems dominate worldwide[45,46] and because a number of LT-ATES systems currently operate in the UK.[47] Other UTES technologies include mine thermal energy storage, in which warmed or cooled water is stored in abandoned mineworkings (**Figure 4.1c**), and borehole thermal energy storage, which can be used when no suitable aquifer or other storage reservoir is available (**Figure 4.1d**).

ATES systems employ pairs of bi-directional wells (termed *doublets*) that inject or produce groundwater depending on the demand for heating or cooling. The wells are defined by the temperature of the groundwater that is stored and produced, so they are called warm (or hot) and cool (or cold). They cannot be defined as *injection* and *production* wells, in contrast to uni-directional, open-loop shallow geothermal installations such as GWHC systems (see **Figure 4.1c**) because ATES systems are distinct in using a natural subsurface aquifer for energy storage. Other open-loop UTES technologies store thermal energy in manmade reservoirs such as abandoned mines, natural caverns, or specially constructed tanks or pits.[48]

The basic operation of a seasonal ATES system is shown in **Figure 4.6**. In winter, warm groundwater is pumped from one or more warm wells. Heat is exchanged from the groundwater to a working fluid via a heat exchanger. A heat pump is used to raise the temperature of the working fluid, which is circulated through the building(s) for which the system provides heating. The cooled working fluid is returned to the heat exchanger to be warmed by the groundwater, and the cooled groundwater leaving the heat exchanger is injected into the aquifer via one or more cold wells.

In summer, the process is reversed: Cool groundwater is pumped from the cold wells, and the working fluid is cooled by the groundwater via the heat exchanger to deliver cooling.[49] In many installations, cooling can be delivered directly without a heat pump.[50] This is direct cooling. In some systems, a heat pump is used to further cool the working fluid. The warmed working

SEASONAL OPERATION OF LT-ATES IN SUMMER AND WINTER

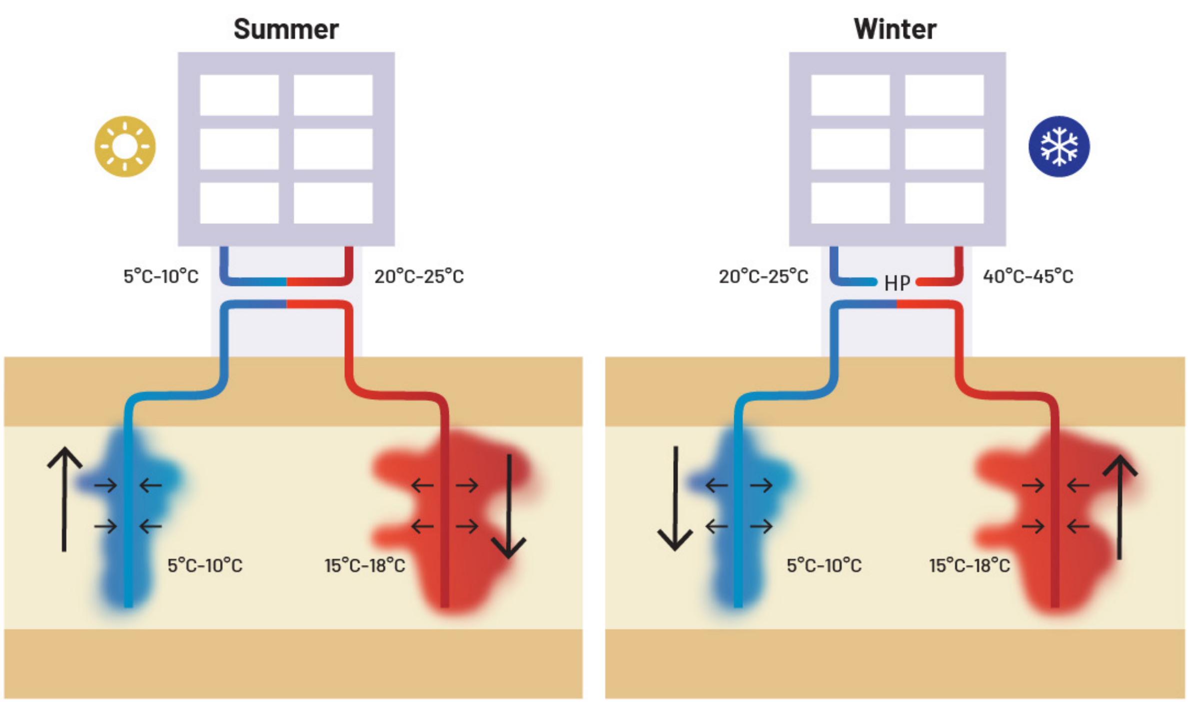


Figure 4.6: Seasonal operation of LT-ATES in summer (left) and winter (right). HP = heat pump. Source: Jackson, M. D., Regnier, G., & Staffell, I. (2024). Aquifer thermal energy storage for low carbon heating and cooling in the United Kingdom: Current status and future prospects. *Applied Energy, 376*, 124096.

fluid is returned to the heat exchanger to be cooled by the groundwater, and the warmed groundwater leaving the heat exchanger is injected into the aquifer via the warm well(s) for later production during the next winter. Only a single doublet comprising a warm well and a cool well is shown in **Figure 4.6**. In practice, the number of doublets can be increased to deliver higher heating and cooling power and storage capacity.

Targets and Initiatives

The basic requirements for deployment of LT-ATES are (i) a seasonal climate with distinct periods of heating and cooling demand, and (ii) a suitable storage aquifer (porous, permeable rock, or sediments/drift) at shallow depth (typically up to around 300 metres below ground surface) beneath the building(s) supplied by the system. The temperate UK climate is well suited to ATES.[51]

Previous work has assessed UK aquifer suitability and availability for GWHP deployments.[52] The screening tool developed by BGS is available to classify the subsurface as more or less suitable for such open-loop systems with capacities greater than 100 kilowatts thermal but was not specifically developed for ATES. The tool considers aquifer productivity and depth, groundwater chemistry, and protected areas,[53] but only aquifers shallower than 300 metres below ground level are considered. (The tool was initially developed for England and Wales[54] and then further extended to Northern Ireland,[55] although in Northern Ireland it includes only aquifers present at the surface, thus significantly limiting the available area.) Many aquifers suitable for ATES are confined by overlying rock units. No tool is yet available to assess aquifer suitability for ATES or GWHP systems in Scotland, but a thorough overview of Scotland's aquifers has been published by BGS.[56]

Jackson and colleagues noted the spatial correlation between UK heating and cooling demand and the location of suitable aquifers for LT-ATES.[57] They used a probabilistic approach to determine that widespread deployment of LT-ATES could supply roughly 61% of the UK's current heating demand and 79% of cooling demand. To realise this target, 85,000 "typical" ATES systems with a capacity of approximately 3 megawatts thermal would have to be installed. This is a large number, but it should be measured against the 23 million domestic gas boilers still operating. The proportion of demand that could be met using shallow geothermal is likely higher, given that borehole thermal energy storage and mine thermal energy storage could be deployed where there are no suitable aquifers or in addition to ATES systems. Hybrid installations can further maximise subsurface use. One example is the One New Change development in London, which uses energy piles to exchange heat with the London Clay aquitard and an ATES system to store heat in the underlying Chalk aquifer.[58]

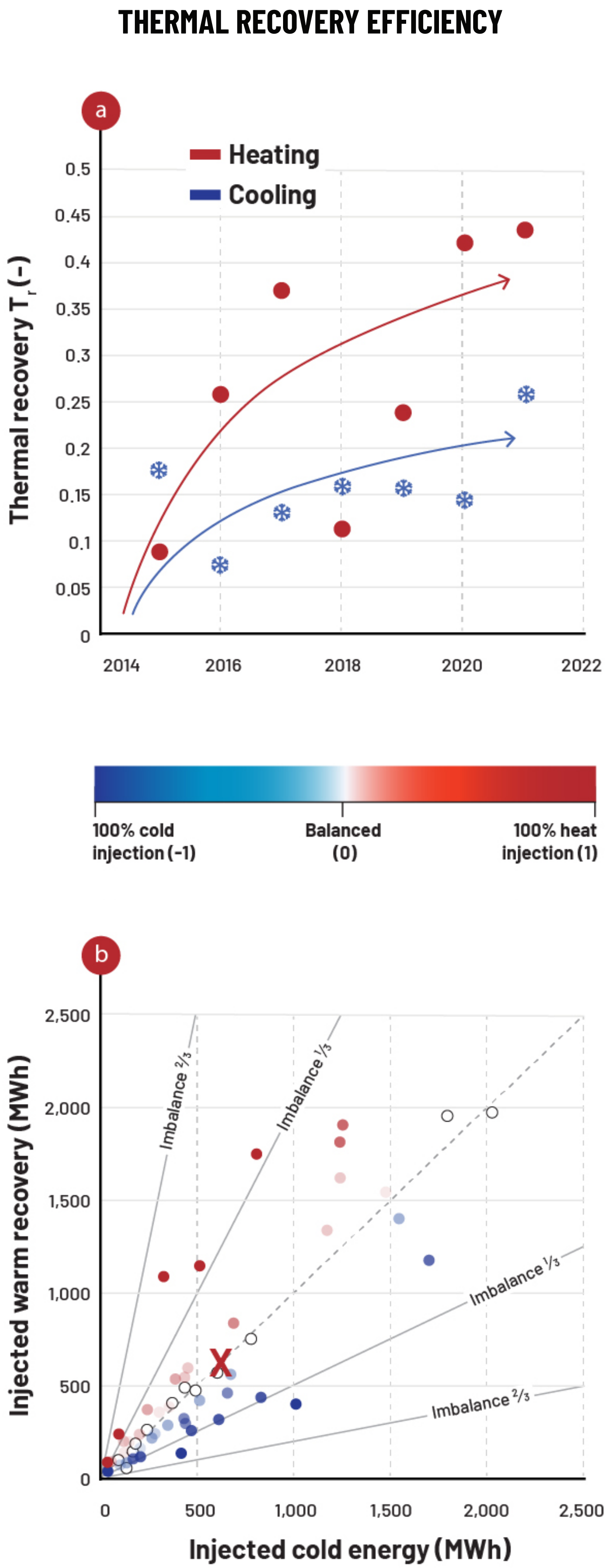
System Performance and Output

ATES systems are characterised by large storage (of order hundred to thousands of megawatt-hours thermal) and power (of order megawatts thermal to tens of megawatts thermal) capacities and can be used to supply large buildings or complexes of buildings or district heating and cooling networks.[59,60] Typical system parameters are summarised in **Table 4.1**. Storage capacity is large compared with that of manmade reservoirs (including thermochemical reservoirs) because of the large volumes naturally available in the subsurface; losses during storage in a well-designed system are primarily due to conductive exchange with surrounding rock, which is limited by low rock thermal conductivity (of order between 2 watts and 4 watts per metre-kelvin; **Table 4.1**). Power capacity is large because pumping groundwater into and out of the storage reservoir allows rapid transport of energy via advection, especially compared with closed-loop systems that rely

TYPICAL PROPERTIES OF ATES SYSTEMS

Property	Values
Aquifer depth (m)	10s–100s m
Well number	2–10s
Total production/injection rates ($m^3\ h^{-1}$)	10s–1000s
Heating/cooling power (MW to 10s MW)	1–10s
Energy storage capacity (GWhth)	1–100s

Table 4.1: Typical properties of aquifer thermal energy storage (ATES) systems. GWhth = gigawatt hour thermal; $m^3\ h^{-1}$ = cubic metres per hour; MW = megawatts. Source: Compiled from Fleuchaus, P., Godschalk, B., Stober, I., & Blum, P. (2018). Worldwide application of aquifer thermal energy storage–a review. *Renewable and Sustainable Energy Reviews*, *94*, 861–76.



on conductive heat transport for heat exchange in the subsurface. The storage and power capacity of ATES systems can be increased by adding more doublets, but they are ultimately constrained by two factors: (i) the maximum sustainable well flow rate, and (ii) the temperature of the produced groundwater. As discussed later in this chapter, both must be estimated using numerical simulation models.

An important design consideration for ATES systems is energy balance—that is, the storage and extraction of equal amounts of heat and cool.[61] Energy balance is important for several reasons. First, it ensures sustainability: A balanced system extracts no net heat or cool from the aquifer, so it never exhausts a finite resource. Second, it ensures there is no net change in aquifer temperature. Although temperature locally changes around the warm and cool wells, the net change is zero because there is no net extraction of heat or cool. In the Netherlands, balanced operation is a regulatory requirement. Balance is typically ensured by, where necessary, providing additional sources of low-carbon heating or cooling (**Table 4.2**).[62]

Another important design consideration for ATES is thermal recovery efficiency, which measures the fraction of stored heat or cool recovered to the surface.[63] Thermal recovery efficiencies of greater than 80% are observed in some operating systems.[64] Recovery efficiency is typically lower when there is (i) significant groundwater flow, which tends to move the thermal plumes away from the wells, so the stored heat or cool cannot be recovered unless the system is specially designed;[65,66] or (ii) significant thermal interference, which occurs when

Figure 4.7: (a) Thermal recovery efficiency from the Riverside Quarter low-temperature aquifer thermal energy storage (LT-ATES) system in Wandsworth, London. (b) Energy balance in Dutch LT-ATES systems. Plot shows injected warm energy plotted against injected cool energy. Systems that plot on the dashed line with gradient = 1 are energy balanced. Also shown for comparison is the energy balance of the Riverside Quarter system denoted by the red cross. MWh = megawatt-hours. Sources: (a) modified from 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; (b) modified from Fleuchaus, P., Schüppler, S., Godschalk, B., Bakema, G., & Blum, P. (2020). Performance analysis of aquifer thermal energy storage (ATES). *Renewable Energy, 146*, 1536–1548.

TEMPERATURE FIELD OF AN ATES SYSTEM

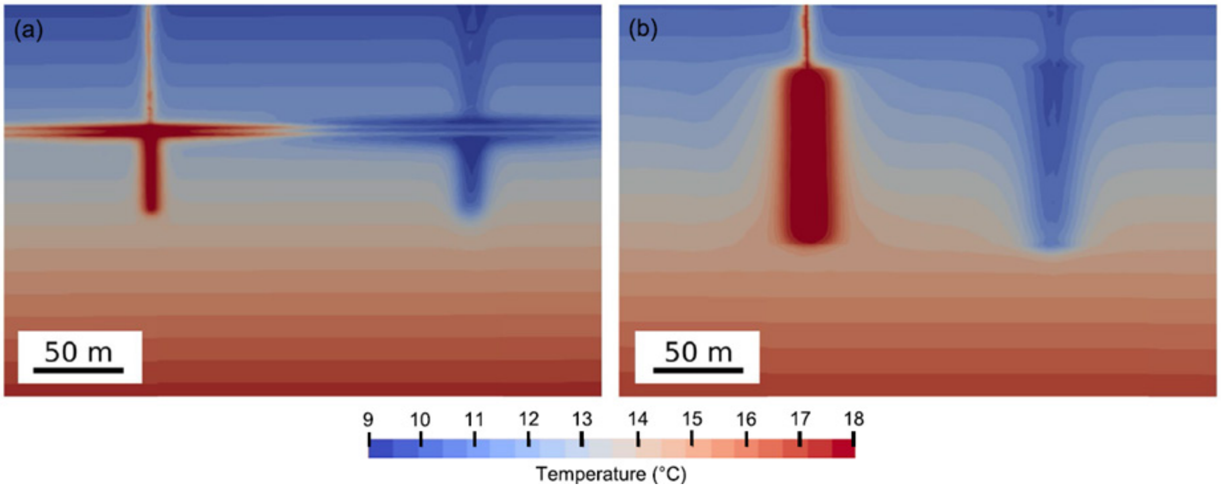


Figure 4.8: Snapshot of the temperature field in a 2D section through a 3D numerical simulation of ATES system operation using a well doublet in (a) the heterogeneous Chalk aquifer in London, and (b) a homogeneous aquifer. Source: Jackson, M. D., Regnier, G., & Staffell, I. (2024). Aquifer thermal energy storage for low carbon heating and cooling in the United Kingdom: Current status and future prospects. *Applied Energy, 376*, 124096.

the warm and cool plumes interact in the aquifer.[67,68,69] Interference typically occurs when warm and cool wells are not spaced sufficiently far apart or the lateral plume spread is larger than predicted due to the presence of geological heterogeneity. For example, in the Chalk aquifer in London, significant lateral plume spread is predicted in high-permeability karst intervals (**Figure 4.8**). If the warm plume reaches the cool wells, and vice versa, then thermal breakthrough occurs, impacting the production temperature and significantly reducing system efficiency.

Jackson and colleagues[70] developed earlier work by Stemmle et al.[71] to demonstrate that the thermal recovery efficiency of a balanced ATES system, with no thermal breakthrough, measures the additional energy supplied by an ATES system as compared with an equivalent GWHC system that sources groundwater at ambient temperature. Thus, a thermal recovery efficiency of zero does not mean the ATES system delivers no low-carbon heating or cooling. Rather, it means the ATES system delivers the same heating and/or cooling energy as an open-loop system without storage.

Jackson and colleagues further showed that ATES systems with thermal recovery greater than zero offer lower electricity consumption and associated CO_2 emissions than equivalent GWHC systems.[72] The reason is simple: Heating is more efficient because ATES supplies pre-warmed groundwater to the heat exchanger, so the heat pump needs to boost the temperature less and operate with a higher COP. Cooling is more efficient because ATES delivers pre-cooled groundwater with a temperature low enough to deliver cooling without a heat pump. Using a probabilistic approach, Jackson et al. estimated that compared with an equivalent GWHC system, ATES offers a reduction in electricity consumption of between 7% and 23% and CO_2 emissions with a mode of 9% for heating (the mode represents the most commonly sampled value in the distribution) and a reduction of between 19% and 93% with a mode of 40% for cooling.[73] The very high efficiency of ATES for cooling is well known;[74,75,76] cooling in an ATES system with high thermal recovery can be thought of as a close-to-free byproduct of heating.

Use Cases and Deployment Examples

ATES was initially deployed in the 1960s in Shanghai, China, to provide cooling to factories.[77] Systems were then installed in other countries, including Switzerland, the United States, France, and Sweden, but the Netherlands remains the leader in LT-ATES systems by far after rapid expansion in the 2000s. Today, of the approximately 3,500 LT-ATES systems worldwide, roughly 3,000 are located in the Netherlands.[78] The Netherlands also hosts the world's

CHARACTERISTICS OF ATES INSTALLATIONS

City (Country)	Purpose	Facility	Year	Well depth (m)	Well #	Maximum flow rate (m^3/h)	Capacity (MW)	Capital costs (Mio. €)	Payback time (years)	CO_2 savings (t/a)
Amersfoot (NL)	H + C	IKEA store	-	-	2	200	1.4	-	-	-
Utrecht* (NL)	HT	University	1991	260	2	100	2.6	1.1	5	750
Amersfoot (NL)	H + C	Office building	1996	240	2	-	2	1.0	6.5	-
Oslo (NW)	H + C	Airport	1998	45	18	200	7	2.65	2	-
Zwammerdam* (NL)	HT	Hospital	1998	150	2	20	0.6	1.3	-	-
Berlin (DE)	H + C	Recihstag	1999	60/300	12	100/300	-	-	-	-
Rostock (DE)	H	District heating	1999	20	2	15	-	1.02	-	-
Amsterdam (NL)	H + C	District heating	2000	130	4	500	8.3	-	6	-
Brasschaat (BE)	H + C	Hospital	2000	65	2	100	1.2	0.7	8.4	427
Malmö (SW)	H + C	Expo building	2001	75	10	120	1.3	0.35	1.5	-
Mersin (TR)	C	Supermarket	2001	100	2	-	-	-	-	-
Agassiz (CA)	H + C	Research centre	2002	60	5	4	0.563	0.22	6	-
Eindhoven (NL)	H + C	University	2002	28-80	36	3,000	20	14.7	6-10	13,300
Malle ETAP (BE)	C	Office building	2003	67	2	90	0.6	0.34	7-15	23
Neubrandenburg (DE)	H	District heating	2005	1,200	2	100	3.3	-	-	-
New Jersey (US)	C	University	2008	60	6	272	2	2.6	12	-
Arlanda (SW)	H + C	Airport	2009	20	11	720	10	5.0	7	7,700
Copenhagen (DK)	H + C	Hotel	2009	-	2	-	2.4	-	6-7	366
Malmö (SW)	H + C	IKEA store	2009	90	11	180	1.3	-	4.5	-
Copenhagen (DK)	H + C	Office building	2010	100	10	250	2.8	-	4	644
Greenwich (UK)	H + C	Museum quarter	2011	60	2	45	0.33	-	-	-
Shinshu (JP)	H + C	University	2011	50	5	-	-	-	-	-
London (UK)	H + C	Apartments	2013	70	8	400	2.9	-	-	-
Amsterdam (NL)	H + C	District heating	2015	-	7	1,100	20	25.0	-	2,900
Copenhagen (DK)	H + C	Airport	2015	110	10	-	5	8.0	8	1,000

*** No longer in operation**

Table 4.2: Characteristics of aquifer thermal energy storage (ATES) installations. C = cooling; H = heating; HT = high-temperature. Source: Fleuchaus, P., Godschalk, B., Stober, I., & Blum, P. (2018). Worldwide application of aquifer thermal energy storage-a review. *Renewable and Sustainable Energy Reviews, 94*, 861–876.

largest LT-ATES system, at the Eindhoven University of Technology: a 36-well system (comprising 18 doublets) delivering 20 megawatts thermal of heating and cooling, with estimated annual CO_2 savings on the order of 13,300 tonnes.[79] Other LT-ATES deployments include universities, hospitals, airports, large commercial premises, domestic properties supplied via heat networks, and controlled environment agriculture (**Table 4.3**).

In addition, high-temperature ATES (HT-ATES) systems are also now being deployed, with storage temperatures on the order of between 40°C and 70°C.[80] At Delft University of Technology, an HT-ATES system currently being installed will operate in tandem with a deeper geothermal system supplying heat for direct use.[81] In summer, surplus heat from the geothermal system will be captured and stored by the HT-ATES system, while in winter, the deep geothermal and HT-ATES systems will both supply heating, meeting a larger proportion of total demand and reducing the load on the heat pump(s). A similar concept is being explored at the United Downs site in Cornwall, which would use mine thermal energy storage to store excess heat from the United Downs deep geothermal project as part of the EU-funded PUSH-IT (Piloting Underground Storage of Heat In Geothermal Reservoirs) project.[82]

Compared with the Netherlands, growth of ATES deployments in the UK has been slow. There are currently 11 known LT-ATES deployments, all located in England; nine are in London, one is in Brighton, and one is in Manchester.[83] The first ATES system was deployed in the UK in 2006 at a residential development in West London (**Table 4.3**). All but one of the operational ATES installations rely on the Chalk aquifer in London or Brighton; the system in Manchester utilises the Sherwood Sandstone aquifer. Buildings that have been equipped with ATES systems in the UK are mostly large, new-build residential developments but also include a shopping centre, offices and workspace, and part of a museum. Most installations deliver less than 1 megawatt thermal of heating and cooling via a single well doublet and are bivalent, supplying part of the heating and cooling demand. In most cases, peak

UK ATES INSTALLATIONS

Project name	Date	Building type	Wells	Max licensed flow rate (m^3/h)	Peak load heating/ cooling (kW_{th})
Westway Beacons	2006	Housing	2	25	250
Grosvenor Hill	2008	Housing	2	50	300/320
One New Change	2010	Shopping centre	2	40.5	600
National Maritime Museum	2011	Museum	2	46	300/350
Trafford Town Hall	2012	Offices	2	60	600
Riverside Quarter	2013	Housing	8	280	1800/2750
St. James Riverlight	2015	Housing	8	240	1800/2900
Spring Mews Student Accomodation	2015	Housing	2	25	400/1204
Cockroft Building, University of Brighton	2016	University building	2	99	703/546
Chelsea Barracks	2018	Housing	8	41.6	1062/650
City, University of London Law School	2019	University building	2	72	600/590

Table 4.3: UK aquifer thermal energy storage (ATES) installations. kW_{th} = kilowatts thermal; m^3/h = cubic metres per hour. Source: 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.

cooling demand is larger than peak heating demand, highlighting the importance of supplying low-carbon cooling as well as heating.

The energy system at the Riverside Quarter in Wandsworth (**Table 4.3**) consists of an LT-ATES deployment that offers space heating and cooling to a large residential development, coupled with gas boilers and a combined heat and power engine for hot water and supplementary space heating. Supplementary space cooling is provided by dry air coolers.

Several of the early ATES deployments in the UK have ceased operation. The reasons are not always clear, but in at least one case the system operated despite a large imbalance in heating and cooling, leading to thermal breakthrough of the warm plume at the cool well and a rapid decrease in system efficiency.[84] In another UK system, there was a breakdown in communication between the ATES system engineers and building-side engineers, so the system operated for several years without being manually switched from heating to cooling mode when required, operating as a GWHP system with consequent impacts on plume formation and migration in the aquifer. Bivalent operation means shortfalls in heating or cooling delivered by UK ATES systems are met from other sources and may not be identified or diagnosed.[85] Failures of early deployments are typical of new technologies and have been recorded in ATES installations outside the UK.

Research and Development Needs

Research and development should focus on lowering barriers to widespread ATES deployment in the UK (**Table 4.4**). Key technical barriers include lack of knowledge of the subsurface and the likely subsurface response during system operation. Despite the availability of the open-loop GWHP mapping tool, previous studies characterising UK aquifer locations and properties and the availability of databases such as the BGS GeoIndex (Onshore), essential data are often unavailable or difficult to obtain for a potential installation site. Groundwater flow is a key control on thermal recovery efficiency but is not included in current mapping tools. Similarly, groundwater quality and chemical data are patchy. Mapping tools for ATES developed elsewhere include these data.[86] Easy access to geological maps, models, and borehole data is important to support the case for ATES in a particular location.

UK aquifers suitable for ATES deployment often offer high storage and productivity but are geologically heterogeneous, leading to uncertainty in subsurface groundwater flow, heat transport, and plume development (**Figure 4.8**). This uncertainty impacts predictions of optimal borehole spacing and thermal recovery efficiency. Well-characterised field experiments, such as thermal response tests (TRT) and open-loop thermal tracer tests (OL-TTT), provide key data and improved understanding of aquifer response. The recently opened UK Geoenergy Observatories' Cheshire Observatory offers a dedicated, at-scale field laboratory for research and innovation in ATES, rock volume characterisation, and monitoring of subsurface processes.[87] The observatory's borehole array penetrates the Sherwood Sandstone aquifer and is equipped with borehole heat exchangers for heating and cooling of the subsurface, advanced sensors for 3D imaging of subsurface processes in close to real time, and equipment for multilevel groundwater monitoring and hydraulic control. Current research, as part of the UK Research and Innovation–funded ATESHAC and SMARTRES projects, is undertaking both TRT and OL-TTT, coupled with extensive geophysical monitoring that is not available in commercial deployments. The tests provide new insights into groundwater flow and heat transport processes in the Sherwood Sandstone aquifer. Similar experiments targeting the Chalk aquifer are being undertaken at a test site in Berkshire as part of the SMARTRES project.

The geological heterogeneity of UK aquifers means that coupled thermal-hydrodynamic numerical models of appropriate resolution and complexity are required to predict the subsurface response during system operation, with extension to chemical transport and reaction if groundwater quality is an important consideration. These models are time-consuming and expensive to implement. The EU-funded FindHEAT project is developing new rapid methods for modelling geothermal reservoirs, including open-loop, shallow geothermal systems.[88] The rapid modelling research is led by UK institutions with the aim of supporting the deployment of geothermal by providing a new generation of agile modelling tools that reduce the time and cost of desktop studies.

The current focus of modelling in the UK is primarily to design and optimise the operation of individual developments, but as uptake of ATES and other shallow

BARRIERS TO WIDESPREAD DEPLOYMENT OF ATES IN THE UK

Barrier Type	Description
Financial barriers	• Larger initial investment compared to conventional technologies • Low price of fossil fuels
Legislative barriers	• Long and/or complex permitting procedures • Lack of regulative framework for permitting • Lack of incentives for installation • Lack of awareness among policymakers
Technical barriers	• Lack of awareness by developers • Lack of technology know-how • Unfamiliarity with subsurface • Unfamiliarity in subsurface response
Societal barriers	• Lack of public awareness • Negative public perception of subsurface uses

Table 4.4: Many barriers are common to other emerging markets for ATES. Sources: Bloemendal, M., Hoekstra, N., Slenders, H., van de Mark, B., van de Ven, F., Andreu, A., Simmons, N., & Sani, D. (2018). *Europe wide use of sustainable energy from aquifers: Barrier assessment*. Deltares; Fleuchaus, P., Godschalk, B., Stober, I., & Blum, P. (2018). Worldwide application of aquifer thermal energy storage-a review. *Renewable and Sustainable Energy Reviews, 94*, 861–876; Pellegrini, M., Bloemendal, M., Hoekstra, N., Spaak, G., Gallego, A. A., Comins, J. R., Grotenhuis, T., Picone, S., Murrell, A. J., & Steeman, H. J. (2019). Low carbon heating and cooling by combining various technologies with aquifer thermal energy storage. *Science of the Total Environment*, *665*,1–10. Table from 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.

geothermal technology grows, predicting interactions between neighbouring installations will become increasingly important, especially in urban settings with high heating and cooling demand. Maximising the use of subsurface space is already a challenge in the Netherlands.[89,90,91,92] The UK has an opportunity to plan for high deployment density, but research is required to address the challenge of district- to city-scale optimisation of geothermal resource use.

Lack of awareness of, and confidence in, ATES technology and its suitability in the UK is also a key barrier to uptake.[93] A recurring issue in stakeholder discussions has been the lack of demonstrator projects with open access to data and the potential for site visits. Commercial deployments rarely make data available (the Riverside Quarter system is a rare exception), so successes are not shared, and there is little wider learning from failures. The UK urgently needs demonstrator and "living laboratory" projects for ATES and similar technologies. Potential candidates include the GeoEnergyNI shallow geothermal project at the Stormont Estate,[94] the University of Leeds Geothermal Campus Project,[95] and Imperial's plan to decarbonise its South Kensington campus in London.[96] However, at present, it is not clear whether these systems will include storage.

Liu et al. recognised slow turnaround for system permitting is another barrier to deployment.[97] Research into the subsurface response to ATES is essential to support permitting processes. Impacts on water quality, such as the potential for mixing of contaminants during operation, must be addressed.[98,99,100] Moreover, heat has recently been designated as a groundwater pollutant in the UK Environmental Permitting Regulations,[101] but the impact of temperature changes on storage aquifers remains poorly constrained. The SMARTRES project is currently assessing the impact of temperature changes induced by LT-ATES on the biochemistry of groundwater in the Chalk aquifer, but significant further research remains to be done, including for HT-ATES deployments in the UK.

Policy and Infrastructure Integration

Many of the policy and infrastructure integration issues impacting ATES are common with other shallow geothermal technologies. Key differences include (i) the high efficiency of cooling that can be delivered by ATES, and (ii) the importance of energy balance for sustainable ATES operation.

Policies encouraging the uptake of low-carbon technologies for heating and cooling have focused on heating. Cooling has been neglected, yet the importance of cooling for healthy living in a warming world is becoming increasingly apparent. Cooling demand in the UK, which is predicted to increase as a warming climate brings hotter summers, is already growing at a rate of 5% in London, the highest rate in the world.[102] Recent articles in the UK press have highlighted the challenges of living and working in buildings that are persistently too hot during the summer.[103,104] No mention is made of the potential deployment of technologies such as ATES that can offer low-cost cooling with low electricity demand and CO_2 emissions. Cooling and heating should be considered when developing policy. ATES systems that offer heating and cooling can be energy balanced, ensuring long-term sustainable operation. GWHP installations that provide heating or cooling but not both are inherently imbalanced, increasing the risk of thermal interference with an ever-growing waste plume that can negatively impact system sustainability.

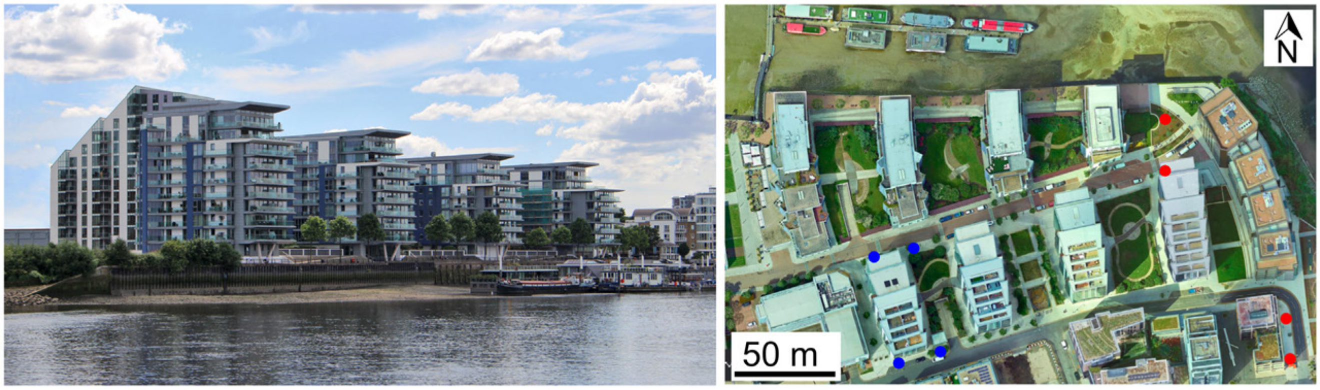
Previous UK policy has incentivised heating and penalized storage. For example, under the now-discontinued Renewable Heat Incentive (RHI), "tariff payments for ground source heat pumps (GSHPs) can be made only for extracted heat that naturally occurs in the ground. As a consequence, heat that is injected into the ground and subsequently extracted by a GSHC system is ineligible for support payments."[105] Moreover, in the RHI scheme, "ground source and water source heat pumps that are capable of cooling are eligible technologies, though only heat generated is eligible for RHI support."[106] Incentives that support only heating and omit storage may instead encourage installation of systems with higher CO_2 emissions, which are less likely to be sustainable.

Delivery of both heating and cooling should also be accounted for in infrastructure integration. Building-site assessments often treat heating and cooling as separate processes with different solutions, consistent with the tradition of heating delivered by gas boilers and CHP plants and cooling delivered by electrical chillers. Heat networks also often consider heating but not cooling. A holistic view of heating and cooling when designing buildings and heat networks is required. Current UK ATES installations typically serve high-cost, luxury accommodation for which cooling is a marketing feature. There is an inequality of access to low-cost, low-CO_2 cooling that ATES could help address.

The aquifer requirements, borehole infrastructure, and surface facilities required for ATES and GWHC systems are similar; the main difference is in the mode of operation. GWHC systems can provide both heating and cooling with higher efficiency and lower CO_2 emissions than air source heat pumps (ASHPs) but are typically less efficient than ATES systems.[107] The additional efficiency and lower electrical grid requirements offered by storage and re-use of thermal energy—especially for cooling—suggest that ATES should be considered ahead of GWHC when considering an open-loop geothermal deployment for both heating and cooling. A balanced ATES system should be considered ahead of a GWHP system when possible.

The policy and regulatory frameworks for ATES in the Netherlands are an attractive model for the UK and other emerging markets.[108,109] The Geo-Energy Systems Amendment in the Netherlands features a simplified permit process, which normally has a maximum decision period of eight weeks (see more in Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential"); company certifications to ensure high system quality; and standardised system monitoring requirements. The regulations specify upper and lower storage temperature limits of 25°C and 5°C, respectively, and the requirement for energy balance. The Dutch have introduced geothermal energy master plans for coordinated spatial subsurface and energy planning of ATES systems in dense urban areas. An interactive

WANDSWORTH RIVERSIDE QUARTER, LONDON—AQUIFER THERMAL ENERGY STORAGE IN THE CHALK



(a) (b)

Figure 4.9: (a) Photograph of Wandsworth Riverside Quarter. (b) Aerial image of the site; well locations shown by blue and red circles for cold and warm wells, respectively. Source: 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. Modified from IF Tech. (2008). *Wandsworth Riverside Quarter, London: Borehole drilling and pumping tests*. IF Tech.

online map by the Dutch Ministry of Economic Affairs and the Ministry of Climate Policy and Green Growth allows municipalities to mark designated areas for geothermal use, aiding ATES planning.

Case Study: Wandsworth Riverside Quarter, London—Aquifer Thermal Energy Storage in the Chalk

The Wandsworth Riverside Quarter (WRQ) residential development in south-west London hosts one of the UK's largest operational ATES schemes.[110,111] The project shows how open-loop, seasonal storage can provide low-carbon heating and cooling to dense urban developments in a fractured Chalk aquifer as opposed to the sandy aquifers more commonly used for ATES across Europe.

Primary Goal and Delivery Model

WRQ's energy system was designed under the London Plan policy framework in force at the time, which promoted on-site low-carbon energy and set minimum CO_2-reduction targets. ATES supplies space heating and cooling; gas boilers and a CHP engine provide domestic hot water and top-up heat; and dry-air coolers are available for supplementary cooling. Controls are configured to redistribute waste heat and cool around the estate before drawing on the aquifer.

Scheme Configuration (Subsurface and Plant)

- **Aquifer and geology:** Eight production/injection wells target the Upper Chalk, first encountered at approximately 79 metres depth; the aquifer is confined by London Clay. Local records indicate the Thanet Sands and Woolwich & Reading Beds are absent at the site. Groundwater flow in the Chalk is fracture-dominated (high matrix porosity, low matrix permeability).
- **Wellfield:** Four warm and four cold wells drilled to between 113 metres and 143 metres below ground level; post-drill flow logs show that most inflow or outflow occurs within the upper approximately 15 metres of the Chalk, with a high-permeability interval at around 80 metres to 82 metres, consistent with prior London Chalk studies.
- **Licensed capacity and plant:** Maximum licensed abstraction = 280 cubic metres per hour. Design capacity = 1.8 megawatts thermal heating and 2.7 megawatts thermal cooling. Two reversible heat pumps serve both modes.

Operations and Measured Performance

- **Monitoring window:** Hourly wellhead flow rate and temperature data from 2015–2022 are available (system in service since 2013). The data set shows the expected seasonal cycling (warm production in winter/cold injection; the reverse in summer).

- **Energy and volume balance (sustainability):** Over the monitoring period, the energy balance ratio is 0.09—cooling energy extracted is approximately 20% greater than heating energy—while the volume balance ratio is -0.03, indicating similar total pumped volumes in both modes. These metrics indicate sustainable, near-balanced operation; the installed dry-coolers could be used to correct any future imbalance.
- **Key monitored means (annual averages)**:
  - Injection = 9.8°C (cold)/22.2°C (warm); production 12.6°C (cold)/17.6°C (warm)
  - Active production flow = 14.4 cubic metres/hour (cold)/13.8 cubic metres per hour (warm)
  - Annual volumes produced = ~46,600 cubic metres (cold)/~48,900 cubic metres (warm)
  - Annual energy produced at the aquifer/HEX: ~508 MWh_{th} cooling/~424 MWh_{th} heating
- **Thermal recovery (storage efficiency):** For 2015–2021, average thermal recovery was approximately 30% (warm) and around 16% (cold), increasing over time as the field matured. Recovery was lower than values typically reported from more homogeneous sandy aquifers, reflecting the fractured Chalk and associated lateral "pancake" plume spreading. Using an effective screen length concept to represent the shallow inflow zone, modelling indicates that if the effective screen length is less than 5 metres, thermal interference between warm and cold plumes becomes likely at the site's minimum warm-cold spacing of 127 metres; less than 1.5 metres risks short-circuiting. Flow logs suggest approximately 2 metres of inflow, so some interference may occur.
- **Delivered energy and carbon:** Delivered low-carbon energy averaged approximately 0.49 gigawatts thermal per year cooling and approximately 0.39 gigawatts thermal per year heating between 2015 and 2021, rising with recovery. Values were lower than some schemes of similar design capacity due to operational flow rates below licence and the site's strategy to maximise internal heat and cool redistribution before drawing on the aquifer. From Year 2 onward, the WRQ system saved more than 100 tonnes of CO_2 per year versus a natural-gas reference; savings should grow with continued grid decarbonisation.

Lessons for Policy and Investors

- **Demonstrated viability in fractured aquifers:** WRQ proves that balanced, monitored ATES can operate successfully in the Chalk, widening the UK deployable footprint beyond sandy aquifers. Seventy-five percent of the UK population resides over these types of aquifers, opening up large parts of the country to deploy this low-carbon heating and cooling method.
- **Importance of monitoring and balance:** Routine capture and interpretation of flows, temperatures, energy balance ratio and volume balance ratio, and recovery enable early issue detection and underpin sustainable operation; the authors recommend explicit identification of ATES in regulatory databases and enforcement of energy balance in licences.
- **Design for heterogeneity:** Well spacing and effective screen length govern plume geometry and interference risk in fractured media; flow-log-informed screen design and conservative spacing (such as multiples of the thermal radius) mitigate losses.
- **Market context:** WRQ is one of approximately 11 active ATES deployments in the UK, the majority of which are in London—highlighting significant scale-up potential with clearer guidance and streamlined permitting.

WRQ offers a bankable, real-world precedent for urban ATES in UK geology that is heterogeneous and fracture-controlled—delivering dependable low-carbon heating and (especially) cooling while providing the monitoring evidence that policymakers and investors need to manage subsurface risk and scale the sector responsibly

Scaling Up Geothermal Heat

The United Kingdom's current geothermal heat projects reveal three key insights for policymakers, investors, and planners:

1. **Technical feasibility is proven.** Across diverse geological contexts from deep sedimentary aquifers to minewater systems and thermal spring discharges, reliable year-round heating and cooling can be delivered using mature and adaptable technologies.

2. **Integration drives resilience.** Each scheme combines geothermal baseload with complementary technologies such as heat pumps, waste heat recovery, combined heat and power (CHP), and district heating, resulting in flexible, robust energy systems.
3. **Governance and planning are critical.** Long-term customer contracts, anchor public-sector loads, supportive planning frameworks, and emerging heat network zoning policies underpin the bankability of these schemes. (See Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," for more on this topic.)

Geothermal heating projects that are already operational, monitored, and delivering quantified carbon savings provide a scalable pathway for reducing emissions from heating and cooling, one of the UK's most energy-intensive sectors. With coordinated investment, clearer regulatory frameworks, and strategic policy support, the Bath, Gateshead, Wandsworth, and Southampton schemes could form the blueprint for a national geothermal heat strategy. By embracing these models, the United Kingdom can accelerate progress towards resilience, enhance energy security, safeguard heritage assets, and drive regional economic growth, establishing geothermal energy as a key enabler of sustainable heating and cooling.

MINEWATER GEOTHERMAL ENERGY IN THE UK

Target Areas

Minewater geothermal energy exploits the heat stored in flooded, disused mines. The UK's industrial legacy (23,000 abandoned mines, primarily but not exclusively for coal[112]) has left an extensive subsurface network of shafts and galleries—many of which have filled with groundwater. This water retains geothermal heat and offers a large, distributed, low-temperature resource ideal for direct-use heating applications.

Many of these flooded mines are located under, or close to, residential and industrial developments. Approximately 25% of the UK population lives above abandoned coalfields (**Figure 4.10**), which could theoretically be harnessed to provide 2.2 million gigawatts of heat, enough to heat all of the UK's houses for more than 100 years.[113] According to a combined study from the Ordnance Survey and the Mining Remediation Authority (formerly the UK Coal Authority), this means just more than 6 million homes, and more than 300,000 offices and businesses, are above abandoned coal mines and could be heated by this resource.[114]

Approximately 25% of the UK population lives above abandoned coalfields, which could theoretically be harnessed to provide 2.2 million gigawatts of heat, enough to heat all of the UK's houses for more than 100 years.

Regions with the most extensive minewater geothermal potential include the South Wales Coalfield, central Scotland (including Glasgow and Lanarkshire), north-east England (such as Durham and Northumberland), the East and West Midlands, Lancashire, and Kent in the south of England. In Northern Ireland, disused mining areas such as East Tyrone (Dungannon–Coalisland) and Ballycastle also have potential for minewater heating, albeit on a smaller scale and with more localised resources (**Figure 4.10**).

System Characteristics and Mechanism

Former coal and mineral mines across the UK present a significant opportunity for geothermal energy development by exploiting the natural geothermal gradient—where temperatures increase with depth. Minewater at depths of up to 1 kilometre can reach temperatures of 40°C (recorded in the Lancashire coalfield),[115] although such levels are unlikely to be sustained once pumping starts. More commonly, flooded mines provide a stable reservoir of water with temperatures typically ranging from 12°C to 49°C (as measured in Plodder and Arley mines in Leigh and Tyldesley Lancs),[116] which can be upgraded using heat pumps. These can supply low-temperature heating systems (40°C–70°C) and provide cooling and thermal storage. Unlike deep geothermal systems, minewater schemes operate at relatively shallow depths, commonly between around 50 metres and 400 metres (**Figure 4.11**), thereby significantly reducing both drilling costs and lifting costs for the water during the production phase.

A typical system includes an abstraction well to pump warm minewater to the surface, a heat exchanger and

DISTRIBUTION OF ONSHORE COALFIELDS, MINERAL MINES, AND DISTRICT HEATING DEMAND ACROSS THE UNITED KINGDOM

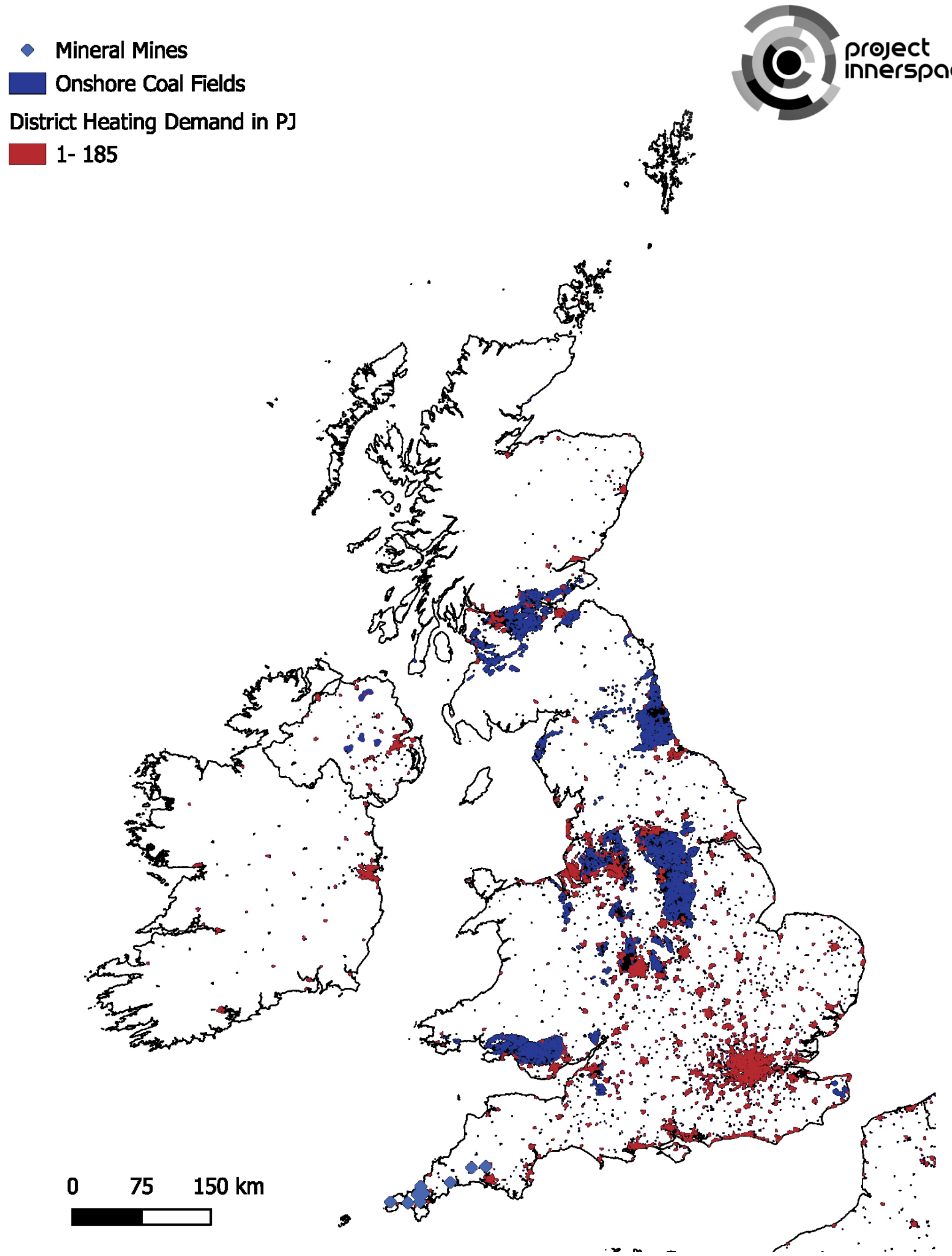


Figure 4.10: Distribution of onshore coalfields, mineral mines, and district heating demand across the United Kingdom. Areas shaded in pink indicate known onshore coalfields, while red diamonds mark the locations of active or historical mineral mines. Purple dots show spatial variation in district heating demand (1–185 PJ), 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. Data sources: 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; Onshore coal fields available from OGL, British Geological Survey. (2020). *Coal resources for new technologies dataset*. Contains British Geological Survey materials © UKRI 2025. Projection: OSGB36 / British National Grid.

INFLUENCES ON HEAT TRANSFER IN MINEWATER SYSTEMS

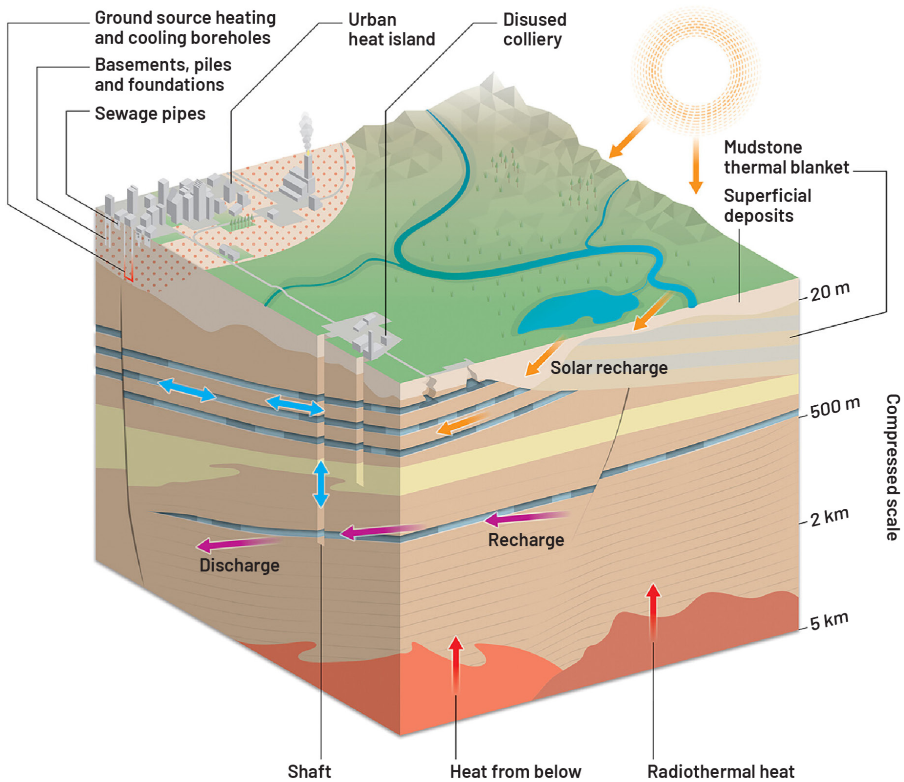


Figure 4.11: Block diagram showing predominant heat sources and variations influencing heat transfer in minewater systems. Red arrows represent conductive processes; blue arrows represent groundwater flow in mines and shafts; orange arrows are indicative of heat transfer via solar recharge; purple arrows represent regional groundwater flow, recharge, and discharge across the mined rock volume. Source: BGS for © Coal Authority 2022, published in Monaghan, A. A., Adams, C. A., Bell, R. A., Lewis, M. A., Boon, D., González Quirós, A., Starcher, V., Farr, G., Wyatt, L. M., Todd, F., Walker-Verkuil, K., MacAllister, D. J., Abesser, C., Palumbo-Roe, B., & Scheidegger, J. (2026). Geological factors in the sustainable management of mine water heating, cooling and thermal storage resources in the UK. *Energy Geoscience Conference Series, 1*, egc1-2023-39.

heat pump to transfer heat to a distribution network, and a reinjection well to return the cooled water back into the mine system—albeit into a different mined level (seam) and/or at a distance from the production well to avoid it mixing with the warmer water being extracted. Although open-loop systems are typically used, closed-loop systems can also work in mines.[117,118,119]

UK Activity

The Mine Remediation Authority plays a key role in permitting and licensing minewater energy developments in the UK. It supports more than 20 minewater heating investigations across the country, providing access to historic and current data; borehole design guidance; and technical advice for local authorities, utility providers, and developers. This support will help build a robust knowledge base and de-risk future projects.

North-east England has seen the greatest amount of progress with large-scale schemes (megawatt thermal scale) already operational at Lanchester Wines and Gateshead.[120,121] The Gateshead minewater heat network, operational since March 2023, is the largest of its kind in Great Britain and among the largest in Europe. It extracts heat from minewater 150 metres beneath the town centre using a 6 megawatt heat pump and a 5 kilometre heat network, supplying homes, public buildings, and commercial facilities. The project is estimated to save 72,000 tonnes of CO_2 over 40 years.[122]

The Seaham Garden Village in County Durham is a domestic-scale scheme in development that is expected to heat at least 1,000 homes with minewater from an existing treatment site. Estimated carbon savings are 2,600 tonnes of CO_2 annually over a 25-year period.[123]

In Wales, the Lindsay scheme in Carmarthenshire is one of the first to supply heat to a commercial facility using submerged heat exchangers in a minewater treatment pond. Funded by Innovate UK, it supports decarbonisation of local industry and serves as a model for future undertakings.[124]

A similar test scheme in Bridgend, Wales, explored the feasibility of using minewater for heating. Initiated in 2016, the project aimed to harness geothermal energy from the flooded former Caerau Colliery to supply heat to approximately 300 homes, as well as community buildings and a primary school.[125] However, the development was discontinued due to significant technical and commercial uncertainties encountered during the design and planning stages. This project highlights the complexities and challenges involved in implementing minewater heating schemes in the UK.

In Scotland, two historical schemes investigated the use of minewater, one at Shettleston in east Glasgow and one at Lumphinnans in Fife, though neither are currently operational.[126] The Shettleston project in Glasgow, completed in 1999, is an early example of an open-loop ground source heat system using minewater. It served 16 dwellings (houses and flats), drawing water at 12°C from flooded coal mine workings (probably in the Glasgow Ell Seam) via an approximately 100 metre-deep borehole. The Lumphinnans project in Fife, completed in 2000–01, was an open-loop ground source heat system retrofitted to a 1950s apartment block of 18 dwellings. Minewater was pumped from flooded coal workings in the Jersey/Diamond seam via a 172 metre-deep borehole, with reported temperatures of between 12°C and 14.5°C.[127] The system at Lumphinnans experienced problems caused by air entering into the reinjection borehole, leading to clogging of the borehole with precipitation of ochre (ferric oxyhydroxide). Shettleston operated trouble-free for at least 10 years, but the costs and logistics of necessary maintenance proved challenging for the social housing operator, which was one reason it failed. A backup gas system was installed to ensure heat could be delivered continuously to residents, and the gas system effectively displaced the minewater heating.

In Northern Ireland, the East Tyrone Coalfield contains workings up to approximately 280 metres deep and has potential for small-scale schemes (subject to further exploration).[128] The Ballycastle Coalfield is shallower and less prospective, but it still offers potential for low-capacity heat extraction, particularly in rural and coastal areas.

Many existing developments in the UK are supported by the Mining Remediation Authority, which also permits access to mine workings and collaborates on research with academic partners. The Gateshead Living Laboratory provides a unique environment for monitoring thermal and hydrogeological behaviour in a real-world setting. This complements research at the Glasgow Observatory, part of the UK Geoenergy Observatories programme, which advances knowledge of shallow geothermal systems and minewater heat extraction.

BGS is also actively engaged in mine geothermal energy and thermal storage research, including the EU-funded PUSH-IT project.[129]

Together, these initiatives demonstrate the UK's growing capacity to harness clean energy from abandoned coalfields, offering a scalable, low-carbon solution for heating buildings and decarbonising heat networks.

Applications and Use Cases

The primary applications of minewater geothermal systems include urban heat networks in former coalfield communities, as well as low-temperature heating for residential housing, schools, municipal buildings such as warehouse storage (Abbotsford and Nest Roads, Lanchester Wines scheme in Gateshead), leisure centres, and industry. Constant-temperature minewater can also be used for greenhouse and aquaculture heating. Additionally, these systems support cooling through reverse-cycle operation and can facilitate seasonal thermal energy storage (see "Underground Thermal Energy Storage in the UK, with a Focus on Aquifer Thermal Energy Storage").

Key advantages include relatively shallow drilling requirements, low-carbon intensity, and a strong spatial correlation between the resource and areas of socio-economic need, such as those affected by fuel poverty. Observations in the Durham Coalfield indicate that residents welcome such schemes, which are seen as positive legacies of a mining heritage.[130] Many UK towns were developed in areas with coal, and homes in such areas were built in vast numbers. Minewater systems are also well suited for integration with low-temperature district heating infrastructure.

An illustrative example is the Heerlen Mijnwater Project in the Netherlands, a geothermal initiative that originated from the European Interreg IIIB NWE programme and the Sixth Framework Programme project EC-REMINING-lowex. The Mijnwater project has been operating since 2008 and was developed as a fourth-generation district heating and cooling network.[131] During winter, warm water (28°C) is extracted from former mine workings and fed into the network to supply heat. In summer, cooler water (16 °C), drawn from shallower sources, is circulated to provide cooling.

By 2020, Mijnwater was supplying sustainable heating and cooling to more than 400 dwellings and 250,000 square metres of commercial buildings. The project makes a significant contribution to the sustainability of the built environment in Heerlen and the wider Parkstad Limburg region. It also plays a key role in positioning Heerlen as an innovative green tech hub in the field of thermal smart grids. The long-term objective is to connect 30,000 homes and offices in Parkstad by 2030.[132]

Lessons Learnt and Next Steps for Minewater Geothermal Resource Assessment in the UK

The exploration and development of minewater geothermal systems in the UK present technical and operational challenges, but minewater geothermal remains one of the most advanced and promising geothermal technologies. With the potential to deliver sustainable, low-carbon heat to economically disadvantaged communities, minewater schemes are attracting more attention. A critical requirement is demonstrating the long-term stability of heat output to build confidence among stakeholders and investors. The Seaham Garden Village project is a leading example, as decades of continuous mine dewatering, treatment, and disposal have already demonstrated the resource's reliability and sustainability. Ongoing monitoring and maintenance are essential to ensuring success, including continuous tracking of key parameters such as temperature, groundwater levels, flow rates, and water quality. Minewater geothermal projects face several technical risks, the most significant of which relate to siting, hydraulics, and water chemistry. Siting risks arise from uncertainty in historical mine plans, which can result in exploratory boreholes missing target voids. Hydraulic behaviour is often unpredictable, with abstraction and reinjection sometimes showing contrasting responses even within the same seam. Water chemistry presents another critical challenge, with oxygen ingress leading to clogging and scaling and dissolved gases such as methane or hydrogen sulfide creating safety and materials issues. These risks vary in their implications. Some, such as siting uncertainty, mainly affect upfront drilling costs, while others, such as clogging or gas hazards, can pose long-term operational and maintenance challenges. Many of these risks are well understood and can be mitigated through established engineering practices, such as phased exploration, sealed pressurised systems, appropriate material selection, and proactive maintenance planning. (**Table 4.5** provides a breakdown of potential risks and case examples.)

Steps to Ensure Minewater Geothermal Energy Schemes Can Be Scaled in the UK

Minewater geothermal energy schemes (MGES) are an emerging innovation both in the UK and globally, with each system presenting its own location-dependent and project-specific characteristics, which can make replication and upscaling challenging. There is no universal framework for assessing, monitoring, and governing minewater geothermal resources, either independently or in hydraulic and thermal communication with one another. There are also significant gaps in our ability to assess the technical viability and environmental sustainability of MGES in urban centres, where

SUMMARY OF KEY RISKS

Risk Area	What Could Go Wrong (Mechanism)	Illustrative Cases	Typical Mitigations	References
Hitting the target (siting)	"Striking open workings" is uncertain, especially where mine plans are old; exploratory drilling may miss mapped voids or hit unmapped ones.	**Nest Road, Gateshead (UK):** Four boreholes were needed to get one good abstraction and one good reinjection borehole.	Allow contingency drilling; use phased exploration; use multiple horizons to increase chances of connectivity.	Walls et al., 2021; Banks, 2021
Unpredictable hydraulics	Abstraction and reinjection in different seams within the same area can show very different responses.	**Nest Road:** Abstraction showed flat drawdown (good connectivity); deeper reinjection behaved like a "sealed reservoir."	Treat models with caution; be prepared for unconventional hydraulic responses; test both production and injection.	Walls et al., 2021; Banks, 2021
Geotechnical stability	Rapid pressure changes or high flows in shallow workings may risk instability or erosion of pillars.	The UK Mining Authority typically requires geotechnical assessment.	Conduct geotechnical risk assessment; use conservative ramp-up; monitor.	Walls et al., 2021; Todd et al., 2019
Inadequate yield or injectivity	Poor void connectivity or chemical/biological clogging of reinjection wells (often from oxygen ingress) lowers capacity.	**Lumphinnans (Scotland):** Free-cascading injection promoted iron oxidation, which led to clogging, which contributed to cessation.	Eliminate free fall into reinjection wells; use pressurised sealed abstraction-heat exchange-reinjection systems; maintain anoxic conditions; wells and other pipework/heat exchangers may need regular maintenance.	Walls et al., 2021; Banks et al., 2009; Banks et al., 2017; Walls et al., 2020
Dissolved gas hazards (hydrogen sulfide [H_2S] and operational)	O_2 ingress oxidises Fe/Mn → ochre; CO_2 degassing raises pH → scaling; asphyxiation risk in enclosed spaces; methane and H_2S require control.	**Markham No. 3 (UK):** methane deliberately vented **Nest Road:** Reducing, H_2S-rich water corroded downhole sensors.	Anoxic, pressurised abstraction-heat exchange-reinjection systems; handling; ventilate/flare methane; gas monitoring; materials compatible with H_2S/CO_2.	Walls et al., 2021; Gunning et al., 2019; Steven, 2021; Banks et al., 2017; Banks et al., 2009; Hill, 2004
Clogging and scaling	Mobilised fines and ochre (ferric oxy-hydroxides) foul filters, heat exchangers and wells; filters can become a "locus for ochre."	**Mieres (Spain):** Mineral grains were found in disassembled plate heat exchanger; widespread ochre issues were noted.	Anoxic, pressurised abstraction-heat exchange-reinjection systems; staged filtration with easy service; periodic chemical/mechanical cleaning; conservative velocities.	Walls et al., 2021; Loredo et al., 2017
Corrosion	Acid generation and elevated "free" CO_2 corrode carbon/mild steels; H_2S accelerates corrosion (even in some stainless steels). Sensors at Nest Road were replaced with titanium.	**Nest Road:** H_2S-related sensor corrosion; general CO_2/H_2S corrosion literature applies.	Material selection (plastics, titanium, high-alloy where justified); control O_2/CO_2 ingress; biocide where appropriate.	Walls et al., 2021; Steven, 2021; Twigg, 1984; Koteeswaran, 2010; Li et al., 2019
Treatment and discharge constraints	Meeting Fe/Mn (UK) or salinity limits may require treatment, if thermally "spent" minewater is to be returned to the surface environment; using "treated" (oxygenated) water in heat exchange systems can trigger fouling.	**Dawdon (UK) pilot:** minewater treated by aeration and settlement to remove iron. This introduced oxygen to the water. Residual iron rapidly oxidised and clogged components of the heat exchange system. The system was redesigned to use anoxic, untreated water.	Use anoxic, pressurised abstraction-heat exchange-discharge systems; monitoring will usually be required to demonstrate that the water quality and temperature of any discharge to the surface environment comply with environmental regulations.	Walls et al., 2021; Banks & Banks, 2001; Loredo et al., 2017; Bailey et al., 2013

SUMMARY OF KEY RISKS (CONTINUED)

Risk Area	What Could Go Wrong (Mechanism)	Illustrative Cases	Typical Mitigations	References
Thermal feedback and interference	Short flowpaths or same-seam doublets can cause cold-front breakthrough; multiple schemes risk mutual interference.	**Tyneside (UK):** Nest Road and Abbotsford Road are ~700 m apart—no clear evidence of thermal conflict to date.	Different mined horizons for abstraction and reinjection; design for long/tortuous flowpaths; monitoring.	Walls et al., 2021; Banks, 2021; Steven, 2021
Pumping head and parasitic load	Deep dynamic heads and pipe losses increase pump energy, resulting in lower system COP and poorer economic outcomes.	Discussed in general and with Markham context.	Minimise lift and frictional losses; do not unnecessarily oversize pumps site energy centres near source; use gravity assists or standing-column where feasible.	Walls et al., 2021; Banks et al., 2017
Demand, permitting, and future availability	Demand density may be insufficient even if resource is good; permits can miss delivery windows; resource access can be lost if pumped/gravity discharges are moved, cease pumping, or dry up.	**Fortissat (Scotland):** technically favourable, demand density insufficient. **Fordell Castle (Scotland):** gravity discharge reportedly dried due to opencast at Muirdean.	Early stakeholder work with operators and regulators; lock-in discharge points; pair schemes with anchor loads (district heating).	Walls et al., 2021; Harnmeijer et al., 2017; Government of the United Kingdom, 2021; Sparling, 2013
Operations and maintenance (O&M) burden (small schemes)	"Accumulated ongoing monitoring and maintenance burdens" can make small and medium systems uneconomical; recurring reinjection/heat-exchanger fouling.	**Shettleston (UK):** long-running scheme ultimately decommissioned, probably due to ongoing financial and logistical challenges of maintenance.	Planned access and budgets for cleaning and descaling; budget for proactive maintenance; favour scale where O&M is economical.	Walls et al., 2021; Banks et al., 2009

Table 4.5: Summary of key risks for minewater geothermal in the UK. Full source list can be found after the conclusion to this section.

assessment and monitoring may be challenging and where one minewater resource may straddle multiple minewater access agreement (MAA) areas. To ensure resilience and environmental sustainability at scale, scalable modelling within the subsurface must be improved in a way that supports operational and planning decisions. To achieve this goal, the UK would need to address the following interdependent issues:

- **Obstacles to at-scale implementation:** high capital expenditures and long payback period; high operational expenditures (non-standardised operation and maintenance); possibly complex to retrofit; no legal or financial framework for heat ownership and sales; low level of customer buy-in; short-, medium-, and long-term liabilities; clogging, scaling, and corrosion of equipment; water treatment requirements; availability of skilled workforce and at-scale supply chain.
- **Potential impacts on social and community key performance indicators:** energy poverty; limited stakeholder engagement; need to shift from passive to active energy citizenship and community "ownership" of low-carbon heating and cooling interventions; risk vs. benefit perception and acceptance; real vs. perceived risks; lack of inclusion of social key performance indicators in energy system models.
- **Subsurface characterisation uncertainties:** geological controls; conditions and geometry of abandoned mineworkings; fluid chemistry; geomechanical stress regime; presence of natural or mining-induced fractures and their transmissibility; fluid/heat pathways; aquifer recharge; natural geothermal gradient vs. anthropogenic heat; subsurface urban heat islands.
- **Understanding dynamic system response:** coupled Thermal-Hydrological-Mechanical-Chemical processes over project life cycle; hysteresis of petrophysical and geomechanical controls; mixing dynamics during pumping; minewater rebound; interference between boreholes in and between MAAs.

- **Potential environmental impacts:** uncontrolled emissions of gas and water; altering water table depth and groundwater-surface water interactions; thermal impacts on aquifer in addition to climate change and urbanisation; chemical impacts such as homogenisation of natural vertical quality gradient; microbiological impacts altering aqueous ecosystem.
- **Potential impact on land and adjacent properties:** subsidence; collapsed mineworkings; induced seismicity; increased heating demand in buildings above cooled subsurface; contamination of groundwater at downstream sites; increased frequency of groundwater flooding jointly with climate change.
- **Limited prospect evaluation experience:** no established MGES "geothermal play" catalogue or "analogue field" concept for initial assessment of resource potential.
- **Unsuitability of conventional exploration methods:** inability to use large-scale 3D geophysical investigations in a built environment; constrained vibroseismic measurements near properties that lack foundations; sensor interference with ground-borne urban noise.
- **Need for both project-level and minewater block-level monitoring:** land accessibility inside/outside MAA area; costs of distributed measurements; requirements for ad hoc spatial and temporal

Table 4.5 sources

Walls, D. B., Banks, D., Boyce, A. J., & Burnside, N. M. (2021). A review of the performance of minewater heating and cooling systems. *Energies*, *14*(19), 6215; Walls, D. B., Burnside, N. M., & Boyce, A. J. (2021). "Old versus new": Comparing mine water geothermal systems in Glasgow [Conference paper]. World Geothermal Congress 2020+1; Todd, F., McDermott, C., Harris, A. F., Bond, A., & Gilfillan, S. (2019). Coupled hydraulic and mechanical model of surface uplift due to mine water rebound: Implications for mine water heating and cooling schemes. *Scottish Journal of Geology*, *55*, 124–133; Banks, D., Athresh, A., Al-Habaibeh, A., & Burnside, N. (2017). Water from abandoned mines as a heat source: Practical experiences of open- and closed-loop strategies, United Kingdom. *Sustainable Water Resource Management*, *5*, 29–50; Bailey, M. T., Moorhouse, A. M. L., & Watson, I. A. (2013). Heat extraction from hypersaline mine water at the Dawdon mine water treatment site. In M. Tibbett, A. B. Fourie, & C. Digby (Eds.), *Mine closure 2013: Proceedings of the Eighth International Seminar on Mine Closure* (pp. 559-570). Australian Centre for Geomechanics; Harnmeijer, J., Schlicke, A., Barron, H., Banks, D., Townsend, D., Steen, P., Nikolakopoulou, V., Lu, H., & Zhengao, C. (2017). Fortissat minewater geothermal district heating project: Case study. *Engineering and Technology Reference*, 1–8; Banks, D., Fraga Pumar, A., & Watson, I. (2009). The operational performance of Scottish minewater-based ground source heat pump systems. *Quarterly Journal of Engineering Geology and Hydrogeology*, *42*(3), 347–357; Banks, S. B., & Banks, D. (2001). Abandoned mines drainage: Impact assessment and mitigation of discharges from coal mines in the UK. *Engineering Geology*, *60*, 31–37; Banks, D., Steven, J. K., Berry, J., Burnside, N., & Boyce, A. J. (2019). A combined pumping test and heat extraction/recirculation trial in an abandoned haematite ore mine shaft, Egremont, Cumbria, UK. *Sustainable Water Resources Management*, *5*, 51–69; Loredo, C., Ordonez, A., Garcia-Ordiales, E., Alvarez, R., Roqueni, N., Cienfuegos, P., Pena, A., & Burnside, N. M. (2017). Hydrochemical characterization of a mine water geothermal energy resource in NW Spain. *Science of the Total Environment*, *576*, 59–69; Banks, D. (2021). 'Fessing up: Risks and obstacles to mine water geothermal energy. In *Proceedings of the Mine Water Heating and Cooling: A 21st Century Resource for Decarbonisation*, 10–11; Athresh, A.P., Al-Habaibeh, A., & Parker, K. (2015). Innovative approach for heating of buildings using water from a flooded coal mine through an open loop based single shaft GSHP system. *Energy Procedia*, *75*, 1221–1228; Gunning, A., Henman, T., Kelly, T., Anderson, B., & McGuire, C. (2019). *Research project to investigate prevalence of CO_2 from disused mineral mines and the implications for residential buildings*. Scottish Government; Hill, S. R. (2004). *The physical and geochemical characterization of oxygen-depleted breathing wells in central Alberta*. University of Alberta; Steven, J. (2021). From Venture Pit to Walker Shore, coal and heat and fathoms of core: Mine water heat exploitation in Newcastle/Gateshead. In *2021 Mine Water Geothermal Energy Symposium-International Energy Agency Geothermal*. Department for Business, Energy and Industrial Strategy; Twigg, R. J. (1984). *Corrosion of steels in sour gas environments*. Atomic Energy Control Board; Koteeswaran, M. (2010). *CO_2 and H_2S corrosion in oil pipelines* [Master's thesis]. University of Stavanger; Li, S., Zeng, Z., Harris, M. A., Sánchez, L. J., & Cong, H. (2019). *CO_2 corrosion of low carbon steel under the joint effects of time-temperature-salt concentration*. *Frontiers in Materials*, *6*, 10; Government of the United Kingdom. (2021). *Get a coal mining licence or other consent*; Sparling, C. (2013, May 28). Fordell Day Level is so important to future quality of land. Central Fife Times; Rowley, A. (2013, May 13). Questions raised over mining operations in Fife. *Alex Rowley MSP* [blog].

resolution; no standards to review and grant adjacent MAAs within a given minewater block.

- **Limitation of modelling capabilities:** no "standard" approach to modelling dynamic MGES performance over project lifetime; primary focus so far on Thermal-Hydrological rather than Mechanical-Chemical processes, and 1D/2D rather than 3D.

Case Study: Gateshead Minewater District Heating Scheme

The town of Gateshead, located in north-east England, has embarked on one of the UK's most ambitious minewater district heating schemes. Led by Gateshead Council and its energy company, this project exemplifies the potential of minewater energy to supply clean, affordable heat to post-industrial communities.[133,134]

The primary goal of the scheme is to reduce carbon emissions and heating costs for local residents and public buildings while demonstrating a scalable model for other former coalfield areas in the UK.[135] Two megawatt-scale, low-enthalpy minewater geothermal heat pump schemes have already been developed in the Gateshead Area, Tyneside, at Abbotsford Road and Nest Road. These are used for low-carbon heating of

GEOLOGICAL MAP OF THE FELLING AREA, GATESHEAD

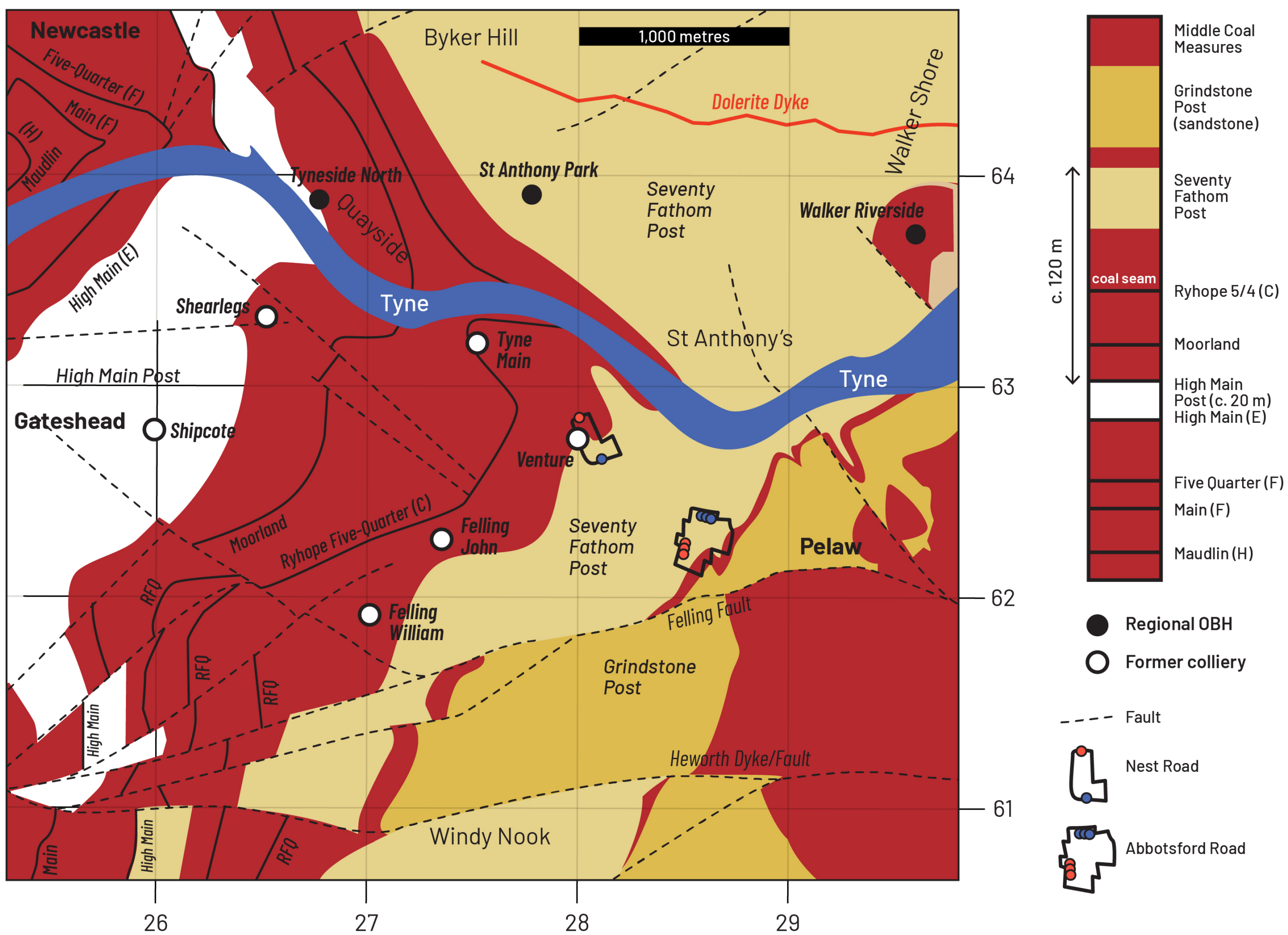


Figure 4.12: Simplified geological map of the Felling area, Gateshead, showing regional Observation Boreholes (OBH). Geological information derived from British Geological Survey (https://www.bgs.ac.uk/, accessed on 25 November 2021) mapping. Contains Open Geoscience public sector information licensed under the Open Government Licence v3.0. Source: Banks, D., Steven, J., Black, A., & Naismith, J. (2022). Conceptual modelling of two large-scale mine water geothermal energy schemes: Felling, Gateshead, UK. *International Journal of Environmental Research and Public Health, 19*(3), 1643.

wine warehouses; their status as of around 2022 was as follows:[136]

- **Abbotsford Road** scheme has typically abstracted between 20 litres per second and 30 litres per second of groundwater from the unmined Coal Measures upper aquifer system (UAS), extracting heat before reinjecting the cooled water into the an aquifer system associated with the High Main (E) coal workings and the overlying High Main Post sandstone (the High Main Aquifer System, or HMAS; see **Figure 4.12**).
- **Nest Road** scheme is located about 700 metres to the north-west of Abbotsford Road. This scheme abstracts 40 litres per second from the HMAS, recovers heat, and reinjects thermally spent water into deeper workings linked to the Hutton (L) and Harvey-Beaumont (N) coal seams, as well as possibly other seams. This deeper network is termed the deep mined aquifer system (DMAS; see **Figure 4.12**).

The UAS, HMAS, and DMAS are vertically discontinuous aquifer systems with distinct hydraulic properties (storage, transmissivity, and connectivity), which would have been extremely difficult to predict prior to drilling. Across both sites, 10 boreholes were drilled to secure five usable production and reinjection boreholes.[137]

Operational since March 2023, a 6 megawatt water source heat pump recovers heat and distributes it via a network of heat network pipes more than 5 kilometres long. This network currently serves more than 350 homes, as well as Gateshead College, the BALTIC Centre for Contemporary Art, the Glasshouse, GB Lubricants, and local commercial offices. There are plans to expand supply to an additional 270 homes, a conference centre, and a hotel.[138] This project has an estimated savings of 72,000 tonnes of CO_2 over 40 years, or about 1,800 tonnes of CO_2 per year.[139]

In 2024, Gateshead Council was awarded £5.9 million in Heat Networks Investment Project funding to install 5 kilometres of new heat network pipes, boreholes, and an energy centre, enabling access to 6 megawatts of minewater heat.[140] It has been developed through partnerships involving Gateshead Energy Company, the Mining Remediation Authority (previously the Coal Authority), BGS, GEA, Balfour Beatty, and local research institutions.

In early 2025, and in agreement with Gateshead Council, the Mining Remediation Authority launched a Living Laboratory adjacent to the heat scheme.[141] This research initiative includes additional boreholes, extensive sensor installations, and open-access data tools to monitor and model the hydrogeological and thermal performance of the minewater system in real time, as well as its interaction with neighbouring minewater thermal schemes. The Living Lab is intended to support improved modelling, risk management, and regulatory decision-making for future minewater energy developments across the UK.

Beyond the technical achievements, the Gateshead project provides valuable social and economic benefits. It addresses fuel poverty by providing lower-cost heating to social housing and public services while supporting the local green economy through skills development and innovation. As a result, it stands as a flagship example of how legacy coalfield infrastructure can be reimagined to support a low-carbon future.

Deep Heat Case Study: Southampton District Energy Scheme—the UK's First Geothermal District Heating Network

The Southampton District Energy Scheme (SDES), launched in 1986, is the UK's first and longest-running geothermal district heating network. Initially catalysed by a deep geothermal exploration programme in the early 1980s, the scheme has since evolved into a multi-source, low-carbon energy network supplying heat, cooling, and electricity across the city. It is widely recognised as a flagship example of sustainable urban energy integration, demonstrating the potential for deep geothermal resources in the Wessex Basin aquifer and their role in the UK's heat decarbonisation strategy.[142]

Origins and Development

In the early 1980s, the Southampton City Council (SCC), with support from central government and the European Union, investigated the deep Triassic sandstone aquifers beneath the city. Drilling in 1981 and 1982 reached 1.7 kilometres depth, accessing a geothermal resource of approximately 74°C hot saline water from the Wessex Basin aquifer. Despite scepticism from some geologists at the time—many predicted the well would "die by the mid-1990s"—the geothermal source remains operational almost four decades later, providing around 15% of the SDES total annual heat supply.[143]

The SCC recognised the opportunity to combine this renewable resource with a public-private partnership to deliver district energy infrastructure. Partnering with Utilicom (now part of Equans/Bring Energy), the Southampton Geothermal Heating Company was established to finance, develop, and operate the network.

The initial anchor customers included the civic centre and other council-owned properties, providing early revenue stability before expanding into commercial and residential markets.[144]

System Configuration and Scale

The scheme utilises a deep geothermal source from the Triassic Sherwood Sandstone aquifer within the Wessex Basin, with 74°C saline water extracted from a depth of 1.7 kilometres via a downhole turbo-pump and transferred through heat exchangers to a clean-water distribution circuit. Geothermal energy contributes around 15% of annual demand, with the majority of heat supplied by three CHP units, including a 5.7 megawatts electric dual-fuel engine that provides more than 70% of the total annual heat load. Eight gas-fired boilers supply additional top-up and peak heat when required, while a district cooling network that

GEOLOGY OF THE GEOTHERMAL WELL

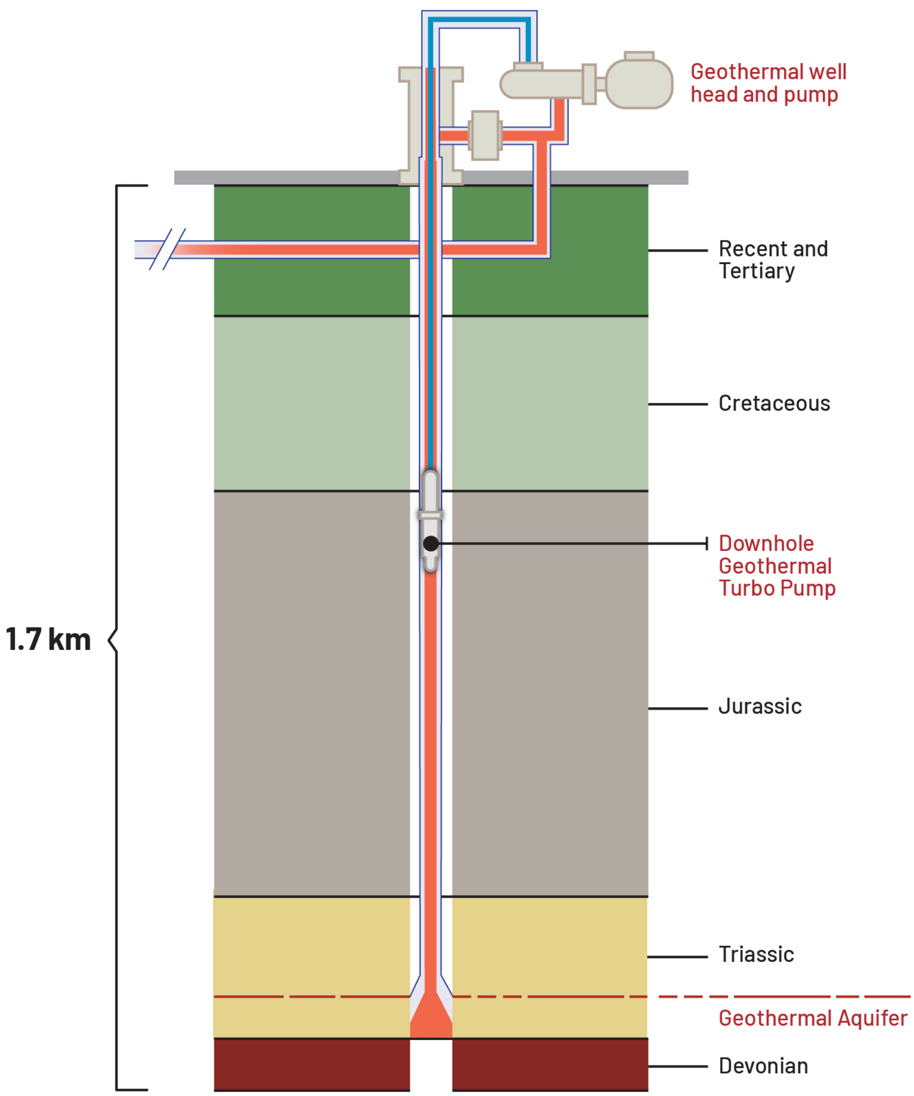


Figure 4.13: Hot water at 74°C is pumped up from a depth of 1.7 kilometres beneath the city centre. Utilising heat exchangers, it is used to heat water for the scheme. At present, 15% of the energy used by the scheme is provided by the geothermal heat source. Source: Southampton City Council & Utilicom. (2003). *Urban community heating and cooling: The Southampton District Energy Scheme*. Southampton Geothermal Heating Company.

has been operational since 1994 uses both absorption chillers powered by surplus CHP heat and conventional vapour-compression chillers.[145]

The network consists of more than 11 kilometres of insulated distribution pipes, delivering approximately 70 gigawatts thermal and cooling annually alongside 23 gigawatts thermal of exported electricity under long-term contracts.[146] It serves more than 45 major customers and hundreds of households, including BBC South Studios, the Royal South Hampshire Hospital, the University of Southampton, Westquay Shopping Centre, and multiple hotels.[147] In 2023, SDES supplied more than 40 gigawatts thermal per year of low-carbon heat and chilled water to the city centre, with the geothermal source continuing to provide a reliable baseload despite the increased contribution from CHP.

The scheme delivers significant carbon savings, avoiding an estimated approximately 11,000 tonnes of CO_2 annually compared with conventional gas boilers. Future decarbonisation strategies include phasing out gas-fired CHP, expanding large-scale heat pump integration, recovering additional waste heat, and enhancing geothermal capacity. System reliability is underpinned by the network's statutory utility status, ensuring coordinated protection of buried infrastructure, alongside built-in redundancy through dual-fuel CHP units, standby boiler capacity, and minimal network heat losses of approximately 1°C per kilometre. Reflecting its long-term success and strategic role, the 2025 *Southampton Heat Network Zoning: Zone Opportunity Report* identifies Southampton as one of the UK's leading heat network growth zones, positioning SDES as a cornerstone for future low-carbon urban heating and cooling infrastructure.[148]

Summary

The success of the SDES has been driven by a durable governance model and a strong public–private partnership between the SCC and Utilicom/Bring Energy. Underpinned by long-term customer contracts (typically 20 years), the scheme ensures both price competitiveness and investment security, while planning policy alignment—including the use of Section 106 agreements[149]—has enabled the SCC to encourage or require new developments to connect to the network. The project has received national recognition, including the Queen's Award for Enterprise (2001) and the Community Heating Award (1999), underscoring its role as a flagship low-carbon infrastructure project in the UK.

For policymakers and investors, SDES provides clear lessons. It demonstrates the proven viability of deep geothermal integration in urban UK settings, with nearly 40 years of continuous operation despite early scepticism about resource longevity. By integrating multiple heat sources—including geothermal, CHP, and waste heat, with future plans for large-scale heat pumps—the scheme delivers operational flexibility and resilience, while supportive planning and zoning policies have de-risked investment and created a bankable framework. Looking ahead, Southampton is strategically positioned to decarbonise CHP, expand geothermal production, and integrate additional renewable sources, cementing its role as a national hub for low-carbon heat innovation.

With its mature technical design, stable governance, and scalable delivery model, SDES offers a replicable pathway for deploying large-scale, low-carbon district heat networks across the UK—from high-potential areas such as southern England (Wessex Basin), which shows the highest heat-in-place values suitable for direct-use heating and potential low-enthalpy power generation, to smaller but significant hot spots in north-west England (Cheshire Basin) and distinct demonstration opportunities in Northern Ireland (Larne and Lough Neagh basins). (See Chapter 3, Figure 3.7, as reference.)

GEOLOGICAL COOLING AND STORAGE FOR THE UK'S AI GROWTH ZONES

The rapid growth of the UK's artificial intelligence (AI) and data centre sector is driving unprecedented demand for cooling, with associated electricity use and carbon intensity rising sharply. Cooling alone already accounts for roughly 40% of total data centre electricity consumption,[150] and as AI workloads push rack power densities from traditional 5 kilowatts to 10 kilowatts toward 30 kilowatts or more, these systems are generating far greater heat per square metre,[151] which is expected to significantly increase the sector's cooling energy needs. Market forecasts suggest that demand for data centre cooling infrastructure in the UK could grow by more than 20% in the coming years, reflecting both rising computational intensity and the expansion of new AI-dedicated facilities.[152] Without corresponding improvements in efficiency or waste heat recovery, cooling is poised to remain one of the largest contributors to the sector's total power draw and emissions.

Many of the UK government's proposed AI Growth Zones[153] (AIGZs)—including Culham, Thames Valley, Bristol, Teesside, Humber, and the Scottish Green Freeports—sit near thick sedimentary basins and within or adjacent to legacy onshore mining districts. Together, these settings offer some of the country's strongest opportunities for geothermal and subsurface cooling and storage resources.

Sedimentary aquifers provide stable temperatures for groundwater-based cooling and storage, circulating water between cold and warm wells to deliver low-carbon cooling and store recoverable waste heat. In parallel, flooded mine workings beneath many industrial corridors (such as the Central Belt of Scotland, Northern England, South Wales, and the Midlands) provide extensive, well-connected subsurface reservoirs with high flow potential, enabling district-scale thermal networks. For large computing hubs and AI campuses where cooling can approach 40% of total energy demand, the subsurface (aquifers and mines) offers a direct path to energy efficiency and carbon reduction.

Analysis of geological and infrastructure data sets (see **Figure 4.14**) shows that the majority of current and planned AIGZs[154] are underlain by thick sedimentary successions and/or mapped minefields, creating multiple technical options (for example, ATES, open-loop groundwater, and minewater systems). Notably, the first two confirmed AIGZs align with basins where geothermal cooling could be deployed to reduce costs and peak power demand. In particular, Culham (Oxfordshire) and Teesside (north-east England)—the first two confirmed AIGZs—both coincide with the sedimentary basins where geothermal cooling could be deployed and help reduce costs and energy demand.

1. **Culham, Oxfordshire:** The UK's first confirmed AIGZ, located near the UK Atomic Energy Authority and earmarked for fusion-powered energy systems. Culham lies within the Wessex–Worcester Basin, where the Sherwood Sandstone Group provides a permeable aquifer network suitable for ATES and shallow geothermal cooling.
2. **Teesside (North East England):** The second designated AIGZ, centred around the Teesworks site, a former steelworks undergoing large-scale regeneration. Plans include one of Europe's largest data-centre campuses (≈500,000 square metres). Centred on the Teesworks regeneration area above the East Yorkshire–Lincolnshire Basin and adjacent to the former Durham/Northumberland coalfield, this pairing of sedimentary aquifers and mine networks is well suited to hybrid systems that combine aquifer cooling with minewater heat rejection and storage for a planned large data-centre campus.

Geothermal Data Centre Cooling Is Already Happening Around the World

The Iron Mountain Data Centers in Boyers, Pennsylvania, in the United States, uses a unique geothermal cooling system located around 61 metres underground in a former limestone mine. The system uses an underground reservoir for cooling, and its mechanics are not overly complex, which keeps maintenance costs low. The data centre also has unlimited backup thermal storage capacity, unlike standard diesel backup generators, which can only provide energy for a limited number of hours. With this system, Iron Mountain saw a 34% reduction in total energy use.[155]

Beyond the confirmed sites at Culham and Teesside, more than 200 regions across the UK have expressed interest in hosting AIGZs. Many of these candidate locations coincide with major sedimentary basins and onshore mines, creating strong opportunities for renewables-integrated sedimentary storage and cooling systems supporting AI and digital campuses:

1. **Scotland (Forth, Cromarty, Irvine, Glasgow):** Coastal and nearshore basins (Forth and Moray Firth groups) contain thick sandstones. Legacy mines include the Central Belt coalfields (such as

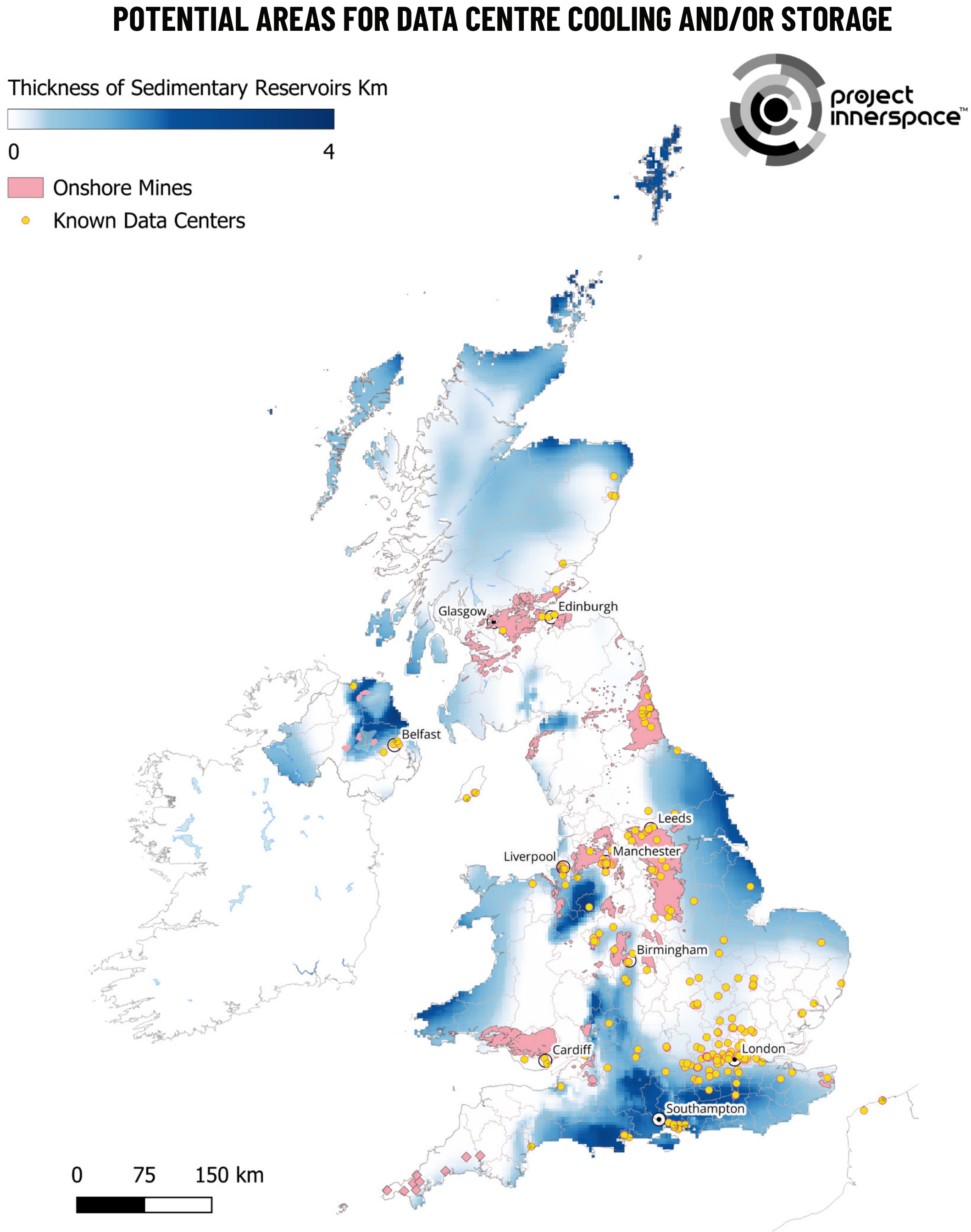


Figure 4.14: Thickness of sedimentary reservoirs across the UK (darker blue = thicker, km), with known data centres (yellow points) and onshore mines (pink areas). Thick basin sequences (for example, Cheshire, Wessex, Worcester, and East Yorkshire–Lincolnshire, plus the Larne and Lough Neagh basins) coincide with clusters of data centres, while extensive onshore mining districts (Central Belt of Scotland, Northern England, South Wales, the Midlands) add minewater geothermal opportunities. The overlap of thick aquifers, legacy mines, and digital infrastructure highlights priority zones for low-carbon cooling, thermal storage, and geothermal-ready AI growth zones. 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.

Glasgow/Clyde Gateway, Ayrshire, Fife), offering extensive flooded workings suitable for mine-cooled systems.

2. **North-West England (Manchester–Liverpool–Warrington corridor):** Within or adjacent to the Cheshire Basin, with extensive Sherwood Sandstone aquifers. Nearby legacy mines include the Lancashire coalfield, North Staffordshire (Potteries), and Cheshire salt mines (for example, Winsford), all providing large subsurface void space and warm water.
3. **Yorkshire and the Humber (Doncaster, Drax, University of York):** Over the East Yorkshire–Lincolnshire Basin with thick Mesozoic strata. Major legacy workings include the Yorkshire coalfield (Selby complex/Kellingley, Hatfield, Barnsley–Rotherham–Doncaster belt), well suited to minewater networks alongside aquifer systems.
4. **North Lincolnshire:** Underlain by Permo-Triassic and Jurassic sequences. Proximal legacy mines include the Humberhead Levels/South Yorkshire coalfield fringe and Gainsborough–Doncaster area collieries; several sites retain accessible shafts and flooded workings.

Co-locating data infrastructure with renewable and geothermal energy would also help deliver the UK's sustainable and energy-resilience objectives while positioning the country as a global leader in sustainable digital infrastructure.

CONCLUSIONS

- **Shallow geothermal systems:** Currently the most mature and widely deployed opportunity, with around 43,700 GSHP installations nationwide. These systems are readily scalable and increasingly integrated into fifth-generation low-temperature heat networks.
- **Aquifer thermal energy storage:** Represents a major opportunity for urban heat and cooling decarbonisation. National modelling suggests ATES could theoretically supply up to 61% of annual heating demand and 79% of cooling demand, but UK deployment remains limited (11 installations) compared with leading international examples. The Chalk and Triassic Sherwood Sandstone Group aquifers—which combine favourable hydraulic properties with proximity to major urban centres (including London, Southampton, Cheshire, and Manchester)—are well suited for integration into district heating and cooling networks and should be considered priorities for ATES development.
- **Minewater geothermal:** Offers an immediately deployable, low-risk pathway by repurposing the UK's approximately 23,000 abandoned mines and 2 billion cubic metres of flooded workings as shallow, low-cost heat sources. The 6 megawatt Gateshead scheme, commissioned in 2023, demonstrates this potential. Ongoing projects across former coalfield regions—including in the north-east, Yorkshire, South Wales, and the Midlands—are also working on feasibility studies and pilot possibilities.
- **Cooling:** Many of the UK government's proposed AIGZs—including Culham, Thames Valley, Bristol, Teesside, Humber, and the Scottish Green Freeports—sit near thick sedimentary basins and within or adjacent to legacy onshore mining districts. Together, these settings offer some of the country's strongest opportunities for geothermal and subsurface cooling and storage resources.

CHAPTER REFERENCES

1 ARUP & Department for Energy Security and Net Zero. (2025). *UK geothermal review and cost estimations*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/689472ada6eb81a3f9b2e1fb/geothermal-energy-review.pdf

2 ARUP & Department for Energy Security and Net Zero, 2025.

3 Government of the United Kingdom. (2015). *Infrastructure Act 2015*. https://www.legislation.gov.uk/ukpga/2015/7/contents

4 Brown, C. S., Kolo, I., Banks, D., & Falcone, G. (2024). Comparison of the thermal and hydraulic performance of single U-tube, double U-tube and coaxial medium-to-deep borehole heat exchangers. *Geothermics*, *117*, 102888. https://doi.org/10.1016/j.geothermics.2023.102888

5 Banks, D. (2024). Hellfire exploration: The origins of ground source heat in early mining technology. *Green Energy and Sustainability*, *4*(3), 0003. https://doi.org/10.47248/ges2404030003

6 Banks, D. (2015). Dr T. G. N. "Graeme" Haldane—Scottish heat pump pioneer. *The International Journal for the History of Engineering and Technology*, *85*(2), 250–259. https://doi.org/10.1179/1758120615Z.00000000061

7 Haldane, T. G. N. (1930). The heat pump—an economic method of producing low-grade heat from electricity. *Journal of the Institution of Electrical Engineers*, *68*(402), 666–675. https://doi.org/10.1049/jiee-1.1930.0066

8 Griffith, M. V. (1948). The heat pump and its economic possibilities. *The Woman Engineer*, *6*(14), 250–257.

9 Griffith, M. V. (1957). Some aspects of heat pump operation in Great Britain. *Proceedings of the IEE—Part A: Power Engineering*, *104*(15), 262–278. https://doi.org/10.1049/pi-a.1957.0068

10 Sumner, J. A. (1976). *Domestic heat pumps*. Prism Press.

11 At the time of writing, the GSHPA is being merged with other trade organisations to form a new Heat Pump Association UK.

12 Ground Source Heat Pump Association (GSHPA). (2025). *Closed loop vertical borehole standard, Issue 4.0*. GSHPA.

13 Galliers, L. (2025, September 18). *Boiler energy efficiency explained*. Which? https://www.which.co.uk/reviews/boilers/article/boiler-energy-efficiency-aCgnH9h8JJP9

14 Dunbabin, P., Charlick, H., & Green, R. (2013). *Detailed analysis from the second phase of the Energy Saving Trust's heat pump field trial*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/5a7f09a0e5274a2e87db3727/analysis_data_second_phase_est_heat_pump_field_trials.pdf

15 Environment Agency. (2025, June 25). *Closed loop ground source heating and cooling systems: When you need a permit*. Government of the United Kingdom. https://www.gov.uk/guidance/closed-loop-ground-source-heating-and-cooling-systems-when-you-need-a-permit

16 Environment Agency & Department for Environment, Food and Rural Affairs. (2023, October 2). *Open loop heat pump systems: Apply to install one*. Government of the United Kingdom. https://www.gov.uk/guidance/open-loop-heat-pump-systems-permits-consents-and-licences

17 Abesser, C., Lewis, M. A., Marchant, A. P., & Hulbert, A. G. (2014). Mapping suitability for open-loop ground source heat pump systems: A screening tool for England and Wales, UK. *Quarterly Journal of Engineering Geology and Hydrogeology*, *47*, 373–380. https://doi.org/10.1144/qjegh2014-050

18 British Geological Survey. (n.d.). *Open-loop GSHP screening tool*. Environment Agency, Government of the United Kingdom. https://mapapps2.bgs.ac.uk/gshpnational2/app/index.html

19 Environment Agency. (2023). *Ground source heating and cooling (GSHC): Status, policy, and market review*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/66d8393afe7cca6f5744d1c4/Ground_source_heating_and_cooling_-_status__policy__and_market_review_-_report.pdf

20 Ministry of Housing, Communities & Local Government. (2021, January 27). *The Future Homes Standard: Changes to Part L and Part F of the building regulations for new dwellings*. Government of the United Kingdom. https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings#:~:text=The%20Future%20Homes%20Standard%20will,performance%20of%20the%20constructed%20home
21 Wilson, W., & Barton, C. (2023). *Tackling the under-supply of housing in England*. House of Commons Library. https://researchbriefings.files.parliament.uk/documents/CBP-7671/CBP-7671.pdf
22 Rosenow, J., Thomas, S., Gibb, D., Baetens, R., De Brouwer, A., & Cornillie, J. (2023). Clean heating: Reforming taxes and levies on heating fuels in Europe. *Energy Policy*, *173*, 113367. https://doi.org/10.1016/j.enpol.2022.113367
23 Environment Agency, *Ground source heating and cooling*, 2023.
24 Environment Agency, *Ground source heating and cooling*, 2023.
25 Environment Agency, *Ground source heating and cooling*, 2023.
26 Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J. E., Hvelplund, F., & Mathiesen, B. V. (2014). 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. *Energy*, *68*, 1–11. https://doi.org/10.1016/j.energy.2014.02.089
27 Cherwell District Council North Oxfordshire. (2023). *Planning application-23/03347/F*. https://planningregister.cherwell.gov.uk/Planning/Display/23/03347/F#undefined
28 Department of Energy & Climate Change. (2016, February 11). *Heat pumps in district heating*. Government of the United Kingdom. https://www.gov.uk/government/publications/heat-pumps-in-district-heating
29 Heat Pumping Technologies. (n.d.). *Brooke Street—South Derbyshire*. https://heatpumpingtechnologies.org/annex47/wp-content/uploads/sites/54/2019/07/brooke-street.pdf
30 Department of Energy & Climate Change, 2016.
31 Boesten, S., Ivens, W., Dekker, S. C., & Eijdems, H. (2019). 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply. *Advances in Geosciences*, *49*, 129–136. https://doi.org/10.5194/adgeo-49-129-2019
32 Brummer, N., & Bongers, J. (2019). *Mijnwater Heerlen: Roadmap to 2040*. HeatNet NWE. https://vb.nweurope.eu/media/10451/heatnetnwe_heerlen-transition-roadmap_district-heating.pdf
33 Kensa. (2022, October). *Heat the streets. The blueprint to decarbonising street by street with networked heat pumps*. https://kensa.co.uk/neighbourhood/case-study/heat-the-streets
34 Hex Energy. (n.d.). *College decarbonisation project*. https://hexenergy.co.uk/commercial/case-study/decarbonisation-of-2-college-campuses/
35 Buro Happold. (n.d.). *Roman baths hot spring water heat recovery system*. https://www.burohappold.com/projects/roman-baths-hot-spring-water-heat-recovery-system/
36 Roman Baths. (2022, March 1). *The Roman Baths and Pump Room to be heated by spa water*. https://www.romanbaths.co.uk/news/roman-baths-and-pump-room-be-heated-spa-water
37 CIBSE Journal. (2023). *Taking the waters: Recovering heat from the Roman baths*. https://www.cibsejournal.com/case-studies/taking-the-waters-recovering-heat-from-the-roman-baths/
38 Bath Abbey. (2021, March 9). *World's first eco-heating system using Bath's hot springs*. https://www.bathabbey.org/worlds-first-eco-heating-system-using-baths-hot-springs-close-to-completion/
39 Renewable Energy Installer & Specifier. (2022, February 9). *Case study: "First of its kind" Bath Abbey*. https://renewableenergyinstaller.co.uk/2022/02/case-study-first-of-its-kind-bath-abbey/
40 CIBSE Journal, 2023.
41 Bath Abbey, 2021.
42 Roman Baths, 2022.
43 CIBSE Journal, 2023.

44 Fleuchaus, P., Godschalk, B., Stober, I., & Blum, P. (2018). Worldwide application of aquifer thermal energy storage—A review. *Renewable and Sustainable Energy Reviews*, *94*, 861–876. https://doi.org/10.1016/j.rser.2018.06.057

45 Fleuchaus et al., 2018.

46 Fleuchaus, P., Schüppler, S., Godschalk, B., Bakema, G., & Blum, P. (2020). Performance analysis of aquifer thermal energy storage (ATES). *Renewable Energy*, *146*,1536–1548. https://doi.org/10.1016/j.renene.2019.07.030

47 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

48 Fleuchaus et al., 2018.

49 Fleuchaus et al., 2018.

50 Bloemendal, M., Olsthoorn, T., & van de Ven, F. (2015). Combining climatic and geohydrological preconditions as a method to determine world potential for aquifer thermal energy storage. *Science of the Total Environment*, *538*, 621–633. https://doi.org/10.1016/j.scitotenv.2015.07.084

51 Jackson et al., 2024.

52 Abesser et al., 2014.

53 British Geological Survey (BGS). (n.d.). *Open-loop GSHP screening tool (England and Wales)*. https://www.bgs.ac.uk/geology-projects/geothermal-energy/geothermal-technologies/open-loop-gshp-screening-tool/

54 Abesser et al., 2014.

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

56 Dochartaigh, B. É. Ó., MacDonald, A. M., Fitzsimons, V., & Ward, R. (2015). *Scotland's aquifers and groundwater bodies*. British Geological Survey. https://nora.nerc.ac.uk/511413/1/OR15028.pdf.

57 Jackson et al., 2024.

58 Trent, I. (2009, May 31). *Why we specified: Energy piles, One New Change, London*. Building. https://www.building.co.uk/why-we-specified-energy-piles-one-new-change-london/3141377.article

59 Fleuchaus et al., 2018.

60 Réveillère, A., Hamm, V., Lesueur, H., Cordier, E., & Goblet, P. (2013). Geothermal contribution to the energy mix of a heating network when using aquifer thermal energy storage: Modeling and application to the Paris basin. *Geothermics*, *47*, 69–79. https://doi.org/10.1016/j.geothermics.2013.02.005

61 Sommer, W. T., Doornenbal, P. J., Drijver, B. C., van Gaans, P. F. M., Leusbrock, I., Grotenhuis, J. T. C., & Rijnaarts, H. H. M. (2014). Thermal performance and heat transport in aquifer thermal energy storage. *Hydrogeology Journal*, *22*, 263–279. https://doi.org/10.1007/s10040-013-1066-0

62 Hoekstra, N., Pellegrini, M., Bloemendal, M., Spaak, G., Andreu Gallego, A., Rodriguez Comins, J., Grotenhuis, T., Picone, S., Murrell, A. J., Steeman, H. J., Verrone, A., Doornenbal, P., Christophersen, M., Bennedsen, L., Henssen, M., Moinier, S., & Saccani, C. (2020). Increasing market opportunities for renewable energy technologies with innovations in aquifer thermal energy storage. *Science of the Total Environment*, *709*, 136142. https://doi.org/10.1016/j.scitotenv.2019.136142

63 Sommer et al., 2014.

64 Bloemendal, M., & Hartog, N. (2018). Analysis of the impact of storage conditions on the thermal recovery efficiency of low-temperature ATES systems. *Geothermics*, *71*, 306–319. https://doi.org/10.1016/j.geothermics.2017.10.009

65 Bloemendal, M., Olsthoorn, T., & Boons F. (2014). How to achieve optimal and sustainable use of the subsurface for aquifer thermal energy storage. *Energy Policy*, *66*, 104–114. https://doi.org/10.1016/j.enpol.2013.11.034

66 Stemmle, R., Blum, P., Schüppler, S., Fleuchaus, P., Limoges, M., Bayer, P., & Menberg, K. (2021). Environmental impacts of aquifer thermal energy storage (ATES). *Renewable and Sustainable Energy Reviews*, *151*, 111560. https://doi.org/10.1016/j.rser.2021.111560
67 Bridger, D. W., & Allen, D. M. (2014). Influence of geologic layering on heat transport and storage in an aquifer thermal energy storage system. *Hydrogeology Journal*, *22*, 233–250. https://doi.org/10.1007/s10040-013-1049-1
68 Bloemendal & Hartog, 2018.
69 Regnier, G., Salinas, P., Jacquemyn, C., & Jackson, M. D. (2022). Numerical simulation of aquifer thermal energy storage using surface-based geologic modelling and dynamic mesh optimisation. *Hydrogeology Journal*, *30*, 1179–1198. https://doi.org/10.1007/s10040-022-02481-w
70 Jackson et al., 2024.
71 Stemmle, R., Lee, H., Blum, P., & Menberg, K. (2024). City-scale heating and cooling with aquifer thermal energy storage (ATES). *Geothermal Energy*, *12*, 2. https://doi.org/10.1186/s40517-023-00279-x
72 Jackson et al., 2024.
73 Jackson et al., 2024.
74 Bloemendal et al., 2014.
75 Bloemendal & Hartog, 2018.
76 Bloemendal, M., Jaxa-Rozen, M., & Olsthoorn, T. (2018). Methods for planning of ATES systems. *Applied Energy*, *216*, 534–557. http://dx.doi.org/10.1016/j.apenergy.2018.02.068
77 Fleuchaus et al., 2018.
78 Fleuchaus et al., 2018.
79 Fleuchaus et al., 2018.
80 Réveillère et al., 2013.
81 Geothermie Delft. (n.d.). *Geothermie Delft*. https://geothermiedelft.nl/en/
82 PUSH IT. (n.d.). *Project objectives*. https://www.push-it-thermalstorage.eu/about/
83 Jackson et al., 2024.
84 Jackson et al., 2024.
85 Jackson et al., 2024.
86 Stemmle, R., Hammer, V., Blum, P., & Menberg, K. (2022). Potential of low-temperature aquifer thermal energy storage (LT-ATES) in Germany. *Geothermal Energy*, *10*, 24. https://doi.org/10.1186/s40517-022-00234-2
87 UK Geoenergy Observatories. (n.d.). *Cheshire Observatory*. https://www.ukgeos.ac.uk/cheshire-observatory
88 FindHeat. (n.d.). *FindHeat*. https://findheat.eu/
89 Bakr, M., van Oostrom, N., & Sommer, W. (2013). Efficiency of and interference among multiple aquifer thermal energy storage systems: A Dutch case study. *Renewable Energy*, *60*, 53-62. https://doi.org/10.1016/j.renene.2013.04.004
90 Sommer, W., Valstar, J., Leusbrock, I., Grotenhuis, T., & Rijnaarts, H. (2015). Optimization and spatial pattern of large-scale aquifer thermal energy storage. *Applied Energy*, *137*, 322–337.
91 Bloemendal, M., & Olsthoorn, T. (2018). ATES systems in aquifers with high ambient groundwater flow velocity. *Geothermics*, *75*, 81–92. https://doi.org/10.1016/j.geothermics.2018.04.005
92 Beernink, S., Bloemendal, M., Kleinlugtenbelt, R., & Hartog, N. (2022). Maximizing the use of aquifer thermal energy storage systems in urban areas: Effects on individual system primary energy use and overall GHG emissions. *Applied Energy*, *311*, 118587. https://doi.org/10.1016/j.apenergy.2022.118587
93 Liu, T., Hanna, R., & Kountouris, Y. (2025). Decarbonising heating and cooling: Barriers and opportunities facing aquifer thermal energy storage in the United Kingdom. *Energy Research & Social Science*, *122*, 104006. https://doi.org/10.1016/j.erss.2025.104006
94 GeoEnergyNI. (n.d.). *GeoEnergyNI*. https://geoenergyni.org/
95 University of Leeds. (n.d.). *Geothermal campus*. https://geosolutions.leeds.ac.uk/geothermal/campus/

96 Imperial College London. (n.d.). *Our journey to a net zero estate by 2040*. www.imperial.ac.uk/media/imperial-college/about/sustainability/Our-journey-to-a-net-zero-estate-by-2040.pdf
97 Liu et al., 2025.
98 Possemiers, M., Huysmans, M., & Batelaan O. (2014). Influence of aquifer thermal energy storage on groundwater quality: A review illustrated by seven case studies from Belgium. *Journal of Hydrology: Regional Studies*, *2*, 20–34. https://doi.org/10.1016/j.ejrh.2014.08.001
99 Regnier, G., Salinas, P., & Jackson, M. (2023). Predicting the risk of saltwater contamination of freshwater aquifers during aquifer thermal energy storage. *Hydrogeology Journal*, *31*, 1067–1082. http://dx.doi.org/10.1007/s10040-023-02630-9
100 Bonte, M., Stuyfzand, P. J., van den Berg, G. A., & Hijnen, W. A. M. (2011). Effects of aquifer thermal energy storage on groundwater quality and the consequences for drinking water production: A case study from the Netherlands. *Water Science & Technology*, *63*(9), 1922–1931. http://dx.doi.org/10.2166/wst.2011.189
101 Environment Agency. (2024). *Ground source heating and cooling: Status, policy, and market review*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/66d8393afe7cca6f5744d1c4/Ground_source_heating_and_cooling_-_status__policy__and_market_review_-_report.pdf
102 Staffell, I., Pfenninger, S., & Johnson, N. (2023). A global model of hourly space heating and cooling demand at multiple spatial scales. *Nature Energy*,*8*, 1328–1344. http://dx.doi.org/10.1038/s41560-023-01341-5
103 Horton, H., Harvey, F., & Goodier, M. (2025, August 10). Low-income and minority ethnic people in England most at risk from dangerously hot homes. *The Guardian*. https://www.theguardian.com/uk-news/2025/aug/10/england-poorest-families-ethnic-minorities-most-at-risk-dangerously-hot-homes
104 Gecsoyler, S., & Goodier, M. (2025, August 12). 'Do not buy these flats': Residents warn about unbearable heat inside London new-builds. *The Guardian*. https://www.theguardian.com/australia-news/2025/aug/12/do-not-buy-these-flats-residents-warn-about-unbearable-heat-inside-london-new-builds
105 Balian, J. (2012, December 5). *Renewable Heat Incentive (RHI)—eligible heat criteria for ground source heating & cooling (GSHC) systems*. Office of Gas and Electricity Markets, Government of the United Kingdom. https://www.ofgem.gov.uk/sites/default/files/docs/2016/08/eligible-heat-criteria-ground-source-heating-and-cooling-systems.pdf
106 Office of Gas and Electricity Markets (Ofgem). (2018). *Easy guide to heat pumps*. Ofgem e-serve. https://www.ofgem.gov.uk/sites/default/files/docs/2018/05/easy_guide_to_heat_pumps.pdf
107 Jackson et al., 2024.
108 Liu et al., 2025.
109 Stemmle, R., Hanna, R., Menberg, K., Ostergaard, P., Jackson, M., Staffell, I., & Blum, P. (2025). Policies for aquifer thermal energy storage: International comparison, barriers and recommendations. *Clean Technologies and Environmental Policy*, *27*, 1455–1478. https://doi.org/10.1007/s10098-024-02892-1
110 Aquifer thermal energy storage (ATES) is a type of open-loop underground thermal energy scheme (UTES) that stores warmed or cooled groundwater in naturally porous, permeable underground rocks and uses this groundwater to provide low-carbon heating and cooling.
111 This case study was prepared using Jackson et al., 2024.
112 North East Combined Authority. (2024). *The case for mine energy—Unlocking deployment at scale in the UK*. North East Evidence Hub. https://evidencehub.northeast-ca.gov.uk/report/a-mine-energy-white-paper
113 Durham University, Department of Earth Sciences (n.d.). *Geothermal Energy from Mines and Solar-Geothermal heat (GEMS)*. UK Research and Innovation. https://gtr.ukri.org/project/0B3478B7-1D87-427B-98BE-A7FC755592E7
114 Ordnance Survey Press Office. (2024, January 23). *Exploring the potential demand for heating homes using disused coal mine water*. Ordnance Survey. https://www.ordnancesurvey.co.uk/news/mine-water-heat-project
115 Farr, G., Busby, J., Wyatt, L., Crooks, J., Schofield, D. I., & Holden, A. (2021). The temperature of Britain's coalfields. *Quarterly Journal of Engineering Geology and Hydrogeology*, 54(3). https://doi.org/10.1144/qjegh2020-109

116 North East Combined Authority, 2024.
117 Ramos, E. P., & Falcone, G. (2013). Recovery of the geothermal energy stored in abandoned mines. In M. Hou, H. Xie, & P. Were (Eds.), *Clean energy systems in the subsurface: Production, storage and conversion* (pp. 143–155). Springer. https://doi.org/10.1007/978-3-642-37849-2_12
118 Peralta Ramos, E., Breede, K., & Falcone, G. (2015). Geothermal heat recovery from abandoned mines: A systematic review of projects implemented worldwide and a methodology for screening new projects. *Environmental Earth Sciences*, *73*, 6783–6795. https://doi.org/10.1007/s12665-015-4285-y
119 Banks, D., Athresh, A., Al-Habaibeh, A., & Burnside, N. (2019). Water from abandoned mines as a heat source: Practical experiences of open- and closed-loop strategies, United Kingdom. *Sustainable Water Resources Management*, *5*, 29–50. https://doi.org/10.1007/s40899-017-0094-7
120 Walls, D. B., Banks, D., Boyce, A. J., & Burnside, N. M. (2021). A review of the performance of minewater heating and cooling systems. *Energies*, *14*, 6215. https://doi.org/10.3390/en14196215
121 Banks, D., Steven, J., Black, A., & Naismith, J. (2022). Conceptual modelling of two large-scale mine water geothermal energy schemes: Felling, Gateshead, UK. *International Journal Environmental Research and Public Health*, *19*(3), 1643, https://doi.org/10.3390/ijerph19031643
122 Coal Authority & Mining Remediation Authority. (2025, May 27). *Mine water heat*. Government of the United Kingdom. https://www.gov.uk/government/collections/mine-water-heat#:~:text=This%20network%20supplies%20heat%20to,1%2C800%20tonnes%20CO2%20per%20annum
123 Coal Authority & Mining Remediation Authority, 2025.
124 Coal Authority & Mining Remediation Authority, 2025.
125 Monaghan, A., Abesser, C., & Kendal, R. (2025, February 7). *Written evidence submitted by British Geological Survey*. Parliament of the United Kingdom. https://committees.parliament.uk/writtenevidence/137144/pdf/
126 Energy and Climate Change Directorate. (2013). *Potential for deep geothermal energy in Scotland: Study volume 2*. Government of Scotland. https://www.gov.scot/publications/study-potential-deep-geothermal-energy-scotland-volume-2/pages/13/
127 Energy and Climate Change Directorate, 2013.
128 Coalisland Local Nature Partnership. (2021). *The story of coal mining in Coalisland & District*. https://coalisland-lnp.com/wp-content/uploads/2021/01/03-LNP-COAL-MINING-IN-COALISLAND-DISTRICT-Resource-notes.pdf
129 PUSH-IT, n.d.
130 Li, J., Hollis, C., & Gallego-Schmid, A. (2025). Equity or profit? Understanding the social sustainability challenges of mine water heating network implementation. *Energy Research & Social Science*, *124*, 104062. https://doi.org/10.1016/j.erss.2025.104062
131 Verhoeven, R., Willems, E., Harcouët-Menou, V., De Boever, E., Hiddes, L., Op't Veld, P., & Demollin, E. (2014). Minewater 2.0 project in Heerlen, the Netherlands: Transformation of a geothermal mine water pilot project into a full scale hybrid sustainable energy infrastructure for heating and cooling. *Energy Procedia*, *46*, 58–67.
132 Euroheat and Power. (2021, September 15). *Mijnwater project in Heerlen, The Netherlands*. https://www.euroheat.org/dhc/knowledge-hub/mijnwater-project-in-heerlen-the-netherlands
133 Department for Business, Energy and Industrial Strategy. (2022). *Heat networks planning database* [Data set]. Government of the United Kingdom. This database tracks heat network projects in the UK, including heat source types, status, and deployment as of 2022.
134 Mining Remediation Authority. (n.d.). *Mine water energy scheme at Gateshead*. Government of the United Kingdom. https://www.miningremediation.co.uk/major-grant-to-connect-gateshead-homes-to-coal-authority-mine-water-energy-scheme/
135 Gateshead Council. (n.d.). *District Energy Scheme benefits*. https://www.gateshead.gov.uk/article/2994/District-Energy-Scheme-benefits
136 Banks et al., 2022.
137 Banks et al., 2022.
138 Coal Authority & Mining Remediation Authority, 2025.

139 Coal Authority & Mining Remediation Authority, 2025.
140 Coal Authority. (2024, January 24). *Gateshead mine water heat scheme gets official seal of approval* [Press release]. Government of the United Kingdom. [Gateshead mine water heat scheme gets official seal of approval - GOV.UK]
141 Mining Remediation Authority. (2025, January 20). *New ground-breaking mine water heat Living Laboratory launched* [Press release]. Government of the United Kingdom. [New ground-breaking mine water heat Living Laboratory launched - GOV.UK]
142 Southampton City Council & Utilicom. (2003). *Urban community heating and cooling: The Southampton District Energy Scheme*. Southampton Geothermal Heating Company.
143 Southampton City Council & Utilicom, 2003.
144 Southampton City Council & Utilicom, 2003.
145 Southampton City Council & Utilicom, 2003.
146 Southampton City Council & Utilicom, 2003.
147 Southampton City Council & Utilicom, 2003.
148 Department for Energy Security & Net Zero. (2025). *Southampton heat network zoning: Zone opportunity report*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/6839acbec99c4f37ab4e8704/southampton-zone-opportunity-report.pdf
149 Section 106 funding is money that developers have to pay to the council for infrastructure works required as a result of new developments.
150 Watson, S. (2023, March 16). *Cool runnings: Making data centres more energy efficient*. MODUS. https://ww3.rics.org/uk/en/modus/natural-environment/climate-change/cooling-data-centres.html
151 Restivo, K., & Bastable, E. (2024, October 29). *AI's impact on data centre development*. CBRE. https://www.cbre.co.uk/insights/articles/ais-impact-on-data-centre-development
152 EfficiencyAI. (2025, August 15). *UK data centres to expand by 20% amid growing tech demands*. https://www.efficiencyai.co.uk/uk-data-centres-to-expand-by-20-amid-growing-tech-demands
153 Department for Science, Innovation & Technology. (2025, January 13). *AI opportunities action plan*. Government of the United Kingdom. https://www.gov.uk/government/publications/ai-opportunities-action-plan/ai-opportunities-action-plan
154 Department for Science, Innovation & Technology, 2025.
155 Better Buildings Solution Center. (2020, September 3). *Iron Mountain Data Centers: Geothermal cooling system*. U.S. Department of Energy. https://betterbuildingssolutioncenter.energy.gov/showcase-projects/iron-mountain-data-centers-geothermal-cooling-system

Part III

Legal, Regulatory, Environmental, Workforce, and Stakeholder Considerations

Chapter 5

Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential

Renewable Energy Association (REA), with contributions from Project InnerSpace

The United Kingdom currently lacks a dedicated geothermal strategy and national deployment targets—a sharp contrast with European peers. A range of interconnected barriers continues to prevent the UK from putting its significant subsurface resources to work for heating, cooling, and electricity generation, yet each of these barriers can be addressed with targeted policy interventions and a comprehensive regulatory effort. Taking such action would set the stage for a robust domestic geothermal industry.

Geothermal offers a renewable, domestic, and reliable energy source for heating, electricity, industrial heat, and cooling—and the UK offers a lot of opportunity. Analysis from Project InnerSpace shows there are approximately 3,900 gigawatts of technical potential down to 3.5 kilometres for heating and cooling applications, the most exciting opportunity for geothermal in the UK. (See Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface Geology," for more details.) In addition to this potential, the heat found in water in former coal mines across the UK can serve as a valuable resource as well. Approximately 25% of the UK population lives above abandoned coalfields (see Chapter 4, "Geothermal Heating and Cooling: Applications for the United Kingdom's Industrial, Municipal, Residential, and Technology Sectors," for more details), which could be harnessed to provide 2.2 million gigawatt-hours of heat—enough to heat all homes in the UK for more than 100 years.[1,2] Analysis by Project InnerSpace also estimates approximately 25 gigawatts of technical potential for electricity down to 5 kilometres.

As the UK moves towards a renewable, reliable, and secure grid—and faces high energy bills driven by exposure to volatile international gas markets and unusually high electricity prices[3]—geothermal can supply domestic, dispatchable, baseload electricity; deliver clean heating and cooling; create thousands of jobs; lower heating costs; and decarbonise industrial heat, all without relying on imported fuels or generating problematic waste streams. Scaling geothermal can also bolster the UK's long-term energy security via its world-leading oil and gas workforce.

The potential of geothermal energy has been recognised, to varying degrees, by UK governments since the 1970s. Mechanisms to support it as an energy source have included grants, subsidy payments (notably the now-defunct Renewable Heat Incentive, which was effectively a generous feed-in tariff), and a state-driven national exploration programme in the 1970s. However, technologies of the time, competitive global energy prices, and shifting government priorities left geothermal as a niche energy source. Today, vast improvements in technologies (many taken from the oil and gas sector); a growing number of start-ups in the region (see Chapter 10, "A New Age of Innovation: The United Kingdom's Geothermal Start-Up Scene"); and the renewed national drive for clean, affordable, reliable energy sources mean that geothermal is primed to become a viable and valuable option.

But while geothermal resources are substantial, deployment has been held back by limited policy support, regulatory uncertainty, and the low visibility of geothermal within the wider UK energy system—factors that have hindered investor confidence and slowed project development.[4]

The urgency of addressing policy barriers is reinforced by the UK's own energy system modelling. The National Energy System Operator's Future Energy Scenarios consistently show that the next decade will include rapid electrification of heat; expansion of heat networks; rising constraints on electricity networks; and a growing need for firm, domestically sourced, low-carbon energy. Crucially, these scenarios highlight that policy and investment decisions made in the next five years will largely determine the shape of the energy system through the 2030s—as infrastructure choices, network layouts, and supply chains become locked in. This shift creates a window for geothermal: Aligning geothermal policy with the system pathways already envisaged in the Future Energy Scenarios and enabling deployment now could allow geothermal to be integrated into emerging heat networks and local energy systems at the lowest cost and highest value. Delaying action risks foreclosing geothermal's role and being left with higher-cost alternatives.

This chapter outlines the policy and regulatory barriers to the development of a robust geothermal industry and presents a menu of solutions to unlock investment, reduce project risk, and accelerate growth. By adapting proven policies already applied in other UK sectors and in leading geothermal markets abroad, the UK can fully harness its geothermal potential.

The "Policy Recommendations" box shows seven proposed policy actions that can catalyse geothermal across the United Kingdom. Many of these recommendations can be implemented independently but could be effective if implemented as part of a comprehensive National Policy Statement issued on behalf of the UK government. **Figure 5.1** outlines the key barriers and specific proposed solutions to reach this goal.

SEVEN PRIORITY POLICY ACTIONS

1. Set a national geothermal strategy (with national geothermal goals).
2. Establish a "geothermal desk" to streamline licensing and permitting.
3. Develop financial incentives.
4. Leverage the government estate to stimulate geothermal demand.
5. Advance skills and supply chains.
6. Enhance data transparency and resource mapping.
7. Advance public engagement and awareness.

A BRIEF HISTORY OF GOVERNMENT INCENTIVES FOR GEOTHERMAL IN THE UK

The UK's first geothermal push came after the 1973 oil crises, when the government funded the Hot Dry Rock programme. This effort involved drilling exploratory boreholes across Britain and constructing a pioneering geothermal plant at Rosemanowes Quarry in Cornwall while also training a generation of engineers and academics. But it never produced a commercially viable power station. With oil prices low and little political return, the programme ended in 1990, and geothermal energy lost support. For the next two decades, geothermal saw little policy development.

POLICY MENU FOR ACCELERATED GEOTHERMAL DEVELOPMENT IN THE UK

Theme	Barrier or Challenge	Policy Solution or Recommendation	Responsible Party
Regulatory and Governance	Lack of national strategy or deployment targets, which undermines investor confidence. Fragmented regulation and unclear planning/permitting roles causing project delays.	**Policy Recommendation 1:** Publish a national geothermal strategy with explicit 2035/2050 heat and electricity goals. **Policy Recommendation 2:** Establish a "geothermal desk" for one-stop coordination between DESNZ and agencies with defined permit timelines; update national planning guidance to classify geothermal as a nationally significant, strategic, resilient, and renewable infrastructure.	DESNZ, Cabinet Office, HMT DESNZ; MHCLG; Environment Agency; Scottish government; Welsh government; Northern Ireland Executive; Mayoral Authorities
Financial and Investment	High up-front exploration and drilling risk that discourages private investors. Limited financial incentives compared with other renewables. Weak bankability of long-term heat offtake contracts.	**Policy Recommendation 3:** Create a geothermal resource insurance facility modelled on France and Germany. **Policy Recommendation 3:** Establish a geothermal exploration grant programme; include geothermal in Contract for Difference auctions; ring-fence funding in the GHNF. **Policy Recommendation 3:** Develop a geothermal financing framework using blended finance, tax breaks, and a contracts for heat regime with standardised heat purchasing agreements. Pair targeted capital support, loan guarantees, and resource insurance to reduce early drilling risk and unlock additional investment.	DBT, DESNZ, HMT Great British Energy, HMT, National Wealth Fund, DESNZ DESNZ, Ofgem, HNDU, local authorities
Market and Infrastructure	Low coverage of district heat networks, limiting viable demand.	**Policy Recommendation 4:** Introduce a public heat purchase obligation requiring public estate to procure low-carbon heat; designate geothermal opportunity zones within network areas.	Ministry of Defence, MHCLG, Cabinet Office, DESNZ, local authorities
Data, Coordination, and Integration	Incomplete or inaccessible subsurface data, which constrains exploration.	**Policy Recommendation 6:** Expand subsurface data resource mapping BGS Geothermal Data Map into a public National Geothermal Atlas; mandate open access to non-commercial well data.	BGS, DESNZ, GSNI
Skills and Awareness	Low awareness of technical skills and domestic capacity. Low public familiarity/examples; confusion with hydraulic fracturing.	**Policy Recommendation 5:** Create a Geothermal Skills Transition Fund for oil and gas workforce retraining; incentivise UK manufacturing of drilling and heat-exchange components by establishing local-content rules. **Policy Recommendation 7:** Run a national geothermal awareness campaign; develop national guidance distinguishing geothermal from hydraulic fracturing; highlight success stories (such as Southampton).	DESNZ, DBT, OPITO DESNZ, local authorities, industry associations

Figure 5.1: BGS = British Geological Survey; DBT = Department for Business and Trade; DESNZ = Department for Energy Security and Net Zero; GHNF = Green Heat Network Fund; GSNI = Geological Survey of Northern Ireland; HMT = HM Treasury; HNDU = Heat Networks Delivery Unit; MHCLG = Ministry of Housing, Communities and Local Government; Ofgem = Office of Gas and Electricity Markets; OPITO = Offshore Petroleum Industry Training Organisation. Source: author.

In 2008, however, the nation passed the Climate Change Act, embedding statutory greenhouse gas reduction targets and reinforcing interest in low-carbon energy sources. By the end of 2010, geothermal projects were eligible for enhanced incentives under the Renewables Obligation, which was revised in 2009 to introduce banded support that provided higher subsidies for emerging and capital-intensive technologies such as geothermal power.[5] Between 2009 and 2011, the nation's Department of Energy distributed nearly £5 million in capital grants via a challenge fund to deep geothermal projects.[6] The 2011 Renewable Heat Incentive offered subsidies close to £50 per megawatt for heat producers (this programme was discontinued in 2023) and limited capital grants from the Department of Energy.[7] The squeeze on public finances following the financial crash in 2008 and subsequent austerity measures constrained long-term support for such initiatives.

In 2014, geothermal became technically eligible for Contracts for Difference, but with no ring-fenced allocation (money specifically allocated for one area), it struggled to compete with cheaper technologies such as wind and solar. The Heat Networks Investment Project (2017–22) and its successor, the Green Heat Network Fund (from 2022), made geothermal heat an eligible option for district heating, though there are opportunities for expansion.[8]

OPPORTUNITIES FOR ADVANCEMENT

The UK has yet to set out a dedicated geothermal strategy or national deployment targets, even as European peers have moved to scale their geothermal sectors. Germany, for example, has recently moved to accelerate deployment with a new KfW geothermal development loan paired with government-funded exploration and resource-risk protection (including debt relief up to 100% of the bank loan if a well makes no—or only partial—discovery), alongside a draft law intended to speed up approvals and elevate geothermal expansion as a matter of overriding public interest.[9] In the UK, a range of interconnected barriers continues to prevent the sector from expanding. Nearly all of these barriers were identified by geothermal start-ups and developers working in the UK (see Chapter 10, "A New Age of Innovation: The United Kingdom's Geothermal Start-Up Scene"). Fortuitously, each of these barriers could be addressed by policy interventions or a comprehensive regulatory effort.

1. **Fragmented regulation and governance:** The UK has a comprehensive system of environmental permitting and regulation, overseen in England by the Environment Agency and a range of equivalent bodies in devolved administrations. While geothermal energy projects are subject to this full suite of mature environmental regulations, the regulatory system has evolved mainly in the context of water wells and the oil and gas industry. The geothermal energy sector therefore lacks a specific and clear framework and a dedicated permitting system, leaving an ad hoc patchwork system where requirements can vary at officials' discretion. Multiple agencies regulate subsurface access, planning, water use, and environmental compliance, along with data access, creating complexity, uncertainty, and long timelines for developers. Compared with streamlined pathways for the deployment of wind, solar, and even nuclear, limited local familiarity of geothermal further slows approvals and undermines investor confidence.
2. **High up-front exploration risk:** Developers face high drilling costs without assurance of viable subsurface resources, difficulty in obtaining exploration and resource-risk insurance, and insufficient geological data to price premiums—a classic market failure. Even successful exploratory wells lack legal certainty to monetise discoveries, allowing other parties to piggyback on the discovery, benefitting from it without sharing the up-front risks. Environment Agency abstraction licences provide a partial solution by allowing legal water extraction, but geological conditions vary from site to site, and risk profiles differ accordingly, leaving investors exposed to high up-front risk.
3. **Limited financial incentives:** Geothermal projects compete against mature wind, solar, and nuclear production with more established support mechanisms. Geothermal projects require major upfront investment—multi-million-pound price tags to drill wells, often between £25,000 and £30,000 per day for the rigs necessary for that drilling[10]—plus early borehole viability risk and few UK demonstration projects, deterring investors. Even ground source heat pumps face relatively high up-front costs despite strong lifetime performance and proven high operational efficiency, leaving a financing gap that current incentives do not bridge.[11,12]

4. **Problems with the planning system:** While major changes to the UK's planning and infrastructure systems are underway, geothermal projects currently face a complex and often time-consuming planning and permitting process. This reflects the fact that each project is a mid-scale infrastructure development involving boreholes, a surface plant, and temporary drilling pads, with preparatory works, drilling operations, and subsequent site reinstatement that can extend over many months. Many authorities are unfamiliar with the technology. And its benefits—small environmental footprints, low emissions, firm energy—can be overlooked amid concerns about noise, water, and induced seismicity.
5. **Lack of public awareness and community acceptance:** Municipal, industrial, and commercial consumers are often unaware of the technical and financial benefits of geothermal heating and cooling in the UK. Without early engagement and education, concerns can cause delays or, even worse, leave geothermal solutions off the table. Community and government outreach about geothermal's benefits, safety, low emissions, and minimal impacts can aid adoption and planning.

Most of these barriers have a proven policy solution, often already in use by other countries that have successfully grown their geothermal sectors.

POTENTIAL POLICY AND REGULATORY ACTIONS TO CATALYSE GEOTHERMAL ENERGY IN THE UK

As a renewable energy capable of meeting continuous demand,[13] geothermal energy could make a significant contribution to the UK's policy objectives on energy security, economic growth, and decarbonisation while also reducing costs for customers. The technology's exceptionally small surface footprint—the smallest of any renewable energy[14]—also makes it suitable in a densely populated country with stringent planning laws.

Where and when doing so is affordable, introducing incentive programmes to encourage the sector—alongside regulatory changes that would be relatively cheap to deliver—could make disproportionately large gains for delivering geothermal projects.

1. Set a National Geothermal Strategy (with National Geothermal Goals)

The UK government could make a clear policy commitment to geothermal energy. The technology has benefitted from various policy measures in the past—for example, the Renewable Heat Incentive—but an explicit statement supporting geothermal in the context of the UK's energy security, economic growth, and job creation goals would give investors more confidence that the technology would have long-term policy support. In Germany and the Netherlands, for example, advances in geothermal deployment were supported by establishing and explicitly stating national goals.[15]

The UK government is currently considering a national geothermal strategy, which could include setting targets for the rollout of geothermal projects. These targets could be aligned with other government initiatives on the future of the energy grid and the development of heat networks.

Under past governments, state support for geothermal energy has seemed ambiguous at times, leaving it outside the group of "most favoured" renewable energy technologies. Setting targets—even ones to signal direction—for the share of renewable heat and electricity generation expected to come online in, say, 2035 and 2050 would reassure investors and developers that the technology is being taken seriously.

Adopting targets is not a novel recommendation; many have been suggested by independent bodies, including the National Geothermal Centre's target of 10 gigawatts of heat and 1.5 gigawatts of electricity by 2050. While these goals have different costs and benefits in terms of decarbonisation, jobs created, and investments stimulated, any goals in this range set by the government would be impactful.

> ***If the policies recommended in this report are enacted soon (for instance, in the next one to three years), the 2050 time frame could be accelerated or the targets could be raised beyond 15 gigawatts for heat and 1.5 gigawatts to 2 gigawatts for electricity.***

Goals of 15 gigawatts for heat and between 1.5 gigawatts and 2 gigawatts for electricity by 2050 are consistent with current technologies, cost estimates, and the data in this report and would be ambitious targets at today's costs. These goals sit at the upper end of projections, however, based on current evidence and capabilities—and if financial, regulatory, planning, and permitting barriers are unlocked, they have the potential to become a reality. If the policies recommended in this report are enacted soon (for instance, in the next one to three years), the 2050 time frame could be accelerated or the targets could be raised beyond 15 gigawatts for heat and 1.5 gigawatts to 2 gigawatts for electricity.

Action: Department for Energy Security and Net Zero/central government

2. Establish a "Geothermal Desk" to Streamline Licensing and Permitting

To unlock its geothermal potential, the UK should overhaul—and streamline—its fragmented and uncertain permitting environment. This process should start with a comprehensive review.

As an example, the Nuclear Regulatory Taskforce's 2025 review of the nuclear industry, led by Chair John Fingleton, concluded that an overly complex nuclear regulatory system has contributed to the "relative decline" of the UK's ability to deliver faster and cheaper nuclear projects.[16] Gold plating—or the idea that utility companies under regulatory pressure from government agencies have overcorrected and gone too far in some areas of a project's development—leads to grossly inflated project costs, with some projects inflated by many billions over their lifetime.[17] The prime minister's announcement signalling the government's intention to expand the scope of the Fingleton review to other parts of UK industry is an opportunity. The geothermal sector should seize on, and even emulate, such a regulatory review process.

Geothermal projects are capital-intensive, site-specific, and subject to an overlapping system of approvals from local planning authorities, environmental regulators, and infrastructure bodies. Across the energy sector, for

Policy Idea: Cross-Agency Strikeforce on Advancing UK Geothermal

Create a unified, whole-government mechanism to accelerate geothermal deployment. The mandate could include coordinating subsurface data sharing, aligning regulatory pathways for deep and shallow geothermal projects, identifying strategic investment zones and ways to incentivise private sector investment, fast-tracking permitting, and unlocking blended finance for heat networks and industrial decarbonisation. By convening economic, geological, regulatory, and investment authorities under one umbrella, the UK Cross-Agency Geothermal Strikeforce would reduce fragmentation, signal high-level political prioritisation, and deliver a clear national strategy for scaling geothermal heat and electricity as a key pillar of UK energy security and economic renewal.

Who could be included: National Wealth Fund; Great British Energy; British Geological Survey; HM Treasury; Department for Business and Trade; Ofgem; Department for Energy Security and Net Zero; Environment Agency; Mining Remediation Authority; Ministry of Housing, Communities and Local Government; and North Sea Transition Authority.

To help solve the challenge of lengthy permitting, the central government could also establish a single-window "geothermal desk," consolidating all required consents into a single portal managed by the Department for Energy Security and Net Zero.

example, the Environment Agency's water abstraction licence timelines and procedures are cited as some of the biggest regulatory barriers to geothermal development in the UK.

Another example is that the current Nationally Significant Infrastructure Projects procedure is considered financially onerous. The patchwork system creates high transaction costs and long lead times that discourage investment. For example, the slow pace of permitting for open-loop and larger closed-loop shallow geothermal systems can be a significant disincentive for developers. The project's up-front capital requirements can also be a barrier for smaller renewable energy developers—particularly geothermal, which is largely driven by small and midsize firms.

To help solve the challenge of lengthy permitting, the central government could also establish a single-window "geothermal desk," consolidating all required consents into a single portal managed by the Department for Energy Security and Net Zero. This desk could be jointly managed by officials from renewable heat and power directorates and other relevant statutory regulators. It should be empowered to grant approvals across drilling, environmental permitting, and infrastructure integration processes and work closely and constructively with the devolved administrations where appropriate. The desk could also introduce statutory "permit clocks"—time-bound deadlines for decision-making that provide certainty for investors and accountability for regulators. Parliament could also grant geothermal heat-only projects public interest or priority infrastructure status, ensuring they are treated comparably to the current 50 megawatt electric threshold for nationally significant low-carbon energy projects. This would streamline land-use decisions, reduce litigation risk, and align geothermal with the UK's legally binding carbon budgets.

Finally, the Department for Energy Security and Net Zero and the Ministry of Housing, Communities and Local Government could issue national guidance for local authorities to treat geothermal resources as strategic infrastructure. Like onshore wind and solar, geothermal should be embedded in local development plans and energy strategies.

Action: Ministry of Housing, Communities and Local Government and Department for Energy Security and Net Zero

3. Develop Financial Incentives

While the previous measures would help deep geothermal developers, they do not directly address the fundamental economic issues. Getting a geothermal project to the breaking-ground stage requires a lot of money and commitments. Developers must also deal with uncertainty due to geological resource levels and future income streams. The overall aim is to combine and improve existing financial levers, including Contracts for Difference (including combined heat and power); targeted capital grants such as the Green Heat Network Fund and an exploration grant programme; and a state-backed drilling and resource insurance program with catalytic public anchors to transfer early subsurface risk, make heat and electricity revenues bankable, and gather private capital. These solutions are described in detail in Chapter 9, "Minding the Gap: Financing Solutions to Advance Geothermal in the United Kingdom."

Contracts for Difference

The UK's Contracts for Difference (CfD) regime—a government-backed mechanism that guarantees a fixed electricity price and stabilises revenues—has successfully taken billions of pounds of risk out of offshore wind investment by guaranteeing an expanded fixed strike price over a 15-year period (extended to 20 years in Allocation Round 7).[18] By offering a geothermal combined heat and electricity CfD, the government could guarantee developers a stable revenue stream for geothermal co-generated megawatt-electric-hours delivered to the electricity grid. Heat sales would be paid for by a different mechanism (see "Contracts for Heat or Standardised Heat Offtake Templates"). The

Lessons Learned from the Netherlands

The Netherlands provides a clear example of how implementing some of the policy recommendations outlined in this chapter has led to real benefits and projects on the ground. The Netherlands has more than 3,000 aquifer thermal energy storage (ATES) systems—about 85% of all the ATES systems on Earth.[19] Why? The country's policy framework.[20] The UK could use a similar framework as a model to help scale ATES and other heating solutions.

The UK could emulate the Netherlands in the following ways:

- **Create demand-pull through building energy performance rules:** New buildings must adhere to performance rules (such as early energy-neutral buildings). Because these performance rules emphasise low primary energy and renewable shares, they promote the development of low-carbon heating and cooling solutions in dense urban developments.[21]
- **Improve project economics with fiscal incentives:** Companies can deduct a large share of eligible investments via the Netherlands' Energy Investment Allowance and use a system called the MIA/Vamil environmental tax program.[22] Households and some businesses can also access subsidies for heat technologies, including ground source heat pumps. Together, these instruments improve the business case for ATES.[23,24]
- **Improve permitting and siting:** The Netherlands' Geo Energy Systems Amendment[25] moved permitting for open ground-energy (ATES) water permits from the uniform public preparation procedure to the regular procedure, which normally has a maximum decision period of eight weeks.[26] Additionally, specified temperature limits and the requirement for an energetically balanced operation promote the long-term efficient operation of ATES systems. The introduction of geothermal energy master plans by Dutch authorities also helps address the increasing scarcity of subsurface space in dense urban areas.
- **Cut soft exploration costs with national screening and data tools:** The public WKO-bodemenergietool provides a first-pass feasibility screen that can evaluate the potential of closed and open geothermal systems or prohibited, restricted, or viable areas. This reduces early transaction costs before detailed studies and permitting are required.[27]
- **Build public trust:** The Dutch government only allows certified companies to design, install, and manage ATES systems—BRL SIKB 11000 for the underground part and BRL 6000-21 for the above-ground scope—anchoring quality, safety, and performance across projects.[28]

After it was approved in the Dutch Senate, a permitting system specifically tailored to geothermal energy was rolled out in mid-2023. This system allowed for cooperation between state actors, local authorities, and private developers and made it easier for geothermal projects to be realised. For example, the system enabled projects in the Westmade-Noord district near The Hague that now provide tens of megawatts of deep geothermal heat to horticultural businesses—and heat to hundreds of homes in nearby residential developments.

Similar enabling programs in the UK could improve permitting and regulatory approvals, enhance data, create fiscal incentives, and build public trust—creating a robust geothermal industry.

CfD regime is administered by the government-owned Low Carbon Contracts Company, in which each hour (or day ahead) absorbs the difference between the market clearing electricity price and a generator's CfD electricity price so the generator receives long-term stable revenue per megawatt-hour of electricity.[29] To ensure geothermal access alongside mature and other emerging technologies, the current Allocation Round 7, £15 million Pot 2, for which all emerging technologies compete could in future rounds be enhanced to provide a ring-fenced pot for the special case of geothermal combined heat and electricity.

Evidence from Cornwall shows this framework can work. In 2023, Geothermal Engineering Ltd secured CfDs for three proposed plants, covering 12 megawatts of electrical capacity at a guaranteed £165 per megawatt-hour-electric (in 2024 money, escalated by inflation). The first of these plants is due to come online in 2026, offering developers and investors a reliable income stream.

While a CfD regime can provide a clear and bankable route to market for geothermal electricity once a plant is built, it does not address the high up-front exploration and drilling risks that deter investment to begin with. Without complementary policies, CfDs alone are unlikely to unlock geothermal deployment at scale. For geothermal combined heat and power projects, CfD electricity revenues should be aligned with standardised long-term, real-terms, fixed-price heat contracts so that both revenue streams can be financed together.

Contracts for Heat or Standardised Heat Offtake Templates

Long-term, bankable heat offtake is essential for project financing. The government should publish model lender-friendly contracts for heat tied to designated heat-network zones. Templates should include standard provisions on indexation, termination, step-in rights, and measurement and verification. These models should be referenced in the Green Heat Network Fund and CfD guidance so combined heat and electricity schemes can finance electricity and heat revenues together.

Action: Ofgem, Heat Networks Delivery Unit, Department for Energy Security and Net Zero, and local authorities

Capital Grants and Loan Guarantees

Capital grants, loan guarantees, and feed-in tariffs can incentivise private investors and lead to more heat and, potentially, electricity projects. Multiple geothermal start-up companies that were interviewed for this report (see Chapter 10, "A New Age of Innovation: The United Kingdom's Geothermal Start-Up Scene") said they would like to see an exploration grant programme created to fund the drilling of exploration wells in different locations in the UK. This approach could prove temperature and flow rates, catalyse private financing, and eliminate the exploration "valley of death." In France[30] and Germany, exploratory grants have been effective for carrying the deep geothermal sector through its early stages. Geothermal projects that have been realised in the UK have relied heavily on grants.

As for the sources of grants that already exist—such as the Green Heat Network Fund, which provides capital grants for low-carbon heat network developers—future rounds should be altered to more explicitly target deep geothermal projects and geothermal district heat networks. Where a project is insured under a geothermal resource insurance facility programme (see "Insurance"), grant milestones should be aligned with insurance verification to reduce timing risk and accelerate construction.

The UK government's new state-backed energy company, Great British Energy (GB Energy), or the UK's National Wealth Fund (formerly UK Infrastructure Bank) could make additional direct investments in geothermal projects or issue other investment sources such as a challenge fund. Further involvement of these institutions could move the sector to more sustainable financial footing at minimal cost to the public.

Action: Department for Energy Security and Net Zero, GB Energy, National Wealth Fund, and HM Treasury

Insurance

Another option to reduce developers' risk is a state-backed insurance program covering first-borehole risk. Governments in France, Germany, and the Netherlands operate such programs, and they have proven catalytic: In the Paris Basin, geothermal now provides a substantial share of heating, and every €1 of government risk mitigation has leveraged private investment worth between €30 and €40.[31] In late 2025, Germany signalled a stronger national commitment to scaling geothermal by pairing permitting reforms with new public finance and de-risking tools—aimed at cutting approval timelines and reducing early drilling and subsurface risk so projects can reach investment-grade status faster and be replicated at scale.[32,33] This kind of clear, government-backed direction—especially when coupled with mechanisms that address the "first projects" risk hurdle—can materially improve investor confidence, spread risk, and accelerate deployment in the UK.

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To make this approach work, the UK can establish a government-backed geothermal resource insurance facility (GRIF) that covers exploration failure, initial underperformance, and early temperature and pressure decline for the first 5 to 10 years, using deductibles, co-insurance, and reinsurance in global specialty markets. To generate the underwriting data and lower the cost of capital, the GRIF can be paired with a non-state philanthropic first-loss fund of between £3 million and £5 million per project to pay for the cost of front-end studies and a pilot borehole.

Action: Department for Business and Trade, Department for Energy Security and Net Zero, and HM Treasury

Portfolio Approach and Data Discipline

Geothermal projects have struggled with duplicative costs and extended timelines. To help avoid these challenges, projects should adopt a common approach for initial work such as standard well design and stimulation workflows; rig specifications; Organic Rankine Cycle specifications; and engineering, procurement, and construction scopes. Health and safety approvals for working fluids should be fast-tracked using standardised evidence practices. Appraisal and flow-test results generated under the insurance programme should be reported to a secure data system to strengthen actuarial evidence and, over time, reduce premiums.

Action: Department for Energy Security and Net Zero (with Health and Safety Executive), delivery partners, and suppliers

Refinancing and Recycling Public Investment to Keep Capital Moving

To lower heat costs and scale deployment without stranding public capital, pilots should be refinanced with low-cost, long-term instruments such as national gilts, local climate bonds, or lending against proven heat reserves. Public sector investors should recycle proceeds into the next round of appraisals and developments, creating a rolling pipeline of projects.

Action: HM Treasury, Debt Management Office, local authorities and financing partners

4. Leverage the Government Estate to Stimulate Geothermal Demand

Even with investors and borehole permissions secured, geothermal projects face the challenge of identifying reliable customers for heat and electricity. Long-term heat contracts are rare in the UK, and developers typically rely on heat networks to aggregate demand. Yet, in 2024, only about 3% of the UK's heat demand is supplied through heat networks,[34] far short of the government's 20% target for 2050.[35]

Recent reforms, however, can address this constraint. Under the Energy Act 2023, designated heat network zones in England (and Local Heat and Energy Efficiency Strategies in Scotland) can require new buildings, large public sector buildings, large private buildings, and existing communally heated residential buildings to be networked for district heating,[36] subject to cost-effectiveness tests.[37] This requirement creates a powerful mechanism to aggregate geothermal demand—but only if zones are strategically located and supplied with low-carbon heat. Heat network zones in Leeds, Plymouth, Bristol, Stockport, Sheffield, and some boroughs of London have so far been formally designated.[38]

The UK public estate—including National Health Service trusts, universities, Ministry of Defence sites, prisons, council buildings, schools, and civic venues—is large and creditworthy and has intensive needs for heating. By prioritising heat network zones near viable geothermal resources and anchoring them with mandatory or long-term public sector heat offtake, the government can underwrite a first scaled wave of geothermal projects and take a significant amount of risk out of early geothermal development while protecting public services from volatile gas prices.

Public Heat Purchase Obligation

- Require central government departments and arm's-length bodies (including executive agencies, non-departmental public bodies, and public corporations) that are publicly funded and accountable to UK government departments[39] to procure a rising share of space heating and cooling and process heat from qualifying low-carbon sources, including geothermal, within designated heat network zones.
- Aggregate public sector loads within each heat network zone and tender them as a single package to geothermal developers, guaranteeing connection to district networks and creating scale for new production wells or minewater heat pumps.

Geothermal Heat Zones

- The Future Homes Standard is already set to increase the rollout of low-carbon heat networks. Within designated heat network zones, local authorities should establish geothermal heat zones in which (i) new or significantly expanded heat networks must assess geothermal as a first option on a levelised-cost basis; and (ii) large new loads such as public anchors and major commercial developments are required to connect to low-carbon heat networks where technically and economically viable.
- Standardised contracts for heat should be available in a pre-approved template to reduce legal negotiations and internal approvals and therefore shorten procurement timing.

Warm Homes Plan

- Carve out an explicit and specialised policy to maximise the rollout of include shallow geothermal heat networks and ground source heat pumps in the deployment of the UK's recently announced Warm Homes Plan, which commits £15 billion of public investment in the coming years to support home energy upgrades.

Additional Enhancements

- **Minimum contract lengths:** Require 10- to 15-year offtake agreements to improve bankability for developers and reduce investor risk.
- **Price indexing or cost pass-through:** Link public sector tariffs to market mechanisms to ensure affordability and predictability.
- **Early adopter incentives:** Offer temporary capital grants or reduced connection fees for demonstration projects serving public loads to encourage early deployment.
- **Private sector co-funding:** Encourage private heat networks to participate alongside public loads, leveraging government contracts to unlock broader commercial demand.

By turning the public estate into a reliable, aggregated customer for geothermal heat and cooling, the government would provide the demand certainty needed to accelerate deployment of low-carbon heat networks.

Action: National Health Service, Ministry of Defence, Department for Energy Security and Net Zero, central government departments, and local authorities

5. Advance Skills and Supply Chains

Developing a geothermal supply chain creates jobs, reduces dependence on imports, and positions the UK to leverage its extensive expertise and technology into an exportable asset for European and global markets.

Britain has world-class engineering expertise in oil and gas development and strong project delivery capacity in offshore wind. These skills can all be deployed for geothermal exploration, drilling, and heat network integration as well. To retrain petroleum engineers, drillers, and subsea specialists for geothermal applications, the government should establish a geothermal skills transition fund.

At the same time, incentives should be offered for domestic manufacturing of geothermal hardware such as drilling rigs, casing, heat exchangers, and ground source heat pumps. Incentives can be offered via innovation grants, preferential purchasing for UK-made equipment, or a Production Linked Incentive-style subsidy tied to manufacturing unit output. These supply chain initiatives must be aligned with the workforce development strategies discussed in Chapter 8, "Beyond the North Sea: Leveraging the United Kingdom's Oil and Gas Expertise to Advance Geothermal." Training programs and cross-sector skills initiatives—such as OPITO's Integrated People and Skills Strategy or the Energy Skills Passport—can be extended to geothermal so that engineers, drillers, and technicians from oil, gas, and coal backgrounds are ready to support an expanding domestic supply chain.

Action: Department for Business and Trade and Offshore Petroleum Industry Training Organisation

6. Enhance Data Transparency and Resource Mapping

The government should invest in expanding and building out subsurface data in several ways:

A. **Comprehensive subsurface heat mapping:** Fund a national programme that integrates seismic data, borehole logs, thermal gradients, and other relevant subsurface information for both shallow and deep geothermal resources.
B. **Standardised and reprocessed data:** Reprocess historic data sets and standardise formatting to improve usability and interoperability, reducing complexity and duplication of effort.
C. **Publicly accessible geothermal atlas:** Maintain and enhance a central digital platform managed by the British Geological Survey and the Geological Survey of Northern Ireland, or another dedicated agency, in which all geothermal data—including new and legacy data sets for seismic data, rock properties, and well data—are shared and available to developers, investors, and local authorities.
D. **Time-bound open data for publicly supported wells:** Require standardised reporting and public release of non-commercial subsurface data within a period of 12 months to 18 months to help take the risk out of future projects and strengthen actuarial evidence for insurance programmes.

Transparent, high-quality data are the backbone of a modern energy industry. Without it, funders will likely hesitate to invest private capital in UK geothermal. By building on the geological survey map and investing in these measures, the government can remove one of the most significant barriers to geothermal deployment.

Action: British Geological Survey, Geological Survey of Northern Ireland, and Department for Energy Security and Net Zero

7. Advance Public Engagement and Awareness

As mentioned, geothermal energy is a valuable contributor to energy security, has excellent green credentials, and has the potential to lower heating bills. Yet, public understanding of geothermal remains limited in the UK. For most residents, geothermal is a new and unfamiliar technology, often confused with controversial activities such as hydraulic fracturing for oil and gas. This lack of awareness can lead to misunderstanding, hesitation, and costly planning delays, which can be prevented using the following strategies.

- **Ensure local community engagement during the planning process:** Involving and informing people and organisations about geothermal's benefits for their communities can make planning and development considerably smoother. During project development, supportive local government partners can help navigate local issues. The Southampton geothermal system, for instance, was created largely because of one local councillor who championed sustainability and innovation. Similar leadership in other parts of the country could help normalise geothermal as a trusted local energy option.
- **Introduce a community benefits package:** To further strengthen public confidence and ensure local communities share directly in the value of geothermal development, the UK could adopt a community benefits package model similar to that used in the onshore wind sector.[40] Such packages—offered voluntarily by developers—could include measures such as reduced heat

Geothermal Energy and the Devolved Administrations

The devolved administrations across the UK are strongly committed to tackling energy security, lowering the cost of heating bills, and addressing climate issues, and they have taken a range of actions to support geothermal projects and programmes.

The Scottish government has supported several geothermal energy projects over the past 10 years, from the Hill of Banchory deep geothermal feasibility study in 2016 to a 2025 study exploring how NHS Grampian can use deep geothermal heat.[41] The latter study received a £50,000 grant from the Scottish government's Sustainable Estates Team.[42] In December 2025, UK Research and Innovation granted £1 million to the University of Aberdeen to drill an instrumented borehole for geothermal assessment.[43]

In February 2025, a study by Scottish Enterprise, the national economic development agency, detailed how Scotland's Midland Valley has many flooded mines with great potential to make use of shallow geothermal energy.[44] In parallel, the Glasgow Observatory run by the British Geological Survey has studied how heat moves within old mine workings to maximise the efficiency of heat recovery.[45]

Wales also has a legacy of flooded mine workings. In 2024, the Welsh Senedd funded the Mine Water Heat Opportunity Map. The principality's first commercial minewater heat programme, in Ammanford (north of Swansea), uses heat exchangers submerged in minewater to produce low-carbon heat and hot water. The system launched in 2025 and supplies heat to a nearby industrial site. The programme is operated by the Mining Remediation Authority, which worked with local company Thermal Earth, with funding from Innovate UK's New Innovators in Net Zero Industry, South West Wales initiative.[46]

In 2023, the Northern Ireland Assembly launched GeoEnergy NI to galvanise growth in the geothermal energy sector and explore the role the sector can play in Northern Ireland's green economy. With funding of £3 million, the programme focuses on the potential for shallow geothermal energy on the Stormont Estate in Belfast and deeper solutions at the College of Agriculture, Food and Rural Enterprise Greenmount Campus near Antrim.[47]

bills for local households, contributions to local community funds, energy-efficiency upgrades, or investment in local skills and training. Introducing clear local benefits within a project's design would demonstrate that geothermal developments deliver not only clean energy but also meaningful, long-term economic value to the communities that host them.

- **Offer guidance on geothermal hydraulic fracturing:** Occasionally, geothermal hydraulic fracturing is needed in highly controlled circumstances to enable access to deep geothermal wells (largely for electricity generation). To prevent this valuable energy source from being ruled out, particularly in the massive granites in the south-west and north-east of England, the government should clearly distinguish geothermal hydraulic fracturing from traditional oil and gas hydraulic fracturing—which carries significantly greater risks to the environment—and articulate geothermal's unique economic and environmental benefits.
- **Implement a national communications and awareness campaign:** To build broad public support, a national geothermal awareness initiative should be launched to make clear that geothermal energy can be a mainstream, domestic, clean energy source within the UK's wider energy security and economic development strategy. Such a campaign could do the following:

    - Highlight geothermal's role in reducing heating bills and providing stable, local energy year-round.
    - Clarify that hydraulic fracturing for geothermal has far greater benefits than hydraulic fracturing for traditional oil and gas, as it is a renewable and low-impact technology that can strengthen local energy resilience.
    - Emphasise the UK's strong environmental safeguards currently in place.
    - Explain how geothermal deployments in Southampton, Cornwall, and university-led demonstration sites created tangible local benefits.
    - Partner with local councils, educational institutions, and media outlets to share accurate and accessible information.
    - Support citizen engagement programs, school initiatives, and skills campaigns to build awareness of geothermal as a future jobs and innovation sector.

Department for Energy Security and Net Zero, local authorities, and industry associations

CONCLUSION

The UK is committed to meeting the challenges of energy security. Geothermal energy can make a significant contribution, but the nation's vast resources have been left almost entirely undeveloped. The government has an opportunity to kick-start a rapid expansion of the technology by putting in place a suite of supportive policies. These policies include easy and inexpensive changes in regulation to more costly but still economically positive actions such as capital grants.

The reward could be a new and expanding renewable energy sector that provides secure, low-carbon heat and electricity. The United Kingdom would take its place alongside other European nations making use of their sustainable geothermal resources.

CHAPTER REFERENCES

1 Coal Authority & Mining Remediation Authority. (2025, May 27). *Mine water heat*. Government of the United Kingdom. https://www.gov.uk/government/collections/mine-water-heat

2 UK Research and Innovation. (n.d.). *Geothermal Energy from Mines and Solar-Geothermal heat (GEMS)*. https://gtr.ukri.org/project/0B3478B7-1D87-427B-98BE-A7FC755592E7

3 Department for Energy Security and Net Zero. (2025, February 25). *Rising energy bills: What you need to know*. Government of the United Kingdom. https://www.gov.uk/government/news/rising-energy-bills-what-you-need-to-know

4 BGS Press. (2023, July 17). *New report assesses deep geothermal energy in the UK*. BGS News. https://www.bgs.ac.uk/news/new-report-assesses-deep-geothermal-energy-in-the-uk/

5 Environmental Programmes. (2009). *Renewables Obligation: Annual report 2007–2008*. Ofgem. https://www.ofgem.gov.uk/sites/default/files/docs/2009/03/annual-report-2007-08_version-4_0.pdf

6 Department for Energy and Climate Change & Huhne, C. (2010, September 15). *Search for hot rocks heats up with £1m fund*. Government of the United Kingdom. https://www.gov.uk/government/news/search-for-hot-rocks-heats-up-with-1m-fund

7 International Energy Agency (IEA). (2019, October 24). *Renewable Heat Incentive (RHI) for domestic and non-domestic generators*. https://www.iea.org/policies/5060-renewable-heat-incentive-rhi-for-domestic-and-non-domestic-generators

8 Department for Business, Energy and Industrial Strategy & Callanan, L. (2022, December 20). *First Green Heat Network Fund awards for cutting-edge low carbon energy projects* [Press release]. Government of the United Kingdom. https://www.gov.uk/government/news/first-green-heat-network-fund-awards-for-cutting-edge-low-carbon-energy-projects

9 KFW. (2025, December 18). *New promotion of deep geothermal plants for municipal heat supply* [Press release]. https://www.kfw.de/About-KfW/Newsroom/Latest-News/Pressemitteilungen-Details_875520.html

10 Amer, M. Y., Salem, S. K., Farahat, M. S., & Salem, A. M. (2025). Reducing drilling cost of geothermal wells by optimizing drilling operations: Cost effective study. *Unconventional Resources*, *7*, 100196. https://www.sciencedirect.com/science/article/pii/S2666519025000627

11 Bielby, S. (2024, December 19). *New study confirms heat pumps vastly outperform traditional heating systems*. Ground Source Heat Pump Association. https://gshpa.site-ym.com/news/689669/New-Study-Confirms-Heat-Pumps-Vastly-Outperform-Traditional-Heating-Systems.htm

12 Salhein, K., Salheen, S. A., Annekaa, A. M., Hawsawi, M., Alhawsawi, E. Y., Kobus, C. J., & Zohdy, M. (2025). A comprehensive review of geothermal heat pump systems. *Processes*, *13*(7), 2141. https://www.mdpi.com/2227-9717/13/7/2142

13 McCay, A. T., Feliks, M. E. J., & Roberts, J. J. (2019). Life cycle assessment of the carbon intensity of deep geothermal heat systems: A case study from Scotland. *Science of the Total Environment*, *685*, 208–219. https://www.sciencedirect.com/science/article/pii/S0048969719323587

14 Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS One*, *17*(7), e0270155. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0270155

15 Platform Geothermie. (2018). *Master plan geothermal energy in the Netherlands: A broad foundation for sustainable heat supply*. https://www.geothermie.nl/images/bestanden/Masterplan_Aardwarmte_in_Nederland_ENG.pdf

16 Department for Energy Security and Net Zero, Ministry of Defence, Miliband, E., & Pollard, L. (2025, November 24). *Taskforce calls for radical reset of nuclear regulation in the UK*. Government of the United Kingdom. https://www.gov.uk/government/news/taskforce-calls-for-radical-reset-of-nuclear-regulation-in-uk

17 Fingleton, J. (2025). *Nuclear regulatory review 2025*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/692080f75c394e481336ab89/nuclear-regulatory-review-2025.pdf

18 Department for Energy Security and Net Zero. (2025, July 15). *Further reforms to the CfD scheme for AR7: Government response to policy proposals*. Government of the United Kingdom. https://www.gov.uk/government/consultations/further-reforms-to-the-contracts-for-difference-scheme-for-allocation-round-7/outcome/further-reforms-to-the-cfd-scheme-for-ar7-government-response-to-policy-proposals-published-july-2025-accessible-webpage

19 Fleuchaus, P., Godschalk, B., Stober, I., & Blum, P. (2018). Worldwide application of aquifer thermal energy storage–A review. *Renewable and Sustainable Energy Reviews*, *94*, 861–876. https://www.sciencedirect.com/science/article/abs/pii/S1364032118304933?

20 Stemmle, R., Hanna, R., Menberg, K., Alberg Østergaard, P., Jackson, M., Staffell, I., & Blum, P. (2025). Policies for aquifer thermal energy storage: International comparison, barriers and recommendations. *Clean Technologies and Environmental Policy*, *27*, 1455–1478. https://link.springer.com/article/10.1007/s10098-024-02892-1

21 Netherlands Enterprise Agency. (2025, October 20). *Energy performance–BENG*. Government of the Netherlands. https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/beng

22 Netherlands Energy Agency. (2025, December 30). *Environmental and energy list 2025*. Government of the Netherlands. https://www.rvo.nl/milieu-energielijst-2025

23 Netherlands Energy Agency. (2025). *Energy Investment Deduction (EIA), Commissioned by the Ministry of Climate and Sustainable Growth*. https://www.rvo.nl/sites/default/files/2025-01/Brochure-EIA-Energielijst2025.pdf

24 Netherlands Energy Agency, *Environmental and energy list 2025*, 2025.

25 Ministry of Infrastructure and the Environment. (2013, March 29). Environmental Management Activities Decree. *Official Gazette of the Kingdom of the Netherlands*, *112*. https://zoek.officielebekendmakingen.nl/stb-2013-112.html

26 Information Point for the Living Environment (IPLO). (n.d.). *Short and comprehensive preparation procedure*. Government of the Netherlands. https://iplo.nl/regelgeving/overzicht-procedures/korte-uitgebreide-voorbereidingsprocedure/

27 Netherlands Energy Agency. (n.d.). *WKO-bodemenergietool*. Government of the Netherlands. https://wkotool.nl/?page=Bodemenergietool

28 Netherlands Energy Agency. (2020, July 16). *Policy on geothermal energy and geothermal energy*. Government of the Netherlands. https://www.rvo.nl/onderwerpen/bodemenergie-aardwarmte/beleid

29 Department for Energy Security and Net Zero. (2025, December 16). *Contracts for difference*. Government of the United Kingdom. https://www.gov.uk/government/collections/contracts-for-difference

30 Schmidlé-Bloch, V. (2021). *GEORISK–Feedback webinar*. French Agency for the Ecological Transition. https://www.georisk-project.eu/wp-content/uploads/2021/09/6-FGGF-GEODEEP-VF.pdf

31 European Geothermal Energy Council & Well Engineering Partners. (n.d.). *Geothermal lessons from Germany, Denmark and France for the Dutch market*. https://www.connaissancedesenergies.org/sites/connaissancedesenergies.org/files/pdf-actualites/Report_Geothermal-lessons-from-Germany-Denmark-and-France-for-the-Dutch-Market_Printing.pdf

32 Federal Ministry for Economic Affairs and Energy. (2025, August 22). *Geothermal energy expansion is being accelerated: New law has been introduced*. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Artikel/Energie/geothermie-ausbau-wird-beschleunigt-neues-gesetz-auf-den-weg-gebracht.html

33 Keller, Y. (2025, December 19). *Munich Re and KfW launch state-based cover for geothermal drilling*. Beinsure. https://beinsure.com/news/munich-re-kfw-launch-state-backed-cover/

34 Department for Energy Security and Net Zero. (2024, July 25). *UK heat networks: Market overview*. Government of the United Kingdom. https://www.gov.uk/government/publications/uk-heat-networks-market-overview/uk-heat-networks-market-overview-accessible-webpage

35 Department for Energy Security and Net Zero, 2024.

36 Government of the United Kingdom. (2023). *Energy Act 2023*. https://www.legislation.gov.uk/ukpga/2023/52/notes/division/13/index.htm

37 Department for Energy Security and Net Zero & Department for Business, Energy and Industrial Strategy. (2023, September 1). *Energy Security Bill contextual note: Heat network zoning and the planning system*. Government of the United Kingdom. https://www.gov.uk/government/publications/energy-security-bill-factsheets/energy-security-bill-contextual-note-heat-network-zoning-and-the-planning-system

38 Department for Energy Security and Net Zero & Fahnbulleh, M. (2024, October 25). *Six towns and cities to pilot clean heating innovation* [Press release]. Government of the United Kingdom. https://www.gov.uk/government/news/six-towns-and-cities-to-pilot-clean-heating-innovation

39 Cabinet Office. (2025, January 7). *Public bodies*. Government of the United Kingdom. https://www.gov.uk/guidance/public-bodies-reform#arms-length-bodies

40 Scottish Renewables & Renewable UK. (n.d.). *Community benefit in action: Case studies from the onshore wind sector*. https://www.renewableuk.com/media/pzhf5bcj/community_benefit_in_action-_case_studies_from_the_onshore_wind_industry.pdf

41 Milligan, G., et al. (2016). *Hill of Banchory geothermal energy project feasibility study report*. Scottish Government. https://eprints.gla.ac.uk/118526/

42 Geothermal Transition Network. (2025, March 11). *NHS Grampian exploring geothermal to heat public buildings*. https://geothermaltransition.com/news/europe/nhs-grampian-exploring-geothermal-to-heat-public-buildings

43 University of Aberdeen. (2025, December 9). *£1 investment in geothermal pilot to unlock heat beneath our feet*. https://www.abdn.ac.uk/news/24918/

44 Scottish Enterprise. (2025). *Unlocking the economic potential of minewater geothermal in Scotland*. https://www.scottish-enterprise.com/insights-and-events/research-evaluation-and-insight/2025/unlocking-the-economic-potential-of-minewater-geothermal-in-scotland

45 UK Geoenergy Observatories. (n.d.). *Glasgow Observatory*. British Geological Survey. https://www.ukgeos.ac.uk/glasgow-observatory

46 Mining Remediation Authority. (2025, May 27). *Landmark mine water heat scheme goes live in Wales* [Press release]. Government of the United Kingdom. https://www.gov.uk/government/news/landmark-mine-water-heat-scheme-goes-live-in-wales

47 Department for the Economy & GeoEnergy NI. (2023). *Unearthing the heat beneath our feet*. https://geoenergyni.org/wp-content/uploads/2023/09/3033-GeoThermal-GeoEnergy-NI-A4-210x297mm-Booklet-D10.pdf

Chapter 6

Who Owns the Heat? Navigating Subsurface Rights in the United Kingdom's Legal and Regulatory System

Ben Thompson, Rachael Coffey, and David Horan, Sidley Austin

There is no obvious national legal framework in place for the ownership, licensing, and management of geothermal heat in the UK. Geothermal projects are in various states of development across the country, but reaching the scale outlined in this report will require a clearer path forward. Luckily, with existing laws and regulations as precedent, improved government focus on geothermal would create that clarity and enable the nation to scale the use of this resource.

With granite deposits, sedimentary basins, and thousands of abandoned mines, the United Kingdom is well suited to make geothermal a cornerstone of its transition to a clean energy future. The resources, technology, and infrastructure that could make the UK a leader in harnessing the Earth's heat for power securely and cleanly are already available.

To build a robust geothermal industry, all stakeholders—including policymakers and developers—must have an understanding of the laws and regulations that would govern the industry: What laws and systems could be considered precedents? What is missing for a legal framework? And what needs to be implemented for geothermal to have the legal and regulatory certainty to scale?

More specifically, with geothermal in mind, the following questions need answers: Who owns the surface land needed to access the underground resources? Who owns the underground resources needed to produce geothermal energy? What laws govern the use of the underground resources that are necessary for geothermal development? And, in the United Kingdom, are geothermal resources established as minerals or not? (This question is important because the mining, mineral extraction, and oil and gas industries offer a precedent for the use of minerals.)

In a perfect world, the answers to these questions would be clear so that public and private entities can access and use the subsurface heat without confusion. And in some parts of the UK, questions around land, surface, and subsurface ownership—and therefore the leasing or severing of resources—are relatively simple to answer.

On the other hand, the governing of land use is very local for the most part. The British Geological Survey (BGS) points out that the legal framework for land-use planning "is largely provided by town and country planning legislation."[1] That means governing systems can be different in different places. On top of that fact, there is no definitive answer to the question of whether or not geothermal resources count as minerals. Unlike other resources such as groundwater or gas, geothermal energy is not currently recognised by law as a natural resource in the United Kingdom. In other words, because there has not been a lot of development of geothermal in the UK so far, the legal and regulatory framework for geothermal energy development remains underdeveloped.

Specific recommendations for developing a legal framework and supporting a robust geothermal industry can be found in Chapter 5. To provide a sense of the precedents and possibilities for building clarity around an industry, this chapter looks at what legal and regulatory structures exist; what agencies and entities currently govern subsurface land use and development; and, in particular, the laws and regulations governing the mining and oil and gas extraction industries (because of these industries' similarities with next-generation geothermal). Policymakers might also look to other European countries with developed geothermal energy resources—such as Germany, the Netherlands, or France—for a legal framework.

LAWS AND PRECEDENTS

An important first step in developing geothermal energy is to clarify who owns the heat in the Earth's subsurface. Because of the transfer of certain powers from the UK Parliament to regional governments, however, not all parts of the UK are governed the same way, which can complicate geothermal endeavours.

The basic principle in England and Wales is that the owner of a surface estate is presumed to own everything up to the sky and down to the centre of the Earth. This principle was reaffirmed in the 2010 UK Supreme Court decision of *Star Energy Weald Basin Limited v Bocardo SA*. (In this decision, Lord Hope concluded that "the owner of the surface is the owner of the strata beneath it, including the minerals that are to be found there, unless there has been an alienation of it by a conveyance, at common law or by statute to someone else."[2]) However, this idea does not always apply.

There are statutory regimes for certain mining activities. For example, most coal interests are held or licenced by the Mining Remediation Authority, even when those mines extend beneath land owned by others.[3] Landowners typically have air space rights only to certain heights (aircraft flying overhead, for example, would not generally be considered trespassing).[4]

Similarly, the default position is that the owner of a parcel of land also owns the minerals underneath it and is able to grant leases of those minerals. Based on this notion, the practical assumption is that a landowner can also permit others to extract and use subsurface heat and steam, though there is no settled authority or legislation to this point specifically. (This idea can also get complicated depending on the classification of geothermal resources, as discussed in the following section.) This assumption is similar to the right that landowners have to extract water running through or percolating below their land, even though the water itself does not form part of the land (as affirmed by the Court of Appeal in *Stephens v Anglian Water Authority*,[5] though some statutory limitations may apply).

It is worth noting that the rights to mines and minerals can be transferred separately from rights to surface land,[6] and a mining lease can likewise be granted for purposes of working mines and minerals.[7] The extent of the minerals excluded from the land (or included in the lease) will depend on the contractual wording in an original transfer or lease documentation. In most cases, these documents are historic and will not include any reference to geothermal energy, so the entitlement to use these subsurface natural assets will be unclear as a matter of contractual interpretation.

As a result, the use of these resources would depend on the specific context and wording of property transfer documents and leases.[8] If a landowner grants rights for the purposes of extracting geothermal energy from the subsurface, then it is prudent for the documentation to be clearly drafted to permit the extraction of heat and any other necessary activities that must take place on the land for the purposes of developing and operating the geothermal plant.

Another practical issue that often arises is that while the Land Registry provides a definitive record of the legal ownership of most surface land in England, this is not always the case for ownership of subsurface mines and minerals, which is often not clear from the public record. The information might be found by inspecting the title deeds, but often there is no definitive answer, and title indemnity insurance is typically obtained where there is doubt about ownership.

DEEP GEOTHERMAL

In 2015, Parliament passed the Infrastructure Act,[9] which established the right to deep exploration (300 metres or more below the surface) in the UK for geothermal energy purposes. But the legislation did not outline any new provisions for accessing the deep-level land, meaning developers would still need to negotiate with the relevant surface landowners (and mineral owners, if they are different) before moving forward with exploration.

Subsurface Geothermal Resources: Minerals or Not?

Today, the state owns or has licenced subsurface rights to (for the most part) oil, gas, coal, gold, and silver. It does not, by default, own other mineral rights in the UK.

The Law of Property Act 1925 clarifies that the term *mines and minerals* in the UK includes "any strata or seam of minerals or substances in or under any land, and powers of working and getting the same."[10] Beyond this clarification, there is no single, codified definition of minerals in English land law.

The BGS says, "In the UK, 'minerals' are defined in town and country planning legislation as 'all substances in, on or under land of a kind ordinarily worked for removal by underground or surface working, except that it does not include peat cut for purposes other than for sale." The BGS adds that minerals are "valuable assets and vital to a modern economy" and that they underpin the manufacturing, construction, and agriculture industries. Additionally, "society enjoys important benefits from their extraction and use through their contribution to wealth creation, infrastructure, housing and consumer needs." Further, the BGS says the overall aim of mineral planning is "to ensure that a steady and adequate supply of minerals remains in place to meet the demands of society at all times."[11]

While none of these definitions make it clear that geothermal energy is treated as a mineral, it could be argued that geothermal resources are—like minerals—valuable assets and vital to a modern economy.

Planning Permission

Today, deep geothermal projects in the UK require navigating a complex web of permits and regulations, most of which were not written with geothermal energy in mind. The process primarily involves local planning authorities, the Environment Agency for environmental permits and the Mining Remediation Authority for access to coal seams. Environmental permits are needed for reinjection or discharge of geothermal water, while planning permission is required from local authorities. Access to coal seams or abandoned coal mine workings necessitates an agreement with the Mining Remediation Authority. The co-production of critical minerals (such as lithium) is increasingly being considered, and while co-production can enhance a project's viability, it might further complicate planning, permitting, and legal aspects.

In the UK, "the legal framework for land-use planning is largely provided by town and country planning legislation. This aims to secure the most efficient and effective use of land in the public interest, and to reconcile the competing needs of development and environmental protection."[12] The steps a public or private entity would need to take to launch a geothermal project could be dependent on, region by region, planning department by planning department.

In other words, local planning authorities are responsible for granting planning permission for a geothermal scheme. Permission from the local planning authority is also required for borehole construction and wellhead development. Additionally, these entities decide whether an Environmental Impact Assessment (EIA) will be required as part of the planning application. In cases that do require an EIA, the applicant must prepare and submit an Environmental Statement that identifies any "significant" (above-ground) environmental effects that a development is likely to cause. Developers must also outline the measures they will take to avoid, prevent, minimise, monitor, and, if possible, offset adverse effects on the environment. Planning submissions need to address ecological impact, transportation, flood risk, pollution of watercourses, and biodiversity net gain, as well as ground movements (induced seismicity) arising from drilling, borehole construction, reservoir development (well testing and production enhancement), and operation of a geothermal scheme. (For more about policies, environmental benefits, and potential impacts, see Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," and Chapter 7, "Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices.")

The EIA regime includes a provision that—while not specific to geothermal—could apply to geothermal drilling. It relates more broadly to energy and infrastructure projects, including thermal power stations and other combustion installations. The provision would apply only to a select set of geothermal energy projects that fall into one of five specific categories set out in the legislation: (i) those that have a heat output of 300 megawatts or more; (ii) those that abstract or discharge of 10 million cubic metres of groundwater or more per year, are in a sensitive area (as defined in the legislation), or have an area of the works exceeding 1 hectare of land; (iii) those where the area of drilling works exceeds 1 hectare or is within 100 metres of controlled water or within a sensitive area; (iv) those that produce or carry electricity or hot water and the area of development exceeds 0.5 hectare or 1 hectare, respectively, or is a sensitive area; and (v) those that form part of an urban development of more than 1 hectare (including more than 150 dwellings) or that are within a sensitive area.[13]

Of course, local planning authorities can ultimately decide whether to approve or refuse geothermal development in the areas they govern. Public consultation is an essential prerequisite for any geothermal development in the UK as well. The opinion of the local community can often have a significant impact on the decision taken by the local authority about whether to grant planning consent for geothermal development. In addition, the Mineral Planning Authorities may prevent development if a proposed development area falls in Minerals Safeguarding Areas—that is, areas where the government has determined that a mineral deposit needs to be safeguarded from non-mineral development. Planning consents may be for a full project, or they could be hybrid consents, in which full consent is issued for early stages (such as site preparation, drilling, and well testing) and outline consent is issued for the subsequent stages. The Health and Safety Executive also needs to be notified about and satisfied with the location of a proposed new geothermal development within a former mining area.

Environmental Permission

Environmental regulators regulate activities that may cause pollution or pose a risk to the environment. Agencies include the Environment Agency, National Resources Wales, Scottish Environment Protection Agency, and the Northern Ireland Environment Agency. Legislation and guidance currently in place, as well as how they are interpreted in relation to geothermal projects, can be confusing for the developer, regulators, and stakeholders. Further consultation between these organisations would help clarify and standardise the process.

For deep geothermal projects, these entities would regulate both water abstractions from and discharges to the environment, as well as the management of naturally occurring radioactive material in areas where such materials are expected to be co-produced with the geothermal water. For England and Wales, regulations usually require a groundwater investigation consent and an abstraction licence for projects that abstract more than 20 cubic metres of groundwater per day. The impoundment of water at the surface only requires consent from the Environment Agency if the volume exceeds 25 million litres. (For more information, see Chapter 7, "Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices.")

WHAT TO DO NEXT: DEVELOP A NATIONAL GEOTHERMAL STRATEGY

Stakeholders have a general consensus that a clearer "route to market" and streamlined legal and regulatory paths are needed to promote the development of the geothermal sector in the UK (see Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential.") In a 2023 review of geothermal energy policy in the UK for the journal *Energy Policy*, McClean and Pedersen describe the UK's current geothermal energy approach as "piecemeal" and call for the establishment of a "regulatory regime" for these resources.[14]

The creation of a national geothermal strategy would therefore represent a major improvement to the current scattered system.

CHAPTER REFERENCES

1 MineralsUK. (n.d.). *Legislation and policy*. British Geological Survey. https://www.bgs.ac.uk/mineralsuk/planning/legislation-and-policy/

2 *Star Energy Weald Basin Limited and another (Respondents) v Bocardo SA (Appellant)* [2010] UKSC 35, paragraph 27. https://www.supremecourt.uk/cases/uksc-2009-0032

3 The licences were originally transferred to the Coal Commission under the Coal Act 1938 in return for compensation.

4 *Lord Bernstein v Skyviews and General Ltd* [1978] QB 479.

5 *Stephens v Anglian Water Authority* [1987] 1 WLR 1381.

6 See *Law of Property Act 1925* s.205(1)(ix), which defines *land* to include "land of any tenure, and mines and minerals, whether or not held apart from the surface, buildings or parts of buildings (whether the division is horizontal, vertical or made in any other way)."

7 See *Law of Property Act 1925* s.205(1)(xiv), which defines a *mining lease* as a lease for mining purposes—that is, the searching for, winning, working, getting, making merchantable, carrying away, or disposing of mines and minerals, or purposes connected therewith, and includes a grant or licence for mining purposes.

8 See *Aldridge Leasehold Law*, Part 3, Chapter 1, Section 3, Subsection 1, and *Earl of Lonsdale v Attorney-General* [1982] 1 WLR 887.

9 See Infrastructure Act 2015, section 43. Note that the act was primarily introduced to support the extraction of shale gas by preventing nearby landowners from obtaining an injunction for trespass of deep-level land. Section 45 of the act also permits regulations that create governing payments with respect to the relevant land, but no such regulations have yet been introduced.

10 *Law of Property Act 1925*, s.205(1)(ix).

11 MineralsUK, n.d.

12 MineralsUK, n.d.

13 Government of the United Kingdom. (2017). *The Town and Country Planning (Environmental Impact Assessment) Regulations 2017*. https://www.legislation.gov.uk/uksi/2017/571/contents

14 McClean, A., & Pedersen, O. W. (2023). The role of regulation in geothermal energy in the UK. *Energy Policy*, *173*, 113378. https://doi.org/10.1016/j.enpol.2022.113378

Chapter 7

Environmental Stewardship in an Energy-Abundant Future: Considerations and Best Practices

Project Innerspace, with contributions from Augusta Grand and Lucy Cotton, Eden Geothermal Ltd

Geothermal energy combines low life cycle greenhouse gas emissions, round-the-clock reliability, and the smallest surface footprint of any renewable energy. Yet there are risks that must be managed. Taking steps to manage these risks will ensure geothermal remains a clean energy option for the United Kingdom.

As the UK looks to develop geothermal energy resources, it faces a challenge: Some stakeholders may be concerned that energy projects—even renewable ones such as geothermal—will affect natural environments. Protecting the natural landscape is important, and care must be taken to limit environmental risks. Most of the focus of this chapter is on deep geothermal electricity; geothermal heat projects present far fewer potential impacts.

Thankfully, it is possible to plan for potential environmental impacts of geothermal exploration and operation, as well as to mitigate harms before they happen. Careful coordination and communication with the public can enable geothermal energy development to proceed safely, with support from communities. As the UK works to move away from fossil fuels and towards more sustainable, domestic forms of energy production, geothermal offers major advantages. It provides clean, firm power and can help decarbonise industrial heat, as well as residential and commercial heating and cooling. Geothermal plants require much less land area for energy production than almost every other energy production source and produce far fewer air and carbon emissions than fossil fuels. Unlike nuclear power, geothermal has no radiation-related risks, and when properly managed and planned for, it can be built and run without significantly disrupting the natural environment.

This chapter identifies the environmental benefits and potential impacts of expanding geothermal energy use in the UK, starting with a summary of possible effects across the timeline of project development. The chapter also looks at two geothermal energy projects in the UK—the Eden Geothermal Project and United Downs—that offer examples for the future development of geothermal systems.

ENVIRONMENTAL BENEFITS OF GEOTHERMAL ENERGY

Reduced CO_2 Emissions

The most obvious environmental benefit of increasing geothermal energy for any nation is a significant decrease in carbon dioxide (CO_2) emissions. The UK's continued dependence on oil and gas for energy and heating needs and the industrial sector's heavy use of oil and gas are major causes of emissions. Greenhouse gas emissions in 2025 amounted to roughly 371 million tonnes of carbon dioxide equivalent.[1] Though emissions have decreased significantly over the past three decades, carbon dioxide still made up around 78% of all emissions in the UK in 2024.[2]

The nation's 2021 Net Zero Strategy set out a plan to reduce greenhouse gas emissions to that level by 2050. The subsequent 2023 Net Zero Growth Plan set a course for reducing emissions by 81% of 1990s levels by 2035.[3] Unfortunately, in July 2024, the UK's independent Climate Change Committee said the UK was not on track to achieve its 2030 targets, and despite significant progress in reducing emissions, only about one-third of the cuts the country would need to make to achieve its goal were backed up with a credible plan. The committee argued for action "across all sectors of the economy, with low-carbon technologies becoming the norm."[4]

The government currently has no targets for geothermal development; however, there are around 30 deep geothermal heating projects in development nationwide, a number of minewater heat and district heating projects underway, and more than a dozen companies that have secured private and public funding for geothermal projects.[5,6] An ambitious heat goal of 15 gigawatts and an electricity goal of between 1.5 gigawatts and 2 gigawatts—as referenced in Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential"—could yield great progress. The National Geothermal Centre has also suggested targets of 10 gigawatts of geothermal heat and 1.5 gigawatts of geothermal electricity by 2050. Achieving these goals would help the country potentially avoid 10 million tonnes of carbon emissions each year—about 3% of the UK's total 2024 emissions.[7,8] A 2023 meta-analysis of hundreds of studies comparing the climate change impacts of

CARBON EMISSIONS OF DIFFERENT ENERGY TECHNOLOGIES

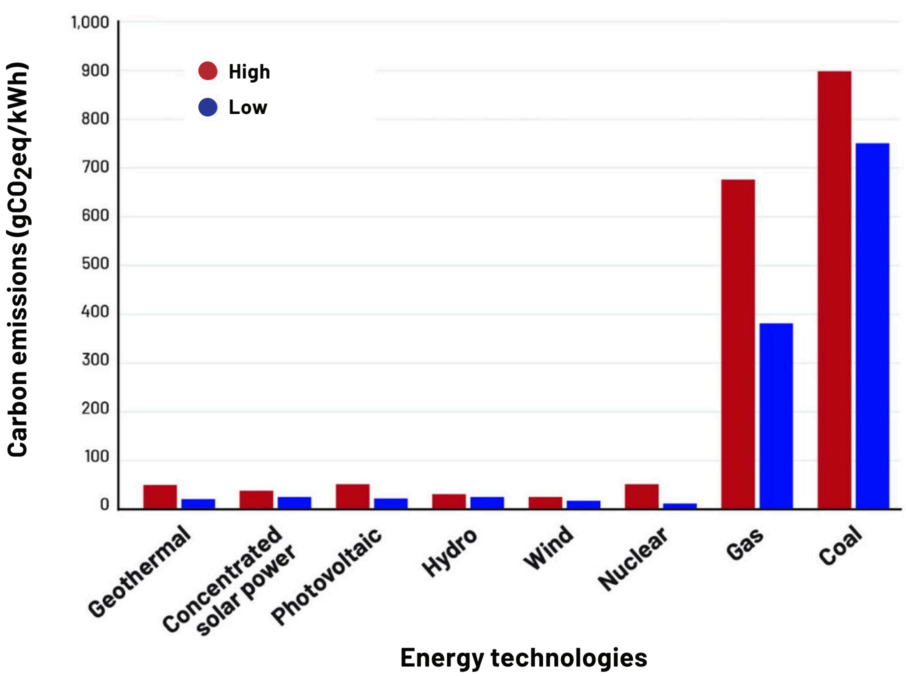
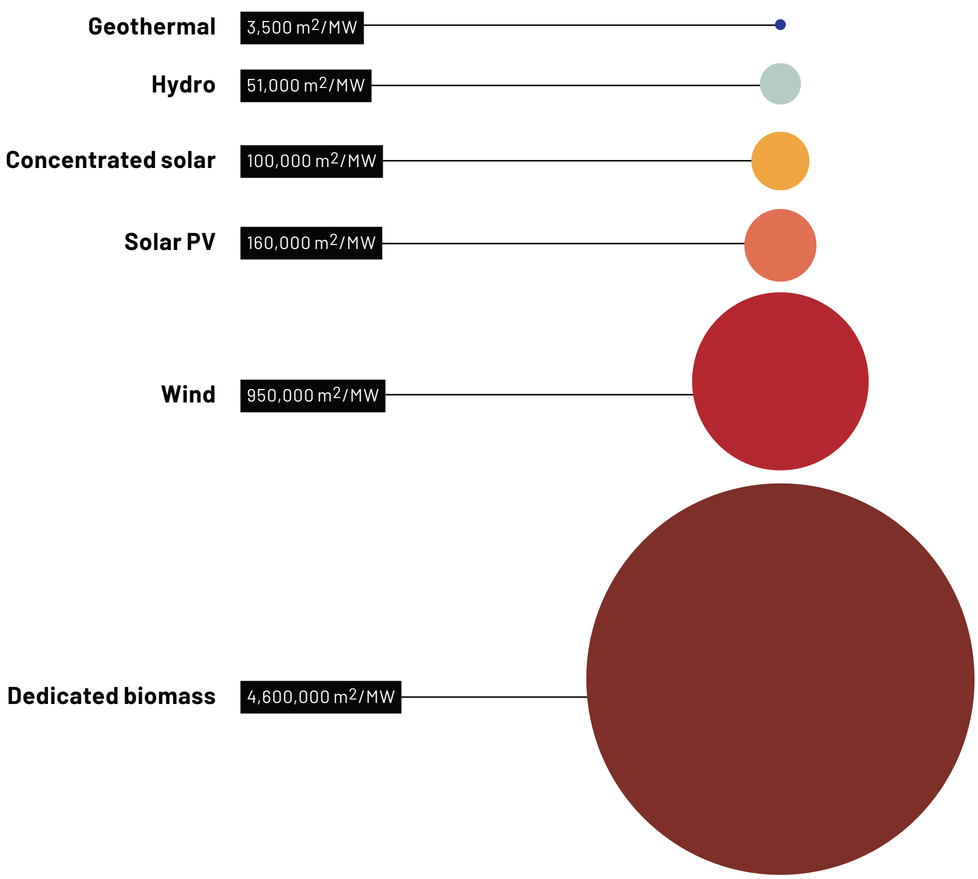


Figure 7.1: Climate impacts of various electricity-generating technologies. Source: Graphs created using figures Guidi, G., Violante, A. C., & De Iuliis, S. (2023). Environmental impact of electricity generation technologies: A comparison between conventional, nuclear, and renewable technologies. *Energies, 16*, 7847.

COMPARING SURFACE FOOTPRINT



Geothermal has the smallest footprint of any renewable energy source

Figure 7.2: The project surface footprint, acre for acre for 1 gigawatt of generating capacity, is smallest for geothermal compared with other renewables. m^2/MW = square metres per megawatt; PV = photovoltaic. Source: Lovering, J., Swain, M., Blomqvist, L., & Hernandez, R. R. (2022). Land-use intensity of electricity production and tomorrow's energy landscape. *PLOS ONE*, *17*(7), e0270155; National Renewable Energy Laboratory (NREL). (2022). *Land use by system technology*.

electricity-generating technologies shows how beneficial the development of geothermal energy can be for enabling the UK to reach its goals related to reducing carbon emissions.[9] The analysis finds that nuclear systems and wind are the technologies that produce the least emissions, followed closely by geothermal, hydropower, photovoltaics, and concentrated solar power. Geothermal performs almost identically with photovoltaics.

Though geothermal power plants have slightly higher CO_2 emissions than solar and wind facilities, they offer a critical advantage: Geothermal plants have a much higher capacity factor. Geothermal plants operate almost continuously, with capacity factors of between 70% and 90%, unlike wind and solar power plants, which generate electricity only when the wind blows or the sun shines. This capacity difference means a 100 megawatt geothermal plant will deliver far more electricity throughout a year than a wind or solar facility of the same size. Because this power is available at all times, its contribution to decarbonisation is more valuable.

Improved Air Quality

Since 1970, the UK has seen significant reductions in harmful emissions affecting air quality due to the end of coal as the dominant fuel for electricity production, ever-tightening regulations around the emissions from road transport, and a shift of some industries overseas.[10] Progress has been substantial, and it continues despite the UK leaving the European Union, where much of the regulation was initiated. Geothermal energy offers a clear advantage in this context due to its minimal emissions during operation. For direct-heat projects, geothermal produces zero emissions at the point of use—an important advantage for heat projects in urban areas and sensitive locations such as hospitals.

Limited Land Use

One of geothermal energy's major advantages over other energy sources is that it uses the smallest land area of any renewable energy source. Geothermal operations also use

WILDFLOWERS AT EDEN GEOTHERMAL PROJECT SITE

Figure 7.3: Wildflower mix planted over the heat main at the Eden Geothermal project site in Cornwall. Source: Image provided by Eden Geothermal, 2023.

the smallest land area of any renewable energy source. Geothermal electricity plants typically use only 2.25% of the land that solar requires, 0.38% of the land needed for onshore wind, and 0.078% of the land needed by electricity plants that burn biomass for fuel (see **Figure 7.2**).

Deep geothermal heat-only projects for industrial or institutional use are even more land efficient and can be retrofitted into urban areas. Many complexes large enough to warrant deep geothermal heating already have access to the land area needed for development and drilling right outside in car parks or brownfields. This is one clear benefit of the technology: Less land is disrupted and less habitat is disturbed than occurs with most other energy sources.

Creation of Additional Wildlife Habitats

In some areas, geothermal power plants have created additional habitats for wildlife. At the Eden Project in Cornwall, project managers have made improvements in species-rich grassland and wildflowers, as trenches were sowed with a diverse seed mix. Ducks, geese, house martins, willow warblers, and grey wagtails all nest there, and foxes and deer are often present at the site.

Eden Geothermal staff also protected an oak and willow woodland area in the centre of the drilling site and retained hedge lines to support biodiversity. During installation of the heat pipeline, they created hibernacula for pollinators. Topsoil trenches were also reinstated and seeded with wildflower mix and topsoil bunds to provide suitable habitats for insects and burrowing bees. Natural stone gabions—rather than concrete pillars—were used to support the above-ground sections of pipe. During drilling, the site was monitored for noise, and the loudest sound recorded was the dawn chorus of birds in the hedge.

As this chapter makes clear, the potential benefits of geothermal energy are plentiful. But scaling geothermal across the UK will also present environmental and community concerns. Next, we consider some potential challenges.

ENVIRONMENTAL CONSIDERATIONS DURING GEOTHERMAL DEVELOPMENT AND CONSTRUCTION

Geothermal energy has numerous benefits, yet there are still some environmental considerations to account for in each stage of a plant's development: exploration to find and characterise the potential of the heat resources in the ground; construction when wells are drilled and cemented and the plant is built; and ongoing operations (addressed later in this chapter). These concerns can be properly mitigated with oversight and management.

When comparing geothermal to other energy technologies, life cycle assessments (LCAs) can provide an understanding of the benefits or trade-offs. An LCA quantifies the environmental impacts of technologies, products, and services throughout the life cycle of a power production plant, from cradle to grave. The standardised methodology enables decision-makers to compare technologies more clearly. The impacts are assessed across several dimensions, such as climate, toxicity, water resource depletion, land use, the creation of ionising radiation, and mineral and fossil resource depletion.

The first step when conducting an LCA is to consider all of the inputs into a system. These inputs are highly site specific, as the choices of well depth, drilling system, casing choice, and generation systems all influence the final inventory (see **Figure 7.4**).

In Cornwall, a preconstruction LCA was conducted at the United Downs Deep Geothermal Power project,[11] which is intended to become the UK's first geothermal electricity plant as of the writing of this report. Some of the takeaways from the study are discussed in further detail later in this chapter.

Geological Explorations

Many geothermal exploration techniques are mostly non-invasive and observational. For example, sampling methods occasionally involve the need to access sensitive areas, but environmental impacts from these activities are largely trivial. Some exploration methods, however, do have a larger effect.[12]

Most **exploration surveys** use existing road and infrastructure networks to save costs, resulting in little habitat loss or vegetation removal. When new infrastructure must be created, developers should take care to minimise environmental impacts.

During the exploration phase, **seismic exploration** involves generating seismic waves at the surface through rapid ground displacement. Active seismic surveys often compress soil or rock at the surface with an air gun or a seismic vibrator.[13] Though this method creates noise and disturbs soil and wildlife, it is temporary and usually does not require excavation or result in any lasting impacts.

For assessing **granite resources**, airborne geophysical surveys offer a non-intrusive exploration method that involves flying sensitive instruments over the ground to assess the subsurface without the need to disturb wildlife, clear vegetation, or build access roads. These surveys leave no permanent trace on the land and deliver high-resolution data for targeting granite-hosted geothermal resources. Because airborne campaigns rely almost entirely on the aircraft platform and leave no lasting footprint on the land, they offer an efficient, low-impact way to refine subsurface models and pinpoint the best drill targets in granite terrains.

There is, however, no replacement for **exploration boreholes** when obtaining the ultimate proof of concept

SAMPLE INVENTORY OF LCA INPUTS

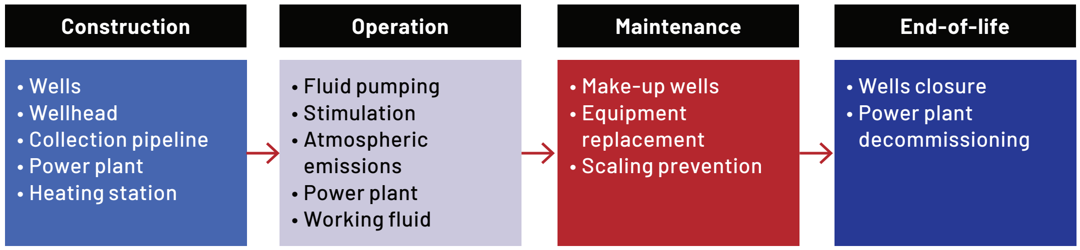


Figure 7.4: Sample inventory of LCA inputs. Source: authors.

and confirming the reservoir properties of a proposed geothermal project. Exploration boreholes require drilling small-diameter holes, much like those used in the exploration drilling that is typical in mining projects. In deep geothermal projects, these boreholes can range from hundreds of metres to a few thousand metres, and they are used to measure subsurface temperatures and collect rock cores to obtain permeability values (either porosity from the reservoir or permeability from fracture networks).

For boreholes, land disturbance is confined to a drill site (or pad) of a few hundred square metres, a space in which vegetation may be cleared and temporary access tracks constructed. As with development drilling, the process generates rock fragments and mud (on a much smaller scale) that are managed on-site or removed per environmental regulations. Although noise, vehicle traffic, and soil displacement occur during drilling, the level of sound generated is small and the duration short-lived, and sites can be reinstated once the borehole is complete. Any abandoned boreholes are safely decommissioned, capped, or repurposed for monitoring throughout the lifespan of the project, so there is minimal lasting impact on land use.

Exploration for new geothermal sites does not produce any other environmental disturbances. The only atmospheric emissions during this stage come from vehicles accessing the site. (In a typical geothermal power plant, any emissions associated with exploration account for only 1% of total life cycle emissions.[14]) Few, if any, issues with surface water contamination arise during this phase.

ENVIRONMENTAL IMPACTS OF CONSTRUCTION

Much of the life cycle impact of geothermal plants occurs due to their construction, which is dominated by the use of diesel for drilling and steel for casing. In the UK, drilling activities are regulated under the Borehole Sites and Operations Regulations 1995, which provide a comprehensive framework for well control, emergency response, and operational safety. Health and safety standards are non-negotiable, drawing on decades of experience from the UK's oil and gas industry, which sets a high bar for safe operations.

Lessons Learned: The Eden Project

The Eden site is a large, flat brownfield that had been used to dispose of building waste in the 1980s. The site is surrounded by farmland on three sides. There is a public bridleway along the fourth edge where people walk their dogs and ride horses. In the middle of the site is an area of willow woodland with several fine veteran oaks. Eden preserved this part of the site, which has become an oasis with deer, foxes, ducks, geese, grey wagtails, green woodpeckers, and blackcaps. The rich mix of wildflowers planted also helped create a welcome environment for insects.

As is standard in the UK, several environmental assessments were conducted before developers applied for planning permission. The assessments included a study of seismic risk and ecological surveys for vegetation, invertebrates, bryophytes, ferns, birds, bats, amphibians, reptiles, mammals, and dormice; they also surveyed for possible noise impact and water resources impact (including flood risk assessment). Other requirements included a heritage statement, a transport statement, landscape and visual assessments, an air quality assessment, ground conditions and hydrogeology impact assessments, tree surveys, and an arboricultural statement.

The ecological surveys showed that a single male dormouse (named Norman by the team) had made his home at the development site. Dormice are protected under UK legislation, so the habitat was cleared under a license and a "precautionary working method statement." Dormice hibernate in root balls at ground level, so the trees and shrubs were cut carefully during winter to avoid disturbing Norman. When dormice wake in spring, they leave to find a new home more to their liking. As the site clearance had to be carried out during winter anyway to avoid the bird nesting season, this task only added a few days to the project.

As part of the regulatory process for the Eden project, the Environment Agency (EA) was consulted ahead of drilling activities and provided with detailed information on the proposed drilling programme and methodology. Early and ongoing engagement with the EA helped the project team identify and manage environmental risks.

A formal letter of agreement was issued following this consultation to confirm that the proposed works aligned with environmental safeguards.

Drilling for a new deep geothermal project can be completed within a few months, making disruption fairly minimal. Even so, along with wells, geothermal operators must install pipelines, transmission lines, heat exchangers, turbines, and more. Work must be done with careful consideration of the environment at each site—with the understanding that each site can have different sensitivities. The drilling phase requires particular vigilance to mitigate possible environmental effects, including seismicity. The LCA of the United Downs geothermal project in Cornwall revealed that 88% of the environmental impacts occurred during the construction phase.[15] The assessment also showed that steel (primarily that used for well casings) and diesel used during the drilling process were dominant contributors to all impact categories. Disposal of drilling waste, or cuttings, made up between 10% and 20% of the toxicity categories. The drilling mud, concrete, and spacers used during well drilling, wellhead, and well closure and the steel used for the downhole pump yielded negligible impacts.[16]

Lessons Learned

1. Analysis of the United Downs project found that the use of electricity for drilling, rather than diesel generator sets, can reduce construction impacts. One study reported a close to 15% improvement in climate impact by using grid electricity rather than diesel.[17] At the moment, unfortunately, grid constraints and electricity prices in the UK mean it is not often possible to use electricity. However, certified hydrogenated vegetable oil is now available as a cost-competitive alternative to diesel, which results in as much as 90% lower greenhouse gas emissions and lower emissions of volatile organic compounds and nitrogen oxide.[18]
2. Although steel consumption cannot be reduced without impairing the normal functioning of a geothermal well, it is worth considering whether recycled content within the steel could be increased to offset ore extraction and processing.

Solid Waste Generation

Geothermal drilling produces solid waste through multiple streams. If not properly handled, waste such as maintenance and construction debris, dried drilling-mud residue, obsolete machinery, damaged piping and flow elements, and drilling cement waste could end up in nearby landfills or sit idle at the geothermal site.[19] When handled correctly, this waste does not pose a threat to the environment. Some waste, however—including drilling circulation chemicals, fuels, lubricants, asbestos, and other hazardous materials—must be handled properly and disposed of through more regulated waste streams involving chemical treatment. In the case of the Eden Project, naturally occurring radioactive material was a particular concern. For that reason, no waste left the site without being tested with a Geiger counter, and all cuttings were tested before disposal.

Careful Use of Water

Water use in geothermal projects is typically carefully managed to minimise environmental impact and make the most of available resources. Although drilling fluids are a necessary part of well development, UK projects use water-based and recyclable materials rather than oil-based ones. Shallow exploration and monitoring wells—typically no deeper than 450 metres—require between 50 kilolitres and 85 kilolitres of water (between 13,000 gallons and 22,000 gallons), while deeper engineered geothermal system wells can require more. However, the geothermal industry in the UK is adopting innovative approaches to keep this footprint as small as possible.

A common practice to use water wisely is the reuse and recycling of drilling fluids, which substantially reduces freshwater demand for future drilling operations and also helps ensure the reservoir's longevity. In fact, most plants reinject geothermal fluid back into the reservoir; this approach both limits consumptive use and sustains the resource. Field experience indicates that roughly 90% of injected water is recovered via reinjection, and a best practice is to avoid potable supplies by using nonpotable (brackish or high total dissolved solids) sources instead.[20] When fluid disposal must occur, responsible management ensures that waste is minimised and environmental risks are mitigated.

The Eden Project offers one strong example. The team reduced water use through novel drilling fluid management practices and selected environmentally friendly ingredients such as barite, bentonite, and xanthan gum—substances more commonly found in medicine, cat litter, and food products than in heavy industry. These water-based fluids lower the risk of pollution and simplify cleanup and reuse.

Eden also demonstrated the value of local partnerships. Community groups and small businesses helped collect and repurpose drilling-related materials, transforming plastic waste into new products such as kayaks. This circular approach shows how geothermal developers in the United Kingdom can conserve water, prevent contamination, and foster community innovation—all while advancing a secure, low-carbon energy future.

Atmospheric Pollution

As mentioned, when building a geothermal operation, nearly 90% of the emissions generally come from the construction phase. The drilling process can release gases into the atmosphere, including carbon dioxide, methane, and hydrogen sulfide, among others. In the UK, geothermal drilling operations fall under the same robust environmental and health and safety framework that governs the oil and gas sector, which ensures that any naturally occurring greenhouse gases, such as carbon dioxide or hydrogen sulfide, are managed to the highest standards of environmental protection and worker safety.

Before any drilling begins, the EA is consulted as part of the planning process, and an Environmental Impact Assessment may be considered, depending on the project's scope. Gas monitoring and mitigation are implemented through a layered set of measures.

Liquid Pollution

A recent wide-ranging literature review in the United States found no instances of groundwater contamination caused by geothermal wellbore failures. In fact, no instances of groundwater contamination resulting from geothermal operations were found in general.[21] However, groundwater contamination still remains a significant concern for some stakeholders, so developers should adhere to regulations to mitigate any spills of fuels, additives, and lubricants. The UK regulations around drilling make sure that proper care is taken to prevent spills from happening in the first place, making them an unlikely occurrence. Liquid emissions from the drilling process can be minimal if drilling fluids that circulate in the wellbore are reused. In geothermal operations in the UK and other parts of the world, significant effort is invested to limit spills during drilling.[22] If spills do occur, however, heavy metals from geothermal brine, including carcinogenic arsenic, could cause some pollution,[23] though such incidents are extremely rare around the world.

Lessons Learned

1. Eden Project staff implemented measures to ensure environmental protection and prevent thermal pollution, or damage caused by inadvertent heating of groundwater, during both the construction and drilling phases. During the construction phase, the entire working area was bounded to prevent any harmful or hazardous substances from entering the environment. Further, a 3,000 square metre lagoon was installed to help manage thermal pollution.
2. Downhole, the casing was designed to provide multiple layers of protection to the surrounding environment and any ecosystems that may be present. The casing consisted of three layers of casing down to 300 metres, two layers of casing down to 1,700 metres, and one layer of casing down to 4,000 metres.

Noise Management

Noise typically is not a long-term issue in geothermal activities. That said, it does occur during drilling and operations, so addressing it is important. Noise levels can be as high as 120 dBA—akin to an emergency vehicle siren or jet takeoff—when field workers are perforating a well during deep drilling.[24] This noise is only temporary, and from 900 metres away, it decreases to match ambient noise levels in urban areas (71 dBA–83 dBA). During normal operations, noise levels drop to between 15 dBA and 28 dBA, which matches the average background noise in wilderness areas (20 dBA–30 dBA).[25] If necessary, geothermal operations can employ muffling techniques such as noise shields, exhaust mufflers, and acoustic insulation to reduce noise by up to 40%.[26] **Figure 7.5** shows reported values for various noise sources for comparison.

NOISE LEVELS ACROSS GEOTHERMAL DEVELOPMENT PHASES COMPARED TO ANTHROPOGENIC SOURCES

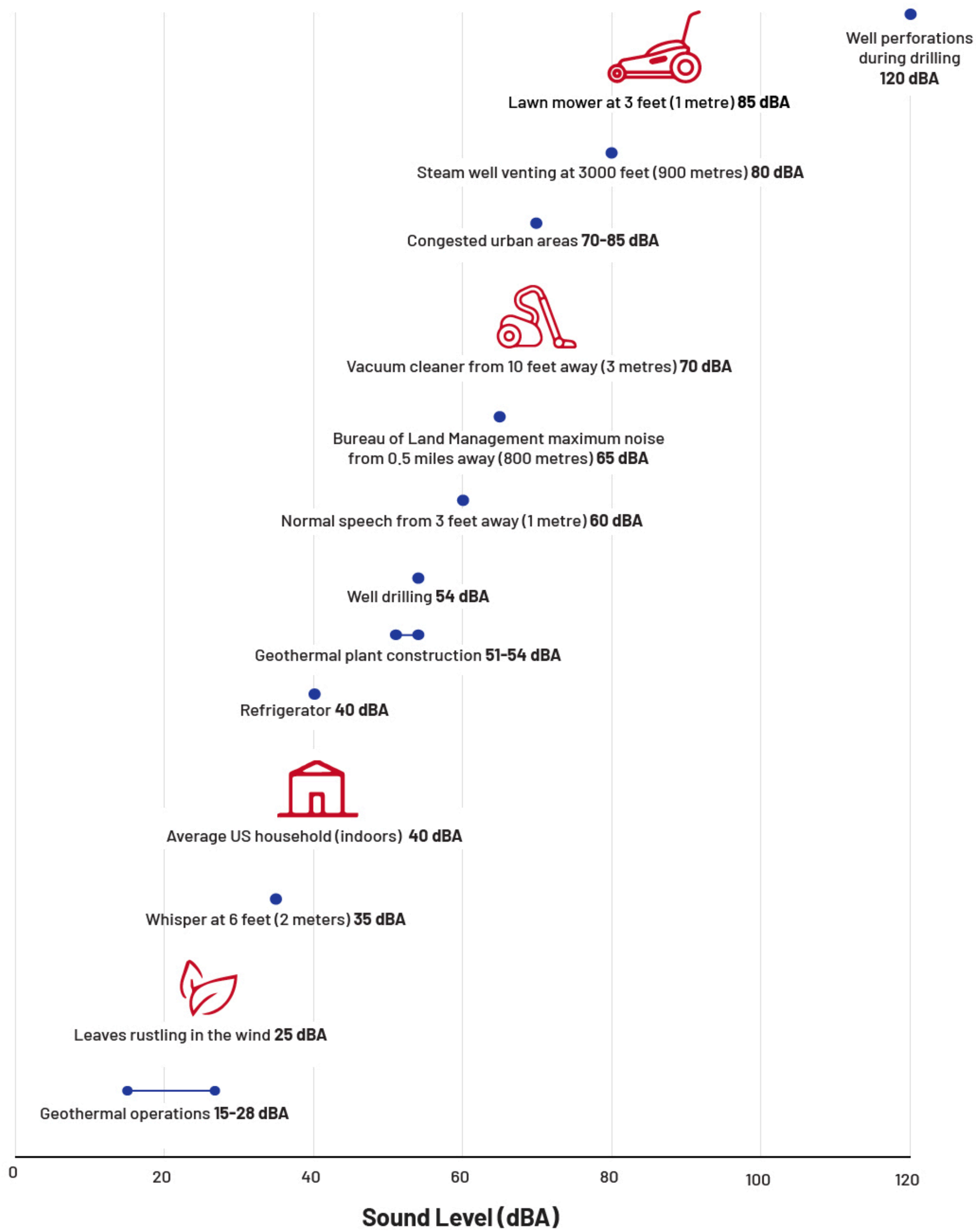


Figure 7.5: Noise levels in geothermal phases comparedwith U.S. anthropogenic sources. Sources: Kagel, A., Bates, D., & Gawell, K. (2005). *A guide to geothermal energy and the environment.* Geothermal Energy Association; Massachusetts Institute of Technology (MIT). (2006). Environmental impacts, attributes, and feasibility criteria. In MIT (Ed.), *The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century* (pp. 8-1–8-20). Massachusetts Institute of Technology; Bryant, M., Starkey, A. H., & Dick-Peddie, W. A. (1980). *Environmental overview for the development of geothermal resources in the State of New Mexico*. New Mexico Department of Energy; Birkle, P., & Merkel, B. (2000). Environmental impact by spill of geothermal fluids at the geothermal field of Los Azufres, Michoacán, Mexico. *Water, Air, and Soil Pollution, 124*, 371–410.

At Eden, noise monitors were installed around the site prior to enabling works, and strict management procedures were put in place in accordance with daytime and nighttime limits.

ENVIRONMENTAL IMPACTS OF OPERATING GEOTHERMAL ENERGY PLANTS

Land Use

As mentioned, geothermal facilities mostly require far less infrastructure than other energy sources, with a typical geothermal energy power plant occupying just 1,500 square metres per megawatt-hour (0.37 acres per megawatt-hour) compared with 40,000 square metres per megawatt-hour (9.9 acres per megawatt-hour) for a coal-fired power plant. (See **Figure 7.2**.) Emerging next-generation geothermal technologies require even less space, such as a single, shallow groundwater circulation well for direct use or a geothermal doublet well for electricity production.

Geothermal facilities require far less infrastructure than other energy sources. A typical geothermal energy power plant uses just 1,500 square metres per megawatt-hour (0.37 acres per megawatt-hour) compared with 40,000 square metres per megawatt-hour (9.9 acres per megawatt-hour) for a coal-fired power plant.

The infrastructure of these geothermal plants includes pipelines, transmission lines, heat exchangers, and turbines, among others. After the drilling rig has gone, periodic access is needed to service equipment and wells using a crane or small workover rig, but again, the footprint of the plant is minimal. (At the Eden Project site, the well pump controller and heat exchanger fit easily into two shipping containers.)

Subsidence

In a geothermal operation, a developer must consider land subsidence, or the possibility that the developed land could sink over time. When pore fluid is removed from the subsurface without reinjection, the stress between soil and rock grains is decreased and the overlying mass compresses deeper layers.

Subsidence often takes place over decades, but it has been seen in multiple geothermal projects around the world, most commonly in porous or pyroclastic reservoirs.[27] Subsidence as high as 6.8 inches per year (17 centimetres) has been seen at Ohaaki in New Zealand; another site in New Zealand, Wairaki, has seen 46 feet (15 metres) of total subsidence over 50 years of operations.[28,29] Subsidence can be mitigated or eliminated by reinjecting fluid into the reservoir.[30] The good news is that nearly all geothermal power plants use reinjection, resulting in very few cases of *extreme* subsidence.[31] This is much less of an issue for geothermal heat projects.

To date, extreme subsidence has not been an issue in the UK, and many projects have been built in granite, which does not suffer from subsidence. (It may be unlikely that a project could get planning permission or an EA agreement for a system that does not reinject fluids.)

Solid Waste Generation

As with drilling, geothermal operations produce solid waste through multiple waste streams. Maintenance debris, obsolete machinery, and other waste can end up in landfills or sit idle at a geothermal site,[32] but when properly disposed of, this waste poses little threat to the environment. As mentioned earlier, some waste must be handled properly and disposed of through more regulated waste streams.

Another form of solid waste generated by geothermal operations is geothermal scale, a solid substance that forms from cooling or depressurising a geothermal fluid. In some geologies, scale formed from fluids with high total dissolved solids can be on the order of several metric tonnes per hour. This scale can be used for other purposes. One study showed that scale, when mostly silica, can be used as an additive in construction when combined with cement, asphalt, lime, and other common building materials.[33] Some sites can extract valuable lithium from geothermal scale for use in the battery industry—another benefit of geothermal development in the race to electrify transport and space heating and cooling.[34] Cornish Lithium, a UK-based geothermal company, is already exploring lithium extraction from geothermal brines in Cornwall, and United Downs is likewise looking to extract lithium at its site. When not used in other applications, solid scale must be transported and disposed of properly.

Water Use

Water use during geothermal operations can vary depending on the type of plant and technology used. As mentioned, engineered geothermal system technology requires the most water (1,900 liters per megawatt-hour) to maintain reservoir pressure and keep fractures open amid losses to the reservoir rock.[35,36,37] Geothermal for electricity generation uses similar amounts of water to natural gas—and far less than coal, nuclear, and concentrated solar power (**Figure 7.6**).

Geothermal for electricity generation uses similar amounts of water to natural gas—and far less than coal, nuclear, and concentrated solar power.

Atmospheric Emissions

In the UK, with its subsurface heat resources between 140°C and 200°C, binary systems with Organic Rankine Cycle generation will be the order of the day. These systems are cooled by air, so they use little water and have no plumes of steam escaping from chimneys. The emissions are dominated by the choice of working fluid: Many are water-glycol hydraulic fluids, so careful consideration is needed to make sure potential impacts are quantified and equipment is regularly maintained to reduce losses.

Deep geothermal systems in the UK—including direct-heat use applications and deep engineered geothermal systems for electricity generation—can be designed as closed systems, keeping the working fluid (whether natural or introduced) entirely contained. Therefore, any potential reservoir-derived gases (such as carbon dioxide, hydrogen sulfide, and methane) remain dissolved or trapped in the closed circuit and do not vent to the surface under normal operations.

Noncondensable gases (NCGs) such as carbon dioxide, hydrogen sulfide, and methane can be present in geothermal fluids and are monitored during drilling operations, but in the UK's hydrothermal and granitic reservoirs, these gases typically amount to less than 1% of the fluid by weight. Field data from UK pilot sites (United Downs and Eden) confirm that trace CO_2 concentrations fall below detection thresholds, and hydrogen sulfide and methane are virtually undetected in surface vents, reflecting the low natural gas content of British subsurface formations.[38]

A recent whole-life carbon assessment for UK deep geothermal schemes found operational greenhouse gas emissions as low as between 5 kilograms and 15 kilograms of carbon dioxide equivalent per megawatt-

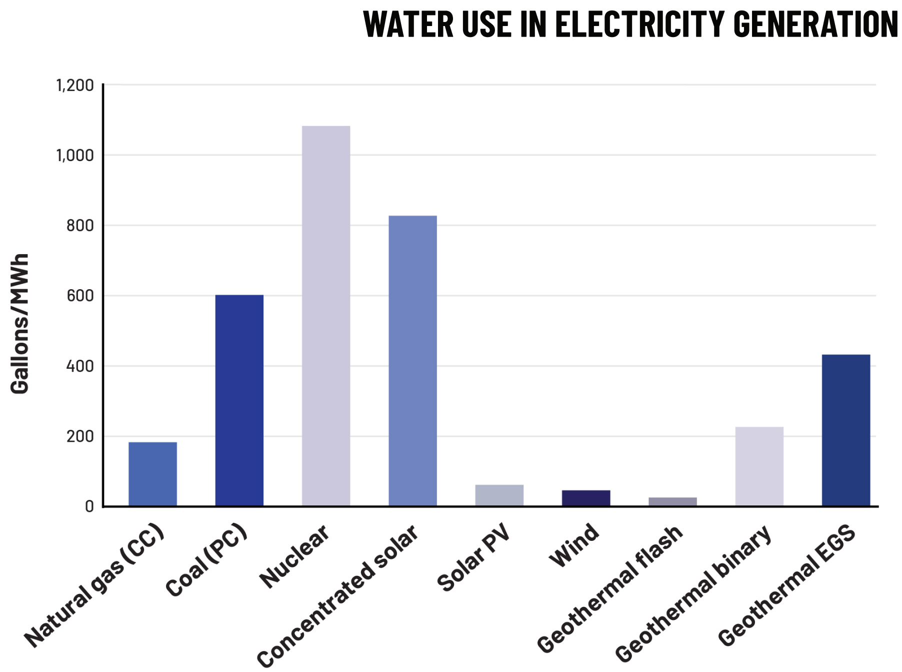


Figure 7.6: Water use in electricity generation by power plant type. CC = combined cycle; EGS = engineered geothermal system; MWh = megawatt-hour; PC = pulverized coal; PV = photovoltaics. Source: Meldrum, J., Nettles-Anderson, S., Heath, G., & Macknick, J. (2013). [Life cycle water use for electricity generation: A review and harmonization of literature estimates](). *Environmental Research Letters, 8*, 015031.

GEOTHERMAL DEVELOPMENT IN THE UK: WHAT ABOUT HYDRAULIC FRACTURING AND INDUCED SEISMICITY?

The vast majority of geothermal projects in the UK will use low- to medium-enthalpy resources for direct-heating applications—ground source heat pumps or closed-loop geothermal installations, for example—which do not require hydraulic fracturing (the application of pressure exceeding that of the subsurface to create or expand cracks in the rock underground). This technique has been successfully used to produce gas and can also be used to increase the efficiency of geothermal energy production. For a small number of projects that extract heat from hard granite, water-based hydraulic fracturing may be employed. These projects carry some known risks, including induced seismicity and fluid migration, but such risks are being well managed through careful site selection, conservative injection pressures, continuous seismic monitoring, well integrity standards, and transparent reporting. UK environmental regulations require multiple layers of well casing and careful fluid management to protect against groundwater contamination. (See Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," for more.)

By applying science-led planning and monitoring, geothermal projects can safely provide clean heat and electricity while minimising environmental impacts. Continuous community engagement, clear communication of safety measures, and real-time monitoring of injection and production ensure that risks remain low and manageable.

Spotlight on Eden Geothermal, Cornwall

During development, Eden Geothermal implemented conservative seismic protocols, monitoring peak ground velocity to ensure community safety. More than 300 micro-seismic events were recorded during drilling, with only two felt at the surface. The team used water-based drilling fluids composed of barite, bentonite, and xanthan gum, as well as multiple containment measures to protect groundwater and minimise waste. They also reused drilling fluids where possible, managed thermal discharge through a dedicated lagoon, and engaged local communities in waste minimisation initiatives, including recycling programs. These measures helped demonstrate that deep geothermal development in the UK can be carried out safely, with minimal environmental impact and transparent communication to the public.

EXAMPLE OF CONTINUOUS SEISMIC MONITORING SYSTEM

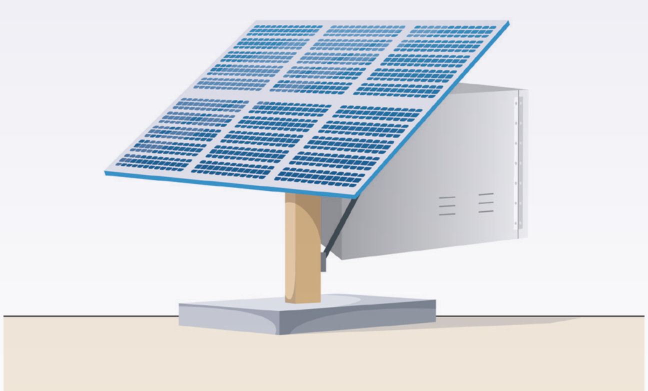


Figure 7.7: Image of a continuous monitoring system. Source: Project InnerSpace.

EXAMPLE OF ENGINEERED GEOTHERMAL SYSTEM (EGS)

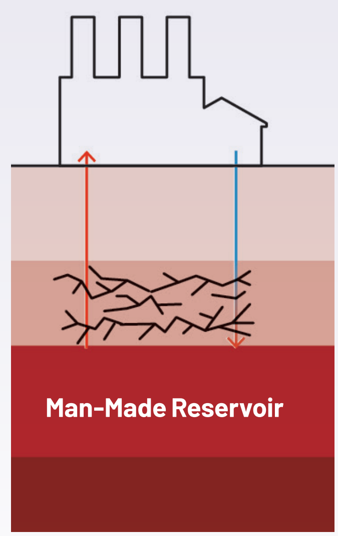


Figure 7.8: Example of engineered geothermal system (EGS). Source: Adapted from D'avack, F., & Omar, M. (2024). Infographic: Next-generation technologies set the scene for accelerated geothermal growth. S&P Global.

hour of thermal output over a 30-year plant life.[39] When reinjection of fluids (and dissolved NCGs) is included, net emissions over centennial time scales effectively match natural background fluxes that would occur in the absence of development.

Residual emissions in UK projects arise only from ancillary equipment: gas-powered pumps, standby generators, drilling rig maintenance, and occasional heavy vehicles. These sources are regulated under the EA in England and corresponding bodies in Scotland, Wales, and Northern Ireland; they must operate within permitted emission limits, with regular monitoring and reporting requirements set by Department for Energy Security and Net Zero guidance.

Liquid Emissions

Liquid emissions during operations can include minor spills of fuels, lubricants, and accessory chemicals. These emissions can generally be prevented through proper employee training and operational practices, but in rare instances, larger accidental spills can occur due to a mechanical failure of the plumbing infrastructure transporting the geothermal fluid. In the UK, the primary use of closed-loop geothermal systems means the risk of accidental spills is extremely low.

Lesson Learned

The management and choice of working fluid in an Organic Rankine Cycle plant can make a big difference. One LCA for a binary geothermal plant in Germany found the greenhouse gas emission estimate was 38.2 grams of carbon dioxide equivalent per kilowatt-hour. The main contributor—at 64%—was the choice of working fluid. Yet another LCA, for a binary power geothermal plant, found that changing to a low-pressure refrigerant as a working fluid resulted in a reduction of the climate impact value from 78 grams to 13.2 grams of carbon dioxide equivalent per kilowatt-hour.

CONCLUSION AND RECOMMENDATIONS

The benefits of geothermal heat use and electricity generation far outweigh the potential impacts. There are a number of examples in the UK and around the world that can help guide developers in establishing geothermal energy plants and systems in a responsible way.

Geothermal does, however, still present risks that need to be minimised. During the planning process of any geothermal project, developers must address any potential significant environmental risks that could occur throughout the lifespan of the development. Although regulations around geothermal are in their infancy in the UK, the following issues must be addressed to gain planning consent.

- **Waste disposal:** The disposal of waste products from the deep drilling operations is an environmental concern. Specialist contractors are brought in to handle disposal, following all regulatory and guideline procedures.
- **Groundwater impact:** Drilling regulations in the UK mean the risk of groundwater contamination is negligible, but operators must take care to follow best practices. Local developers and authorities should ensure that the data are well understood and part of a local communications strategy to reassure the public about the low risks.
- **Traffic and transportation:** The impact on the local network for the transportation of heavy goods vehicles and drilling rigs is always a concern for the surrounding community and must be carefully managed, as all developments are required to do under UK planning laws.
- **Site restoration:** Once a project has reached the end of its life, the developer must restore the site to its former condition.
- **Noise pollution:** Noise can be a concern during various phases of the project. Specific conditions related to noise during enabling works, drilling, and operations need to be managed throughout the development and operational phases. However, drilling and construction phases are short-lived, and noise is generally not an issue over decades of operation.
- **Seismic activity (when relevant):** Any developer dealing with the subsurface has a duty of care to monitor any changes and to mitigate risks that may occur. As a minimum, each project must include the installation of a micro-seismic monitoring network to monitor and control seismicity if hydraulic fracturing is necessary.

Implementing careful environmental protections and mitigating damage will help maximise the benefits of geothermal energy development while avoiding the risks associated with waste disposal, water use, and induced seismicity. By taking necessary steps, the UK can ensure that geothermal—a low-carbon, homegrown energy source—fulfills its potential to be transformative for the nation.

Lesson Learned

At Eden Geothermal, potential environmental risks were addressed publicly. Simple solutions such as sharing an FAQ page on a project's website, providing a contact number for people to call if they were concerned, holding regular meetings with a community liaison group, and having a publicly accessible viewing area helped facilitate communication and build trust with the local residents most affected by the operation. All members of the Eden team were encouraged to engage with the public throughout the duration of the project, and if anyone was at the viewing area, their questions would always be answered by personnel.

CHAPTER REFERENCES

1 Department for Energy Security and Net Zero. (2025, March 27). *2024 UK greenhouse gas emissions, provisional figures*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/67e4060df356a2dc0e39b4cd/2024-provisional-greenhouse-gas-emissions-statistics-statistical-release.pdf

2 Department for Energy Security and Net Zero, 2025.

3 Burnett, N., Stewart, I., & Hewitt, T. (2025). *The UK's plans and progress to reach net zero by 2050*. UK Parliament. https://commonslibrary.parliament.uk/research-briefings/cbp-9888/

4 Climate Change Committee. (2024). *2024 progress report to Parliament*. https://www.theccc.org.uk/publication/progress-in-reducing-emissions-2024-report-to-parliament/

5 Government Office for Science. (2024). *Future of the subsurface: Geothermal energy generation in the UK (annex)*. Government of the United Kingdom. https://www.gov.uk/government/publications/future-of-the-subsurface-report/future-of-the-subsurface-geothermal-energy-generation-in-the-uk-annex

6 Abesser, C., Gonzalez Quiros, A., & Boddy, J. (2023). *The case for deep geothermal energy—unlocking investment at scale in the UK*. Department for Energy Security and Net Zero. https://evidencehub.northeast-ca.gov.uk/downloads/665/nel1435a-geothermal-white-paper-report-v10.pdf&sa=D&source=editors&ust=1768605971414711&usg=AOvVaw2_HrV61zQtprvVCyjv_seh

7 Department for Energy Security and Net Zero, 2025.

8 National Geothermal Centre. (n.d.). *National Geothermal Centre learning zone*. https://ukngc.com/learning-zone/

9 Guidi, G., Violante, A. C., & De Iuliis, S. (2023). Environmental impact of electricity generation technologies: A comparison between conventional, nuclear, and renewable technologies. *Energies*, *16*, 7847. https://doi.org/10.3390/en16237847

10 Mayo, F. (2024). *The UK's journey to a coal power phase-out*. Ember. https://ember-energy.org/latest-insights/the-uks-journey-to-a-coal-power-phase-out

11 Paulillo, A., Cotton, L., Law, R., Striolo, A., & Lettieri, P. (2020). Geothermal energy in the UK: The life-cycle environmental impacts of electricity production from the United Downs Deep Geothermal Power project. *Journal of Cleaner Production*, *249*, 119410. https://doi.org/10.1016/j.jclepro.2019.119410

12 Bryant, M., Starkey, A. H., & Dick-Peddie, W. A. (1980). *Environmental overview for the development of geothermal resources in the State of New Mexico*. New Mexico Department of Energy. https://doi.org/10.2172/6725435

13 Dabros, A., Pyper, M., & Castilla, G. (2018). Seismic lines in the boreal and arctic ecosystems of North America: Environmental impacts, challenges, and opportunities. *Environmental Reviews*, *26*(2), 214–229. https://doi.org/10.1139/er-2017-0080

14 Soltani, M., Kashkooli, F. M., Souri, M., Rafiei, B., Jabarifar, M., Gharali, K., & Nathwani, J. S. (2021). Environmental, economic, and social impacts of geothermal energy systems. *Renewable and Sustainable Energy Reviews*, *140*, 110750. https://doi.org/10.1016/j.rser.2021.110750

15 Paulillo et al., 2020.

16 Paulillo et al., 2020.

17 Pratiwi, A., Ravier, G., & Genter, A. (2018). Life-cycle climate-change impact assessment of enhanced geothermal system plants in the Upper Rhine Valley. *Geothermics*, *75*, 26–39. https://doi.org/10.1016/j.geothermics.2018.03.012

18 Crown Oil. (n.d.). *Benefits of switching to HVO fuel*. https://www.crownoil.co.uk/environment/crown-hvo-fuel-benefits/

19 Were, J. O. (2003). An overview of waste management aspects of geothermal development. *Geothermal Resources Council Transactions*, *27*, 511–516. https://publications.mygeoenergynow.org/grc/1021962.pdf

20 Jacobs, T. (2024, September 16). Fervo and FORGE report breakthrough test results, signaling more progress for enhanced geothermal. *Journal of Petroleum Technology*. https://jpt.spe.org/fervo-and-forge-report-breakthrough-test-results-signaling-more-progress-for-enhanced-geothermal

21 Robins, J. (2021). *The impacts of geothermal operations on groundwater*. 2021 Geothermal Rising Conference. San Diego, CA, United States. https://research-hub.nrel.gov/en/publications/the-impacts-of-geothermal-operations-on-groundwater

22 Kruszewski, M., & Wittig, V. (2018). Review of failure modes in supercritical geothermal drilling projects. *Geothermal Energy*, *6*, Article 28. https://doi.org/10.1186/s40517-018-0113-4

23 Bundschuh, J., & Maity, J. P. (2015). Geothermal arsenic: Occurrence, mobility and environmental implications. *Renewable and Sustainable Energy Reviews*, *42*, 1214–1222. https://doi.org/10.1016/j.rser.2014.10.092

24 Birkle, P., & Merkel, B. (2000). Environmental impact by spill of geothermal fluids at the geothermal field of Los Azufres, Michoacán, Mexico. *Water, Air, and Soil Pollution*, *124*, 371–410. https://doi.org/10.1023/A:1005242824628

25 Bryant et al., 1980.

26 Dobson, P., Dwivedi, D., Millstein, D., Krishnaswamy, N., Garcia, J., & Kiran, M. (2020). Analysis of curtailment at The Geysers geothermal field, California. *Geothermics*, *87*, 101871. https://doi.org/10.1016/j.geothermics.2020.101871

27 Soltani et al., 2021.

28 Birkle & Merkel, 2000.

29 Allis, R., Bromley, C., & Currie, S. (2009). Update on subsidence at the Wairakei–Tauhara geothermal system, New Zealand. *Geothermics*, *38*(1), 169–180. https://doi.org/10.1016/j.geothermics.2008.12.006

30 Kagel, A., Bates, D., & Gawell, K. (2005). *A guide to geothermal energy and the environment*. Geothermal Energy Association. https://www.osti.gov/servlets/purl/897425-q5NDer

31 Soltani et al., 2021.

32 Were, 2003.

33 Lund, J. W., & Boyd, T. L. (1996). Research on the use of waste silica from the Cierro Prieto Geothermal Field, Mexico. *Geothermal Resources Council Transactions*, *20*, 227–233.

34 Dobson, P., Araya, N., Brounce, M., Busse, M. M., Camarillo, M. K., English, L., Humphreys, J., Kalderon-Asael, B., McKibben, M. A., Millstein, D., Nakata, N., O'Sullivan, J., Planavsky, N., Popineau, J., Renaud, T., Riffault, J., Slattery, M., Sonnenthal, E., Spycher, N., … White, M. C. A. (2023). *Characterizing the geothermal lithium resource at the Salton Sea*. Lawrence Berkeley National Laboratory & Office of Energy Efficiency and Renewable Energy. https://doi.org/10.2172/2222403

35 Meldrum, J., Nettles-Anderson, S., Heath, G., & Macknick, J. (2013). Life cycle water use for electricity generation: A review and harmonization of literature estimates. *Environmental Research Letters*, *8*(1), 015031. https://doi.org/10.1088/1748-9326/8/1/015031

36 Harto, C. B., Schroeder, J. N., Horner, R. M., Patton, T. L., Durham, L. A., Murphy, D. J., & Clark, C. E. (2014). *Water use in enhanced geothermal systems (EGS): Geology of U.S. stimulation projects, water costs, and alternative water source policies*. Argonne National Laboratory, Environmental Science Division, Environmental Science Division. https://publications.anl.gov/anlpubs/2014/10/108702.pdf

37 Clark, C. E., Harton, C. B., Schroeder, J. N., Martino, L. E., & Horner, R. M. (2013). *Life cycle water consumption and water resource assessment for utility-scale geothermal systems: An in-depth analysis of historical and forthcoming EGS projects*. Argonne National Laboratory, Environmental Science Division. https://publications.anl.gov/anlpubs/2013/09/101680.pdf

38 Arup. (2025). *Annex C: Department for Energy Security and Net Zero*. https://assets.publishing.service.gov.uk/media/689206db66bdd4490c61098d/Annex_C_-_Levelised_Cost_of_Electricity.pdf

39 McCay, A., Feliks, M. E. J., & Roberts, J. J. (2019). Life cycle assessment of the carbon intensity of deep geothermal heat systems: A case study from Scotland. *Science of the Total Environment*, *685*, 208–219. https://doi.org/10.1016/j.scitotenv.2019.05.311

Chapter 8

Beyond the North Sea: Leveraging the United Kingdom's Oil and Gas Expertise to Advance Geothermal

Iain Martin, Net Zero Technology Centre
John Clegg, Hephae Technologies

By developing a robust geothermal industry, the United Kingdom can convert its oil and gas know-how into a world-class geothermal industry—lowering bills, strengthening energy security, and creating high-value jobs.

The United Kingdom's oil and gas industry is recognised globally for its expertise. Adding geothermal energy to the landscape may offer a powerful way to create jobs and spur economic growth by capitalising on the country's existing knowledge and oil and gas workforce.

The oil and gas sector currently supports close to 200,000 jobs in the UK and contributes £25 billion in economic value annually.[1] But a report from Robert Gordon University forecasts that direct and indirect jobs in the sector will fall to between 57,000 and 71,000 by the early 2030s.[2]

In that same period, geothermal energy production could grow, increasing demand for drilling engineers, geoscientists, plant operators, and complex project managers. Of all of the low-emission technologies available, geothermal and oil and gas have the most overlap in necessary skills and expertise.

The Robert Gordon University report underscores the urgent need for a coordinated transition strategy focused on recruitment, re-skilling, and maintenance of a balanced workforce. The transition must be handled in a way that ensures workers can transfer their knowledge into a thriving, sustainable energy sector. This is particularly true in Scotland, where expertise in exploration, engineering, fabrication, and financial services can apply to geothermal and help ensure the health of the country's economy.

According to the World Bank, geothermal "creates more jobs than natural gas and other utility-scale electricity generation technologies on a per megawatt basis at a comparable cost of electricity," and these jobs are of better quality and longer duration.[3] Multiple studies assume that somewhere between 5 and 10 jobs are created per megawatt of geothermal power, heat, or cooling generated.[4,5,6]

Currently, the most promising near-term opportunities to grow geothermal in the UK are for heat. This potential can be found in small-scale home heating and cooling systems; larger, district-wide heating networks like the Gateshead minewater heating scheme, which uses the water from underground mines to heat community buildings and hundreds of homes; and industrial process heat. These projects require many of the same technical skills and supply chain capacities that underpin the oil and gas sector, including drilling, reservoir characterisation, safety and environmental safeguarding, and project integration. The United Kingdom could adopt a geothermal goal of 15 gigawatts for heat and between 1.5 gigawatts and 2 gigawatts for electricity by 2050, which could yield between 80,000 and 170,000 jobs. This estimate is in line with other projections: The UK's National Geothermal Centre estimates that achieving its suggested goal of 10 gigawatts of geothermal heat and 1.5 gigawatts of electricity could create 50,000 direct jobs and 125,000 indirect jobs.[7] By leveraging its established industrial base, the United Kingdom could cultivate a domestic geothermal heat industry capable of supporting thousands of skilled jobs and contributing to regional economic renewal.

The United Kingdom could adopt a geothermal goal of 15 gigawatts for heat and between 1.5 gigawatts and 2 gigawatts for electricity 2050, which could yield between 80,000 and 170,000 jobs.

Other European nations—including France, Germany, Belgium, and the Netherlands—have shown that geothermal energy projects offer both environmental and social benefits, from greenhouse gas reductions to economic stimulus and job creation. Since 2000, the German geothermal sector has generated €16.7 billion and created 35,000 jobs.[8] This chapter explores how the geothermal and oil and gas industries can work together to be productive partners in the United Kingdom.

OPPORTUNITIES FOR THE UK OIL AND GAS WORKFORCE

The United Kingdom has a range of potential applications for geothermal energy, including ground source heat pumps for residential properties, direct-use thermal networks for communities and businesses, and hot dry rock for electricity generation. While there is considerable overlap, the skill sets needed for each type of project are not identical.

Mines

One of the most obvious opportunities for partnerships between the oil and gas and mining industries and geothermal is the significant number of inactive and closed mines—and capped or decommissioned oil and gas wells—that can be ideal and cost-efficient to use for heat production.

The United Kingdom has about 23,000 deep coal mines and thousands of metal mines,[9] with water in them at temperatures between around 15°C and 25°C. The conditions offer promising opportunities for heat production. A study by the British Geological Survey showed that 25% of properties in the UK are located near or above flooded mines.[10] A number of projects designed to take advantage of this potential are currently in development, and some are already active: In 2023, for example, the Gateshead Energy Company began using a 6 megawatt water source heat pump to pull heat from 150 metres below the surface of abandoned coal mines within the UK's largest minewater network. The project supplies heat to a range of buildings in town, including 350 council buildings. It is projected to save 72,000 tonnes of carbon dioxide over its 40-year lifetime.[11]

Wells

The United Kingdom has about 2,100 onshore wells that were drilled for oil and gas, coal bed methane, or other purposes.[12] Depending on a few factors—such as heat at depth and location—a number of these wells could be repurposed to produce heat or electricity, which could reduce geothermal development costs by avoiding high capital costs associated with drilling. In 2023, CeraPhi,[13] a UK geothermal development company, partnered with the Net Zero Technology Centre,[14] Third Energy, Weatherford, and Genius Energy Lab on the first successful attempt to produce geothermal energy from a repurposed hydrocarbon well in Kirby, Yorkshire. The project in Kirby could provide a model for using other wells in the future.

MOBILISING THE SKILLED OIL AND GAS WORKFORCE

The UK oil and gas industry has many skilled workers who would be crucial to developing geothermal energy projects, including project managers, well-site geologists, drillers, mud engineers, wireline loggers, rig crews, casing engineers, subsurface modelling experts, drilling professionals, corrosion mitigation specialists, and data analysts.[15]

TRANSFERABLE SKILL SETS FROM THE OIL AND GAS INDUSTRY

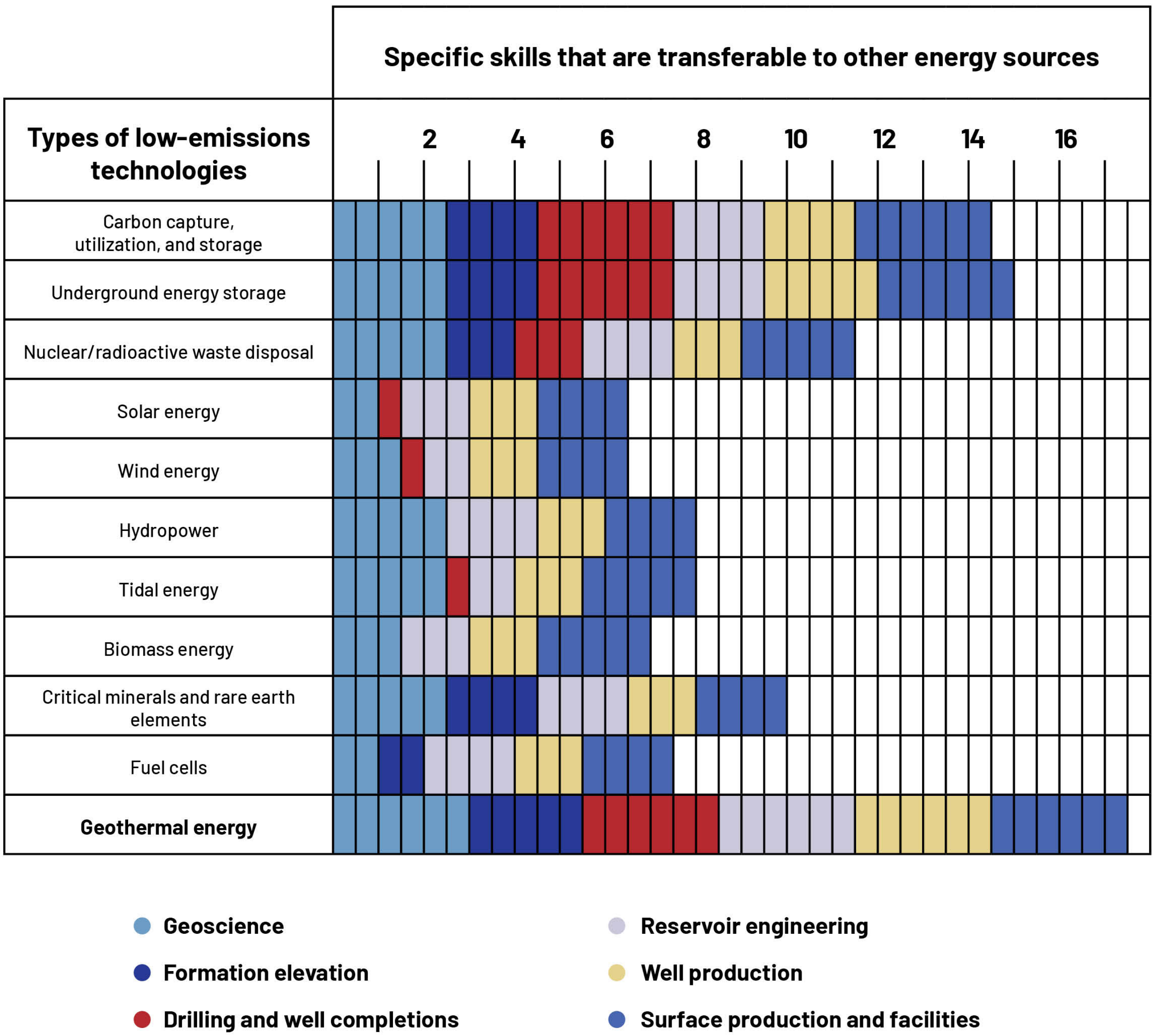
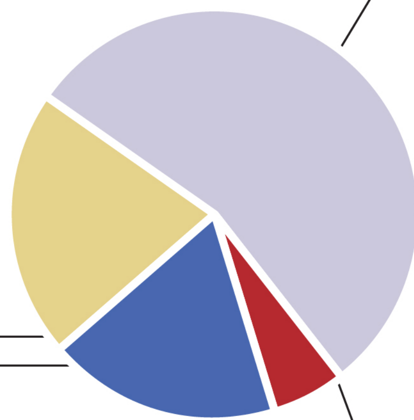


Figure 8.1: Geothermal requires the most skills from the oil and gas industry of all resilient energy production. Source: Tayyib, D., Ekeoma, P. I., Offor, C. P., Adetula, O., Okoroafor, J., Egbe, T. I., & Okoroafor, E. R. (2023). *Oil and gas skills for low-carbon energy technologies*. Society of Petroleum Engineers Annual Technical Conference and Exhibition. San Antonio, TX, United States.

OIL AND GAS SKILLS OVERLAP WITH DEEP GEOTHERMAL PROJECTS

Exploration

- Desk-based surveys
- Remote sensing
- Structural geology field investigations
- Geophysics and geochemistry
- Hydrogeological/geothermal reservoir modelling
- Economics analysis
- Community engagement
- Slim-hole/gradient test drillings
- Seismic hazard assessment and monitoring



Well Field Development and Construction

- Site enabling works
- Drilling
- Hydraulic stimulation (if required)
- Pumping test
- Power and/or heat plant/ energy centre construction
- Steam gathering system and substations, connection to grid (if a power plant)
- Construct infrastructure
- Health and safety
- Community engagement

Planning

- Well design
- Power plant/energy centre
- Health and safety
- Planning application
- Environmental and regulatory approvals
- Community engagement
- Contractor procurement

Operation and Maintenance

- Start-up commissioning
- Operations and monitoring
- Maintenance, refurbishments, workovers, and makeup well drilling (if required)

Direct job for a typical deep geothermal project

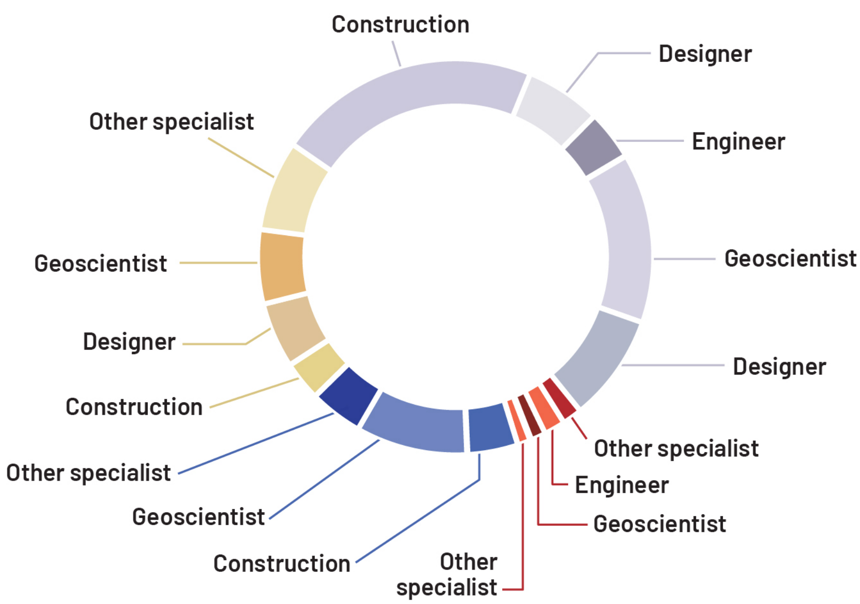


Figure 8.2: Supply chain activities for deep geothermal projects and the considerable overlap with oil and gas workforce skill sets and activities. Source: Adapted from ARUP. (2021). *Deep geothermal energy: Economic decarbonisation opportunities for the United Kingdom*.

SHARES OF GEOTHERMAL INVESTMENTS THAT OVERLAP WITH OIL AND GAS INDUSTRY SKILLS AND EXPERTISE

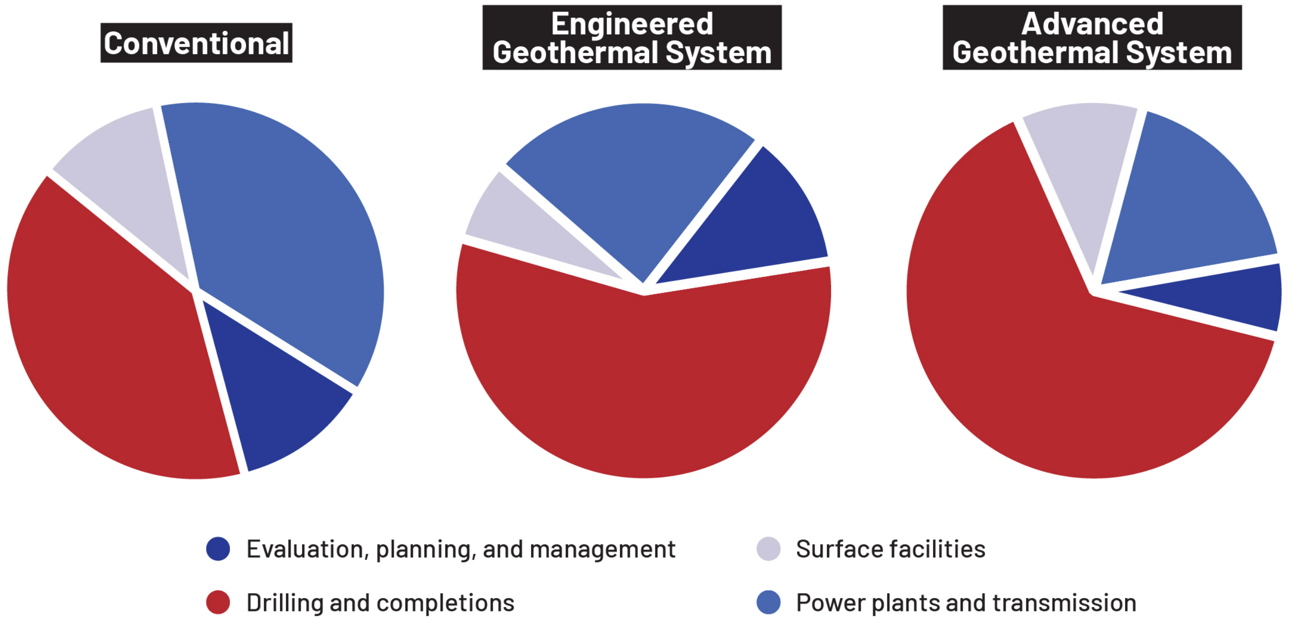


Figure 8.3: Each variation of geothermal requires pretty much the same skills as those found in the oil and gas industry. Source: International Energy Agency (IEA). (2024). *The future of geothermal energy*. IEA.

Given the high degree of skill overlap, it is no wonder that geothermal has one of the highest transferable skills bases across low-emission technologies, as shown in **Figure 8.1**.[16]

Oil and Gas Skills Overlap in Deep Geothermal Projects

Developing new geothermal projects requires subsurface evaluation, modelling, drilling, and surface operations—processes similar to those used in many upstream oil and gas projects. These tasks draw heavily on the expertise of geologists, geophysicists, petrophysicists, geochemists, drilling and reservoir engineers, data acquisition crews, and geographic information specialists.

Similarly, civil, mechanical, chemical, and electrical engineer designers are required for many phases of a geothermal project, including planning, construction and operation for well design, drilling, operation, monitoring, and maintenance. Both experienced and new petroleum engineering professionals' skills map well to the requirements of a geothermal reservoir engineer.[17]

Some of the biggest project overlaps between the oil and gas and geothermal industries are in the areas of project planning and management. Project management challenges such as permitting, Environmental Impact Assessments, and stakeholder engagement are similar in both sectors, as are demands around drilling and completion, surface facility construction and maintenance, and operations and production monitoring.

Oil and Gas Skills Overlap in Geothermal Heat Projects

The United Kingdom's shallow geothermal resources also offer opportunities for workers in the oil and gas industry. While volcanic deep systems dominate global attention, the UK approach focuses on accessible solutions such as heat pumps (with more than 40,000 installations supported by government programmes as of 2025[18,19]), district heating networks, and minewater systems. The Gateshead minewater heat network demonstrates the commercial viability of these systems, whereas newer projects in Wales and Seaham demonstrate the promise of geothermal heat across former coalfield regions.

Oil and gas professionals have directly transferable expertise that is relevant to geothermal development, particularly in subsurface geology modelling, fluid dynamics, and safety management. Their understanding of geological interpretation, structural analysis, and 3D modelling applies to geothermal resource assessment, whether in aquifers or flooded mine workings. The oil and gas sector's established health, safety, and environmental management provides useful foundations for geothermal operations. Existing frameworks for gas detection, blowout prevention, environmental compliance, and regulatory approval require adaptation for geothermal applications. The UK also has a supply of experienced drill rig operators who understand how to work efficiently and safely and would require minimum retraining and reskilling to drill the shallower wells required for district heating and cooling.

The oil and gas fabrication and manufacturing supply chain is positioned to support shallow geothermal deployment, bringing precision engineering expertise that is applicable to ground source heat exchangers, drilling infrastructure, and modular heat pump systems. Beyond domestic applications, the UK's North Sea drilling experience provides relevant capabilities for engineered geothermal systems in international markets with different geological conditions. By developing geothermal as a domestic opportunity and a potential technology export, the oil and gas sector can diversify operations, support the transition to low-carbon heating solutions, and contribute to decarbonisation efforts.

Training the Future Geothermal Workforce

As geothermal develops, there is likely to be significant competition for positions among workers transitioning from other sectors and new entrants to the field. A shared challenge across sectors is compensation. Currently, the renewables market does not offer salaries at the same level as oil and gas. An industry pay bechmarking report commissioned by Offshore Energies UK concluded that oil and gas remains the highest-paying sector, with salaries exceeding those in offshore wind, hydrogen, carbon capture, and other renewables by an average of between 15% and 50% and that emerging sectors (including geothermal) tend to pay lower on average.[20] Although the UK oil and gas industry is mature and the number of roles may decrease, this trend is not universal. Many oil and gas professionals are willing to work internationally, attracted by higher pay, which can contribute to skills shortages for renewable projects in the UK.

One opportunity for workforce development might be among the coal mining communities in areas like South Yorkshire, England, and Lanarkshire, Scotland. The UK's transition away from coal has resulted in economic hardship in those communities. The government provided £75 million in funding for training and retraining programmes in pit closure areas specifically to help former miners find new employment, but the regions still suffer from high levels of unemployment.[21] These workers would be good candidates for retraining and deployment in a newly burgeoning geothermal sector.

Where to Get Training

With engineering and design (mechanical, chemical, and civil), geoscience, and petroleum engineering as the core backgrounds required for geothermal, there is no shortage of training opportunities for those wanting to learn about the field. Several universities are pivoting from an oil and gas focus by offering dedicated modules within broader energy programmes or specialised short courses. The British Drilling Association provides information on the training and qualifications required to undertake geothermal drilling.[22] The following university programmes are a sample of what is available:

- The University of Manchester offers a Master of Science in subsurface energy engineering.[23]
- Robert Gordon University offers a short course on geothermal energy and applications.[24]
- The University of Aberdeen offers a master's-level online short course on geothermal and hydro energy.[25]
- The University of Edinburgh School of Geosciences GeoEnergy Master of Science program looks at research on established energy technology and developing areas such as geothermal.[26]
- Durham University has a leading UK geothermal research centre.[27]

Additionally, the London School of Business Administration offers a certificate programme in geothermal that covers areas such as energy systems,[28] plant design, and energy policies and practices.

In addition, joint research and development projects between public institutions and private companies can drive innovation in geothermal technology. These partnerships could focus on developing new drilling techniques, improving efficiency, and reducing costs while also providing training opportunities for researchers and engineers.

Today, the geothermal industry provides around 145,000 jobs globally.[29] The oil and gas industry employs about 12 million workers globally.[30] To narrow that gap, UK governments could expand partnerships with universities and private companies to develop specialised geothermal training programmes and include internships, apprenticeships, and hands-on training opportunities to ensure students gain practical experience alongside theoretical knowledge. These efforts would help geothermal grow into a thriving industry.

Existing Programs as Potential Models

A number of existing skills programmes could be expanded to include geothermal. For instance, the Offshore Petroleum Industry Training Organization (OPITO) developed an Integrated People and Skills Strategy[31] as part of the UK's North Sea Transition Deal, a partnership between the government and industry to transition the United Kingdom away from fossil fuels. Launched in May 2022, the program aims to train people on skills that translate to other energy sources. OPITO offers apprenticeships that provide training and qualification in the energy industry.[32] Many of the apprenticeships focus on opportunities in oil and gas, hydrogen, carbon capture and storage, and offshore wind. With some effort, these apprenticeships could also include geothermal-specific qualifications and skills.

Offshore Energies UK (OEUK), in partnership with RenewableUK, launched the Energy Skills Passport website in January 2025. The platform is currently designed to help workers identify the qualifications needed for specific roles within the oil and gas and offshore wind sectors. The tool also outlines potential career pathways within the broader energy industry. The program started as a pilot and will be released later this year. As the UK energy landscape continues to advance, the passport will be regularly updated to include new training opportunities and job availability, with plans to extend coverage beyond offshore skills to areas such as geothermal energy.

TECHNOLOGY DEVELOPMENT AND CHALLENGES AND WHERE THE OIL AND GAS INDUSTRY CAN HELP

Around the world, technical hurdles in both conventional and emerging geothermal operations represent opportunities for the UK oil and gas supply chain and workforce. This section provides an overview of the various geothermal systems, the challenges they face, and ways they could benefit from oil and gas experience.

Well Structure Stability

Well structure stability is an ongoing issue for the geothermal industry, particularly in mature conventional geothermal wells, which were designed according to oil and gas standards without taking into account geothermal's unique environment and operational stressors.[33] The dynamic conditions of injection and production and the high temperatures in geothermal wells can lead to an increase in stress, resulting in casing fatigue and failure. These issues can have a large impact on the productivity of a well and create ongoing maintenance costs.

These challenges present an opportunity for the oil and gas supply chain to develop innovative solutions for geothermal well stability and to extend the life of conventional wells. Opportunities could include new cements, new materials to strengthen casing, and flexible couplings. GeoWell and DEEPEGS are two European Union–funded projects already looking into solutions.[34]

Scaling and Corrosion

Geothermal fluids contain various substances that can cause scaling and corrosion of materials over time. Fluid composition is site specific, making this a complex problem, but the oil and gas industry has significant knowledge in this space that could be applied to geothermal projects. One oil and gas supply chain company, Roemex, has begun developing a range of chemicals, monitoring, management, and reporting services for the deep geothermal market.[35] Its solutions include inhibitors for corrosion and scaling as well as remedial treatments designed to reduce injection pressures to improve or restore re-injectivity.

High Flow Rates

Geothermal operations require high flow rates to make projects economically viable, so wells tend to be larger in diameter than wells in other industries, requiring non-standard drilling techniques and tools. The oil and gas industry's knowledge of drilling in different environments is relevant for geothermal operations.

Pump Failure

Pumps are often required to lift the hot brine to the surface or increase fluid pressure. Electrical submersible pumps are useful and can be applied in the oil and gas industry, but they are not designed for geothermal conditions, leading to frequent failures and reduced life expectancy. Expertise from the oil and gas industry could help improve designs for geothermal operating conditions.

Next-Generation Geothermal

For electricity generation, geothermal systems need to tap into high subsurface temperatures, which often means drilling very deep. Depending on the temperature at depth, that could mean drilling to a depth of more than 7 kilometres. (See Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface Geology," for the places in the UK that are best suited for power development.) The challenges and costs of drilling to that depth are significant. It is also difficult to ensure reliable instrumentation and sensing at the extreme temperatures at depth. A number of former oil and gas experts are working in this field in places around the world, but more oil and gas know-how can continue to benefit deep geothermal operations in a few areas.

New Drilling Techniques

Reduction in drilling time, whether for oil and gas or geothermal projects, has a significant impact on project costs. The need for new technologies that increase the rate of penetration (especially into hard rocks) offers a significant opportunity to innovate. Examples of technologies in this space include the following:

- GA Drilling, a drilling company based in Slovakia, is developing a plasma drill to evaporate hard rock.[36]
- Imperial College London is part of a project looking at the development of drilling systems that combine a high-pressure water jet and a high-powered advanced hammer action.[37]
- Quaise Energy,[38] fueled by research from Massachusetts Institute of Technology professor Paul Woskow, is developing techniques that use millimetre waves at high frequencies to melt rock and attempting to access "superhot" geothermal resources (around approximately 400 °C and higher).

New Drill Tools

Drilling into hard rock requires higher weight on drill bits, which can lead to cutting element damage and loss of performance. Tungsten carbide-based drill bits are commonly used, but the industry is seeking alternatives—especially affordable ones. New drive mechanisms also offer an opportunity. Systems that can more effectively and efficiently provide power to the drill bit can enhance penetration rates.

Modelling and Simulation

The oil and gas industry is a world leader in modelling the subsurface to understand rock and fluid interactions. Application of advanced modelling techniques for oil and gas could greatly enhance and de-risk deep geothermal projects. Companies such as tNavigator[39] and Seequent[40] specialise in providing reservoir modelling software.

Sensor Technology

As geothermal wells become more complex, more information on performance and the surrounding formations is needed. Tools such as measurement while drilling (MWD) that have been developed in the oil and gas industry can be used to provide real-time information on drilling performance—but these tools need to be rated for the potentially higher temperatures experienced in geothermal wells.

Distributed temperature sensing (DTS) and distributed acoustic sensing (DAS) are increasingly being used in the oil and gas industry,[41] but they could be improved to meet the needs of geothermal, where sensors must operate at high temperatures and pressures and be reliable over a long period of time.

If the geothermal industry in the United Kingdom were supported by clear policy signals and targeted financial mechanisms that de-risk the use of reservoir stimulation techniques such as hydraulic fracturing (read Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," for more), long-term monitoring would be necessary to generate ongoing data on reservoir performance, temperature, deformation, fracture networks, and fluid flow.

Directional Drilling

As with sensing technology, existing directional drilling systems are typically only rated up to 175°C. An engineered geothermal system must be able to withstand higher temperatures (above 220°C). In the United States, some test sites–including Fervo Energy's site in Utah—have successfully drilled at temperatures above 250°C.[42]

Engineered and advanced geothermal systems—including closed-loop systems—require advanced drilling techniques such as directional and horizontal drilling. Companies with the capability of providing precise control of directional drilling, rotary steerable tools, and tools that can see ahead of the bit to measure and control position while drilling could provide valuable technology and skills to these projects.

There is considerable opportunity to transfer knowledge and expertise from shale gas operations to the development of engineered geothermal systems. Novel drilling rigs and well construction technologies developed for shale gas operations could be deployed for engineered geothermal systems, creating a substantial opportunity to leverage an existing skilled workforce and mature service supply chains in support of this resilient and secure energy source.

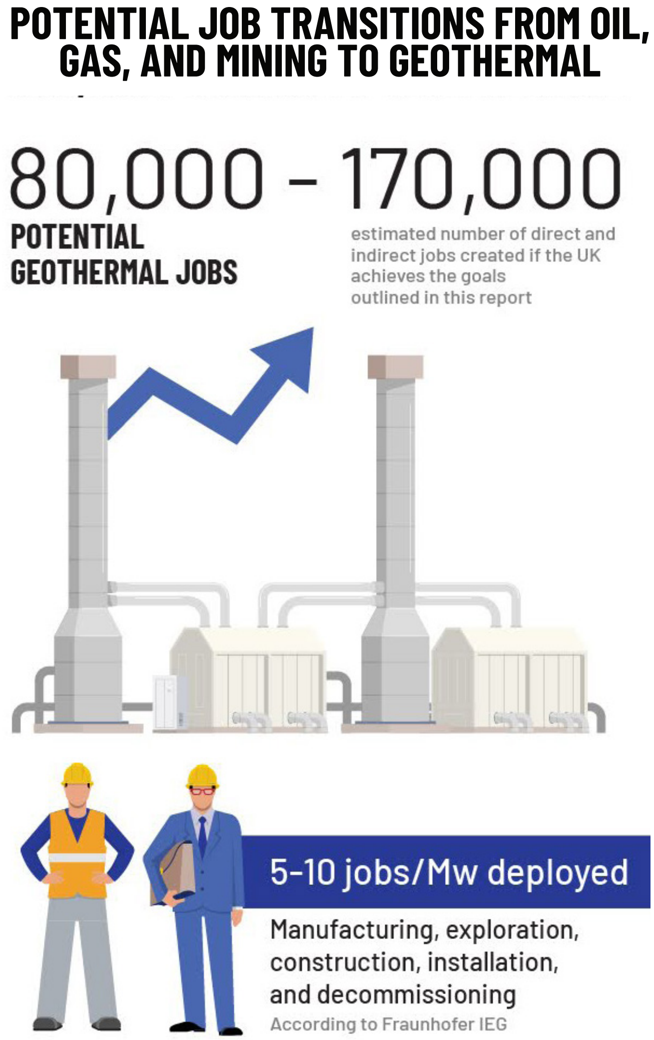


Figure 8.4: Potential job transitions from oil, gas, and mining to geothermal. Source: Bracke, R., & Huenges, E. (2022, February 2). *Shaping a successful energy transition* [Press release]. Fraunhofer IEG.

Geothermal Power Plants

The oil and gas industry also has expertise in the development of new turbines, which could help optimise operations to increase power conversion efficiency.

GEOTHERMAL ENERGY STORAGE

The oil and gas industry can also help create geothermal wells for energy storage. As mentioned in Chapter 1, "United Kingdom Underground: An Overview of Geothermal Technologies and Applications," underground thermal energy storage, also known as geothermal energy storage (GES), captures and stores waste heat or excess electricity by pumping fluids into natural and artificial subsurface storage spaces, from aquifers to boreholes to mines. GES can be primarily mechanical, with hydraulic fracturing techniques storing pressurised fluid in subsurface reservoirs.

There are plenty of examples of UK manufacturers or service providers with capabilities that could transfer to geothermal, including companies that manufacture drill bits, directional drilling tools, logging tools, power sections for pumps and drilling motors, and high-temperature blowout preventers, as well as services such as engineering, procurement, construction and installation management, and engineering consultancy. Start-ups in geothermal have also established engineering offices in the UK to leverage available skills and expertise in the country, including suppliers to many companies working in geothermal.

UK OIL AND GAS COMPANIES AT WORK IN GEOTHERMAL

Geothermal is rapidly being developed around the world. Germany[43] and the Netherlands[44] both have comprehensive road maps for the development of a geothermal sector, emphasising the benefits and contributions that geothermal can make to a nation's energy security. The United Kingdom should follow suit.

Many UK-based companies are already expanding their businesses in geothermal. Likewise, all of the major supply chain companies—including Expro, SLB, Halliburton, Baker Hughes, and Weatherford—are exploring and actively engaged in geothermal projects. With the lack of opportunities and projects in the United Kingdom, much of these companies' attention is international, but the lessons learned from those efforts can be applied to projects and help create jobs and secure heat and power at home as well.

CHANNELING THE SUPPLY CHAIN TO SUPPORT GEOTHERMAL INFRASTRUCTURE DEVELOPMENT

Today, a number of technologies are being developed for the design and operation of next-generation geothermal wells. Some, like engineered geothermal systems, require hydraulic fracturing of the surrounding formation, while technologies such as advanced geothermal systems do not. (See Chapter 1, "United Kingdom Underground: An Overview of Geothermal Technologies and Applications.") Most or even all of these new technologies will require the accurate placement of complex trajectories to get the wells in the right locations and the right distance from each other.

The features of next-generation wells mean new capabilities are needed for their development and operation. They will require fast drilling because of high drilling costs and will likely require monitoring to understand formation properties. The range of measurements will most likely be less involved than those in oil and gas because geothermal does not try to characterise reservoirs, but rather to make new ones. Next-generation wells will also need more maintenance because of the longer lifespan of the wells compared with oil and gas. Many of the technologies required have been developed and manufactured in the UK. The skill base that created them is still around, although without new opportunities, that may change. By developing a robust geothermal industry, the UK can convert oil and gas know-how into a world-class geothermal industry, lowering bills, strengthening energy security, and creating high-value jobs. That said, more training will be needed as skilled workers may retire or move.

Some experts believe parts of the UK oil and gas supply chain can also be adapted to support shallower, low-temperature geothermal applications, including minewater systems, sedimentary aquifers, and district heat networks. Many of the technologies and assets developed for hydrocarbons—such as drilling services, casing and cementing systems, pumps, and precision manufacturing—can be combined with existing technologies for shallower boreholes and heat exchange systems. Smaller, medium-depth drilling and workover rigs can be retooled for smaller-diameter geothermal wells, while pipeline and fabrication firms experienced in subsea or onshore gas networks can design and install insulated heat distribution systems and energy centres. Subsurface data and instrumentation companies can redirect their expertise in reservoir monitoring, automation, and control systems toward geothermal heat networks, providing real-time monitoring and performance optimisation. By strategically mobilising these existing capabilities, the UK can create a domestic geothermal supply chain that underpins large-scale deployment of low-carbon heat, reduces dependence on imported equipment, and drives resilient industrial growth.

A BIT OF OIL AND GAS (AND DRILLING) HISTORY

By John Clegg

The UK oil and gas industry grew significantly in 1934, when Parliament passed the Petroleum Act, making it clear that the Crown owned all oil and gas resources in Great Britain. More oil was discovered during the Second World War and over the next two decades, when oil was found in the East Midlands, Scotland, and Southern England, including at Wytch Farm and Kimmeridge, where the K1 well has been continuously pumping oil since 1961.[45]

The second big acceleration for the industry was the discovery of the Groningen gas field in the Netherlands in the late 1950s and early 1960s, which stimulated exploration of the North Sea. After the UK Continental Shelf Act was passed in 1964, exploration began. In 1969, Phillips Petroleum discovered the Ekofisk field in the Norwegian sector and Amoco discovered the Montrose field in the UK sector. Both contained a wealth of oil, and a major industry in the North Sea was born.

To extract this oil, technology was initially imported from the United States, where the first offshore platform had been installed in the Gulf of Mexico in 1955. But the harsher environment of the North Sea, combined with more difficult reservoirs to drill and produce from, meant that new technologies had to be developed to fully exploit these fields. Drilling is expensive, especially from platforms located in hostile environments, and reliability is key to success. The result was an industry based on integrity, reliability, and the understanding of a high potential cost of failure.

Although a number of ports on the east coast of England and Scotland were used to service the growing North Sea industry, Aberdeen became the prime location and much of the supply chain began to gravitate there.[46]

At the same time, other areas began to develop their own supply chains, including in the Newcastle area and East Anglia, on the east coast, and Gloucestershire and Somerset in the southwest. This part of England became, and remains, a global centre of excellence for electronics and electromechanical systems (effectively, robotics) used in harsh, demanding environments. Products including MWD systems, rotary steerable systems, polycrystalline diamond compact drill bits, subsea valves, and subsea wellhead control systems were produced along a line stretching from Tewkesbury to Nailsea, south of Bristol. They leveraged capabilities found in aerospace, including high-integrity materials, precision machining, advanced manufacturing, rugged and reliable sensors, and reliability electronics. Some of these suppliers have since moved to other countries as the market shifted away from the North Sea, but many remain, along with local supply chains. For example, Schlumberger develops the directional drilling technology it uses in its global operations in the small town of Stonehouse in Gloucestershire.[47]

The policies enacted in 1934, and again in 1964, have had major benefits for the United Kingdom’s economy, workforce, health, and emissions. Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," outlines suggested policies that could spur the next major energy industry in the United Kingdom.

CONCLUSION

To help geothermal energy emerge as a critical way to lower costs and enable workforce development, the UK can look to its oil and gas and mining sectors. With their deep expertise in technology, infrastructure, subsurface exploration, drilling, and resource management, these industries are well positioned to play a catalytic role and help significantly lower project costs and de-risk early-stage development.

This transition from legacy energy to geothermal also offers a powerful way to create jobs. If supported with appropriate incentives, infrastructure, and workforce development, these industries can play a transformative role in positioning the United Kingdom as a global leader in geothermal innovation.

CHAPTER REFERENCES

1 Offshore Energies UK. (2024). *Economy and people report 2024*. https://oeuk.org.uk/wp-content/uploads/woocommerce_uploads/2024/06/Economy-and-people-report-2024-OEUK-fthaik.pdf

2 Robert Gordon University, Aberdeen. (2025, June 3). *RGU report issues UK offshore energy industry jobs warning*. https://www.rgu.ac.uk/news/news-2025/8232-uk-offshore-energy-industry-faces-grangemouth-scale-redundancies-every-fortnight-without-intervention-warns-new-rgu-report

3 Energy Sector Management Assistance Program (ESMAP). (2023). *Geothermal energy: Unveiling the socioeconomic benefits*. World Bank. https://documents1.worldbank.org/curated/en/099122823090547278/pdf/P1744881ab11080191a03411d191385e065.pdf. See page 31.

4 Fraunhofer IEG. (2022, February 2). *Shaping a successful heat transition* [Press release]. https://www.ieg.fraunhofer.de/de/presse/pressemitteilungen/2022/erfolgreiche-waermewende-gestalten.html

5 Matek, B. (2015). *Geothermal Energy Association issue brief: Additional economic values of geothermal power*. Geothermal Energy Association. https://geothermal.org/sites/default/files/2021-02/Issue_Brief_Economic_Values_2015.pdf

6 Halimatussadiah, A., Irhamni, M., Riefky, T., Ghiffari, M. N., & Afifi, F. A. R. (2024). *Employment impacts of energy transition in Indonesia*. Institute for Research on Economics and Safety, University of Indonesia. https://en.lpem.org/employment-impacts-of-energy-transition-in-indonesia/

7 National Geothermal Centre. (2025, June 30). *Ten takeaways from the Geothermal 2025 conference*. https://ukngc.com/ten-takeaways-from-the-geothermal-in-the-uk-whats-next-conference

8 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/535567/1/report_OR23032.pdf

9 Environment Agency. (2025). *Abandoned metal mines in England: Baseline length of rivers and estuaries polluted by harmful metals*. Government of the United Kingdom. https://www.gov.uk/government/publications/abandoned-metal-mines-in-england-baseline-length-of-rivers-and-estuaries-polluted-by-harmful-metals/abandoned-metal-mines-in-england-baseline-length-of-rivers-and-estuaries-polluted-by-harmful-metals

10 Coal Authority. (2020, December 1). *New maps reveal heat stored in Britain's abandoned coal mines* [Press release]. Government of the United Kingdom. https://www.gov.uk/government/news/new-maps-reveal-heat-stored-in-britains-abandoned-coal-mines#:~:text=The%20British%20Geological%20Survey%20and,to%20heat%20homes%20and%20businesses

11 Coal Authority & Mining Remediation Authority. (2025, May 27). *Mine water heat*. Government of the United Kingdom. https://www.gov.uk/government/collections/mine-water-heat

12 Watson, S. M., Falcone, G., & Westaway, R. (2020). Repurposing hydrocarbon wells for geothermal use in the UK: The onshore fields with the greatest potential. *Energies*, *13*(14), 3541. https://doi.org/10.3390/en13143541

13 CeraPhi. (n.d.). *Our solutions*. https://ceraphi.com/solutions/

14 Net Zero Technology Centre. (n.d.). *CeraPhiWellTM-Turning oil and gas liabilities into geothermal assets*. https://www.netzerotc.com/projects/ceraphiwell/

15 Optimat. (2021). *Scotland's geothermal supply chain analysis and global market opportunities study*. Scottish Enterprise. https://www.scottish-enterprise.com/media/cyyf50ls/full-report.pdf

16 Okoroafor, R. E., Etkind, J., & Fournier, A. (2022, July 14). Transferable skills: Petroleum engineering and geoscience skills are shaping the low-emission energy transition. *The Way Ahead* (blog), Society of Petroleum Engineers. https://jpt.spe.org/twa/transferable-skills-petroleum-engineering-and-geoscience-skills-are-shaping-the-low-emission-energy-transition

17 Okoroafor et al., 2022.

18 Pocklington, J. (2025, April 3). *Letter to Sir Geoffrey Clifton-Brown MP*. Department for Energy Security and Net Zero. https://committees.parliament.uk/publications/47588/documents/248287/default

19 Department for Energy Security and Net Zero. (2025). *Heat pump deployment quarterly statistics United Kingdom: 2025 Q2*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/68b5c751536d629f9c82a983/Heat_pump_deployment_quarterly_statistics_United_Kingdom_2025_Q2.xlsx

20 Offshore Energies UK. (2025). *Workforce insight 2025*. https://oeuk.org.uk/wp-content/uploads/2025/11/Workforce-Insight-2025-OEUK.pdf

21 UK Parliament. (1993, November 30). *Coal miners (retraining)*. Hansard. https://hansard.parliament.uk/commons/1993-11-30/debates/4bd4ea64-e0c4-47c1-a6e5-bb8f2098335a/CoalMiners%28Retraining%29

22 British Drilling Association. (n.d.). *Geothermal drilling–training and qualification toolkit*. https://www.britishdrillingassociation.co.uk/competence/geothermal-drilling/

23 University of Manchester. (n.d.). *MSc subsurface energy engineering*. https://www.manchester.ac.uk/study/masters/courses/list/12561/msc-subsurface-energy-engineering/

24 Robert Gordon University, Aberdeen. (n.d.). *Geothermal energy and applications*. https://www.rgu.ac.uk/study/courses/6328-geothermal-energy-and-applications

25 University of Aberdeen. (n.d.). Geothermal and hydro energy. https://on.abdn.ac.uk/courses/geothermal-and-hydro-energy/

26 University of Edinburgh. (n.d.). *Degree finder: GeoEnergy MSc*. https://study.ed.ac.uk/programmes/postgraduate-taught/944-geoenergy

27 Durham Energy Institute. (n.d.). *Geothermal energy*. Durham University. https://www.durham.ac.uk/research/institutes-and-centres/durham-energy-institute/research—impact/research-themes/decarbonising-heating-and-cooling/geothermal-energy

28 London School of International Business. (n.d.). *Advanced skill certificate in geothermal energy systems*. https://www.lsib.co.uk/2022/course-details.aspx?id=2730329&CourseTitle=Advanced%20Skill%20Certificate%20in%20Geothermal%20Energy%20Systems%20

29 International Energy Agency (IEA). (2024). *The future of geothermal energy*. https://www.iea.org/reports/the-future-of-geothermal-energy

30 International Energy Agency (IEA). (2023). *The oil and gas industry in net zero transitions*. https://www.iea.org/reports/the-oil-and-gas-industry-in-net-zero-transitions

31 Offshore Petroleum Industry Training Organization (OPITO). (n.d.). *North Sea Transition Deal*. https://opito.com/external-engagement/north-sea-transition-deal-people-and-skills-report

32 Offshore Petroleum Industry Training Organization (OPITO). (n.d.). *APTUS apprenticeships*. https://opito.com/for-learners-opito/apprenticeships-energy-sector-opito

33 Marbun, B. T. H., Ridwan, R. H., Sinaga, S. Z., Pande, B., & Purbantanu, B. A. (2019). Casing failure identification of long-abandoned geothermal wells in Field Dieng, Indonesia. *Geothermal Energy*, *7*, 31. https://doi.org/10.1186/s40517-019-0146-3

34 DEEPEGS. (n.d.). *DEEPEGS: Deployment of deep enhanced geothermal systems for sustainable energy business*. https://deepegs.eu/

35 Roemex. (n.d.). *Renewable energy*. https://roemex.com/renewable-energy-2#geothermal

36 GA Drilling. (n.d.). *Breaking barriers in geothermal: Engineering what's next*. https://www.gadrilling.com/about-us/

37 Orchyd. (n.d.). *Discover the project*. https://www.orchyd.eu

38 Quaise. (n.d.). *Quaise*. https://www.quaise.energy

39 Rock Flow Dynamics. (n.d.). *tNavigator*. https://rfdyn.com

40 Seequent. (n.d.). *Seequent*. https://www.seequent.com

41 WellSense. (n.d.). *WellSense*. https://www.well-sense.co.uk

42 Fervo Energy. (2025, June 10). *Fervo Energy drills 15,000-ft, 500°F geothermal well pushing the envelope for EGS deployment* [Press release]. https://fervoenergy.com/fervo-energy-pushes-envelope/

43 Harmsen, S. (2025, August 7). *Federal Cabinet adopts Geothermal Acceleration Act and abolishes gas storage levy*. E&M Power News. https://www.bayern-innovativ.de/en/emagazine/energy-construction/detail/cabinet-launches-faster-heating-transition

44 Platform Geothermie. (2018). *Master plan geothermal energy in the Netherlands*. Platform Geothermie. https://geothermie.nl/images/bestanden/Masterplan_Aardwarmte_in_Nederland_ENG.pdf

45 Northern Mine Research Society. (n.d.). *Kimmeridge oil well*. https://nmrs.org.uk/mines-map/oil/kimmeridge

46 Clegg, J. M. (2022). *Strategy and innovation for a changing world: Part 2: Sustainability through velocity*. Troubadour Publishing. https://troubador.co.uk/bookshop/business/strategy-and-innovation-for-a-changing-world-part-2

47 SLB. (2024, November 12). *SLB unveils its latest geoenergy demonstrator in Stonehouse, UK*. https://www.slb.com/news-and-insights/newsroom/updates/2024/slb-unveils-its-latest-geoenergy-demonstrator-in-stonehouse,-uk

Chapter 9

Minding the Gap: Financing Solutions to Advance Geothermal in the United Kingdom

Tim Lines, Project InnerSpace and Geothermal Wells UK

The barrier to a powerful geothermal industry is not natural resources or technology, but finance. Geothermal heat and electricity exploration offers a high-upside opportunity for the UK. With the right financing pathways, the UK can attract new capital and catalyse projects nationwide.

Just as the United Kingdom transformed the North Sea from an unexplored frontier into a world-leading energy province between the 1960s and 1990s, the nation now stands at the threshold of another transformative opportunity. In the coming decades, demand will rise sharply for domestic renewable energy as industry, heating, and agriculture shift away from oil and gas. Projected increases in renewable energy demand are driven by the electrification of heat, transport, and industrial processes.[1,2] Geothermal can meet this demand with round-the-clock heat and electricity while creating between 80,000 and 170,000 jobs, reducing imports, and lowering system costs—as well as establishing the United Kingdom as a global leader in dispatchable, low-carbon energy and building expertise and domestic supply chains. This chapter sets out the finance and de-risking levers that turn the resource mapped in Chapter 3, the pilots identified in Chapter 4, and the policy pathways set out in Chapter 5 into a bankable project pipeline that can deliver the report's geothermal targets of 15 gigawatts for heat and between 1.5 gigawatts and 2 gigawatts for electricity by 2050.

The success of North Sea oil and gas required coordinated public–private investment, risk-sharing mechanisms, and a long-term policy commitment. To achieve the proposed geothermal goals and build a robust geothermal industry, early-stage funding for exploration and subsurface appraisal will be essential. Encouragingly, recent US experience indicates that much of the early subsurface and delivery risk is quickly retireable when projects are executed as a disciplined portfolio. In the United States, programmes such as the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) and early commercial deployments led by Fervo have accelerated standardisation and learning-by-doing, strengthening the case for a modest UK demonstration programme to generate investable performance data. With modest philanthropic support and new public financing, first-of-a-kind pilot projects for heat and electricity can be drilled, proven, built, and then financed to become commercially stable.

This pathway relies principally on the following initiatives—some of which are already represented by existing organisations and projects, while others have not yet been created. The initiatives in the latter group in particular will require coordination across several government departments. The following initiatives are discussed in more detail in the section "Organising UK Public Finance to Mind the Gap":

- The Heat Networks Delivery Unit, in collaboration with the British Geological Survey, to create standardised, publicly accessible site-assessment packages for priority geothermal locations aligned with heat network zoning and local heat and energy strategies (see Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential"). This approach follows successful precedents in France, where BRGM (French Geological Survey) provides public subsurface data to help developers de-risk projects,[3] allowing commercial operators to compete on a level playing field with access to high-quality geological data, anchor-load mapping, and preliminary feasibility assessments. In a similar fashion, Project InnerSpace's GeoMap is a global service that overlays subsurface and surface data with high-grade investment opportunities.[4]
- Great British Energy, the National Wealth Fund, and the British Business Bank (the latter for small and medium enterprises) to fund a national demonstration programme for exploration, appraisal, and pilot plants at near-commercial rates (to be created).
- A government-backed first-loss geothermal resource insurance facility, along the lines of the French government's geothermal dry hole insurance programme, to de-risk early development stages (to be created).
- Institutional investors, supported by long-term electricity contracts (Contracts for Differences) and standardised long-term heat purchase agreements (contracts for heat, which will be created), to finance utility-scale geothermal plants.
- The Green Heat Network Fund, crowding in institutional capital for heat network developers.
- Great British Energy, the National Wealth Fund, institutional investors, and government gilts or local climate bonds to refinance and replicate de-risked projects at fully commercial rates.

The pathway should also include a non-state first-loss contribution funding of up to 20%, or between £3 million and £5 million of the exploration stage of each project for the initial 20 projects to de-risk public investment and inform the geothermal resource insurance facility.

With all of these pieces taken together, this pathway organises today's tools into a single, catalytic route from first-of-a-kind projects to a robust geothermal industry. The following sections set out each stage—who leads, what is funded, how decisions are made, and immediate next steps.

SYSTEM VALUE CONTRIBUTIONS

The United Kingdom will need between 30 gigawatts electric and 35 gigawatts electric of natural gas combined-cycle gas turbine (CCGT) power generation through the 2030s to back up a renewables-dominated system,[5] with availability payments expected to rise four-fold this decade.[6] Since geothermal Organic Rankine Cycle units ramp up at between 10% and 25% per minute[7]—comparable to the range of 20% to 40% per minute for CCGTs—they can also back up renewables and compete with CCGTs in frequency, capacity, and reserve markets. Embedded geothermal capacity lowers national energy costs in the following ways:

- Cheaper heat delivery than reinforcing the electricity grid for heat pumps
- Whole-system cost reductions by easing grid constraints and transmission and distribution losses

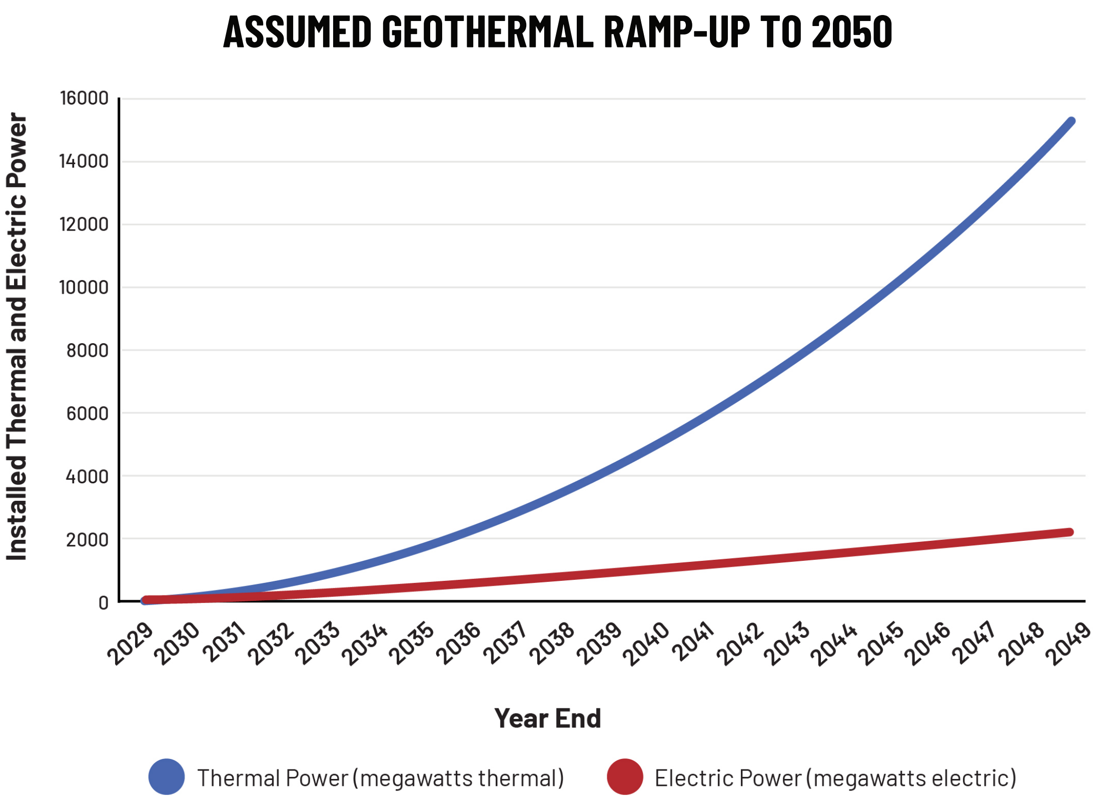


Figure 9.1: Assumed geothermal ramp-up to 2050. Source: author.

- Competition with CCGTs for ancillary services
- Avoiding gas imports and carbon, fossil fuel costs, and pollution

This section estimates the monetary and other system contributions to ramping up geothermal production to 15 gigawatts for heat and between 1.5 gigawatts and 2 gigawatts for electricity by 2050 (**Figure 9.1**), with reference to two real-life example projects in north-east England that the author is currently evaluating:

- 40 megawatts thermal and 1.6 megawatts electric geothermal heat project (sufficient power for parasitic pumping loads)
- 40 megawatts thermal and 25 megawatts electric geothermal combined heat and power project

This chapter's national deployment estimate assumes 327 thermal-only projects (each approximately 40 megawatts thermal at a 30% capacity factor) and 56 combined heat and power (CHP) projects (also around 40 megawatts thermal with approximately 25 megawatts electric output) are installed by 2050, with project cash flows extending to 2060. When aggregated, this portfolio would deliver approximately 38.3 terawatt-hours per year of useful thermal energy by 2050. This level of deployment represents a conservative share of the broader UK opportunity for efficient heating infrastructure. The UK's Second National Comprehensive Assessment of the Potential for Efficient Heating and Cooling identifies economic potential for heat networks totaling 95 terawatt-hours per year by 2050—meaning the geothermal target represents approximately 40% of the identified district heating opportunity.[8]

Independent research and government resources confirm that the UK has substantial geological conditions favourable to geothermal heat exploitation across both shallow and deep systems. The British Geological Survey's UK Geothermal Platform provides national-scale data on geothermal potential, helping planners identify where subsurface conditions—including temperature gradients, geology, and aquifer characteristics—are most favourable.[9] Geological studies indicate that medium- to high-enthalpy geothermal potential is geographically distributed across regions with radiogenic granites and favourable subsurface conditions, including Cornwall, parts of northern England, and Scotland.[10]

Potential for Cheaper Heat Delivery

Meeting winter demand with geothermal networks in areas served by deep, high-temperature geothermal district heat networks can be substantially cheaper than reinforcing the electricity grid to serve large-scale electric heat pump deployments in those same locations. For geothermal systems that supply heat at temperatures high enough for direct district heating (that is, with no need to boost the temperature with electric heating), the marginal cost of heat delivery has been estimated at around £7.9 per kilowatt thermal per year,[11] whereas reinforcing the grid to accommodate peak winter heat pump capacity is estimated to require an investment equivalent to an annualised £73 to £173 per kilowatt electric.[12] This 9- to 22-fold cost advantage makes deep geothermal heat an attractive option for shaving peak winter electric demand in heat-dominant cities.

In the 40 megawatts thermal example, avoided reinforcement costs equal £1.6 million annually over a 32-year operating life. Nationally, a 15 gigawatts thermal geothermal portfolio could displace roughly 6 gigawatts electric of peak demand (a 2.5 winter coefficient of performance [COP], which is the ratio of useful heat output to electrical energy input), cutting the need for additional peak generation and avoiding £360 million per year in annualised reinforcement costs—freeing capital for storage, integration, and resilience.

The British Geological Survey Atlas reports heat yields between 1 megawatt thermal and 100 megawatts thermal per well doublet near major population centres (such as East Midlands, Greater Manchester, Humber, and Cheshire).[13] Assuming 10 megawatts thermal per doublet, 3,000 wells drilled to less than 3.5 kilometres could deliver 15 gigawatts thermal in 16 years with 10 rigs, with a surface footprint of roughly 315 hectares (more than 750 acres).[14] (Conversations with drilling operators suggest they would be willing to bring rigs to the UK with the level of sustained work envisioned in this chapter. This statement reflects this understanding.) For context, the UK oil and gas industry has drilled about 1,500 onshore and 6,500 offshore oil and gas wells since 1980, illustrating that the number of wells envisioned in this chapter has already been surpassed by the oil and gas industry.[15,16] Additionally, the drilling rates required for this analysis have been achieved in Fervo's project in Utah in the United States. While rural Utah is different from the UK, the rock underneath both is granite, and in Utah, Fervo is able to drill 4,800 metres into granite in 16 days.[17]

Whole-System Cost Reductions by Easing Grid Constraints

In 2023, constraint payments to limit electricity generation exceeded £1.5 billion,[18] largely from curtailing Scottish wind farms due to limited transmission to the south. To stabilise supply, fossil-fuel generators in England charged "constraint relief" to generate instead. Geothermal power capacity located in England reduces these constraint-relief payments, providing additional firm generation local to demand. While planned new transmission capacity will lower—but not eliminate—constraint payments in the 2030s,[19,20,21,22] geothermal can make a material impact. In our 25 megawatts electric example, the avoided discounted-cash-flow constraint costs equal £14 million between 2030 and 2040. The relatively small proportion of the electric portfolio assumed to be deployed by 2040 could reduce constraint-relief payments by £100 million social discounted cash flow (S-DCF).[23]

When geothermal electricity is sited between 5 miles and 10 miles from population centres, this also cuts transmission losses by about 2% from a national average of 7.2%.[24] Cutting such losses could save £340 million S-DCF for 2 gigawatts electric, based on the HM Treasury long-run variable costs.

Assuming that permitting, environmental and social impact assessments, land access negotiations, and stakeholder consultations are initiated in parallel—and that regulatory approvals proceed without undue delay (discussed in Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential")—2 gigawatts electric could be delivered in less than 10 years by drilling 800 engineered geothermal system wells at about 5.5 kilometres depth into radiogenic granites using 10 rigs with a surface footprint of roughly 270 hectares (670 acres).[25]

POTENTIAL BENEFITS OF GEOTHERMAL DEPLOYMENT

Benefit Area	Financial Impact Estimate
System Value Contributions	By 2050, ramp up to 15 gigawatts of geothermal heat networks and 2 gigawatts of electricity at 30% and 95% capacity factors.
Avoided grid reinforcement (heat pumps)	~£360 million annualised avoided reinforcement cost
Whole-system impacts (at HM Treasury *Green Book* Social Discount Rate)	~£450 million from avoided constraint relief payments and reduced transmission losses
Ancillary services revenue	~£200 million per year potential revenue (average to 2050, consistent with a projected £4 billion balancing market by the late 2020s)
Avoided grid reinforcement (heat pumps)	~£320 million annualised avoided reinforcement cost
Energy Security and Wider Economic Benefits	
Avoided gas imports	~2.8 trillion cubic feet avoided (around 88 billion cubic feet per year, about 2.6% of UK annual consumption), with balance-of-payments and resilience benefits
Social Net Present Value (at HM Treasury *Green Book* Social Discount Rate)	~£9 billion avoided carbon, fossil fuel costs, and pollution
Gross Value Added	~£37 billion

Figure 9.2: Potential system and energy security benefits from geothermal deployment in the United Kingdom. Source: author's calculations based on varied government sources.

Competing with CCGT for Ancillary Services

Balancing services cost about £1 billion annually in 2023 and 2024,[26] with roughly 45% for ancillary services,[27] and are projected to rise to £4 billion annually by 2029 (an estimated £1.8 billion ancillary). Geothermal plants can compete with CCGT for five ancillary services (capacity market, reactive/voltage support, stability/inertia, black start, and dynamic containment down) without compromising baseload supply. Our 25 megawatt electric example could compete for £4 million annual revenue. The ramp-up to 2 gigawatts electric could compete for an estimated annual average £200 million per year in ancillary services revenue, placing downward pressure on rising CCGT ancillary service costs while adding zero-carbon capacity.

Avoided Gas Imports

Geothermal deployment also reduces reliance on imported natural gas. A 40 megawatts thermal and 25 megawatts electric project avoids a cumulative 14 billion cubic feet of gas to the 2060 analysis cutoff date. At a national scale, 15 gigawatts thermal and 2 gigawatts electric of geothermal capacity could displace about 2.8 trillion cubic feet—around 88 billion cubic feet per year, equal to 2.6% of current annual UK consumption.[28] These avoided imports strengthen the balance of payments, complementing the social and environmental benefits already quantified through the Green Book.

Avoided Carbon, Fossil Fuel Costs, and Pollution

The thermal example project has a social discounted net present value (S-NPV; the social discounted monetised value of avoided carbon, fossil fuel costs, and pollution) of £75 million and a Gross Value Added of £100 million; the CHP example has values of £280 million and £250 million, respectively.[29,30,31] Achieving the national goal could generate a S-NPV of £9 billion and Gross Value Added of £37 billion.

The economic, social and system, and balance-of-payments benefits described are summarised in **Figure 9.2**.

Over the decades, these effects represent billions of pounds per year in economic growth and potential savings to the energy system, alongside bankable project-level returns once early-stage risks are addressed. The next section outlines financing structures to redirect existing mechanisms toward geothermal development, unlocking both the system-wide benefits and the long-term economic gains.

CURRENT FINANCING ARCHITECTURE AND FUNDING GAPS

The UK has several funding programmes for the development of low-carbon heat and electricity, but almost none of these programmes cover geothermal's pre-construction risk:

- The Green Heat Network Fund (GHNF) provides grants of up to 50% of the total eligible commercialisation and construction costs for heat networks.
- The Heat Networks Delivery Unit (HNDU) helps councils undertake techno-economic assessments but does not fund subsurface risk.
- Combined authorities have similar Net Zero Accelerator funding.
- Contracts for Differences (CfDs) provide long-term power-price certainty for operational projects.
- The National Wealth Fund (NWF) can invest in proven assets and crowd-in private capital but is not designed for exploration risk.
- Great British Energy (GB Energy) is a new state-owned developer with potential to invest earlier in geothermal—if explicitly mandated.
- The British Business Bank (BBB) provides small and medium enterprises with finance and venture capital indirectly, operates on commercial terms, and does not cover geological risk.

Implementation of two complementary instruments proposed in this document would close the risk gap. First, a geothermal resource insurance facility (GRIF) would transfer the risks of exploration failure, initial underperformance, and early decline into global reinsurance markets, lowering the cost of capital through credible risk take-out. Comparable public-backed drilling-risk and geothermal guarantee schemes already operate in Europe (including France's GEODEEP,[32] the Netherlands' Garantieregeling Aardwarmte,[33] and Germany's KfW-supported program[34]), showing this kind of risk-transfer tool is a proven way to crowd-in private investment. GRIF is conceived to interface directly with the GHNF and CfDs so that insured appraisal results can move seamlessly into bankable construction and revenue frameworks (details are set out later in this chapter).

Second, standardised long-term contracts for heat would provide a lender-friendly offtake for the heat business case, complementing electricity CfDs for CHP schemes. These contracts require a policy wrapper and templates and are discussed later; their role here is to make post-resource-proving heat revenues bankable rather than bespoke.

Because early-stage funding is misaligned, viable projects struggle to move beyond concept. The central gap is subsurface risk capital for appraisal drilling (**Figure 9.3**). Venture and other private risk investors have shown limited appetite for this financing, leaving projects stranded before they can access mainstream debt and equity. (See "Potential Funding Pathways in the United Kingdom" for the specific mechanisms and the fuller GRIF and contracts for heat proposals.)

Figure 9.3 describes the scope of the programmes described, and **Figure 9.4** plots the programmes' applicability by geothermal development stage.

ORGANISING UK PUBLIC FINANCE TO MIND THE GAP

This section sets out five steps to move from today's fragmented funding to a single pipeline for first-of-

FINANCING ARCHITECTURE AND FUNDING GAPS

Fund/ Mechanism	Administering Body	Scope and Eligible Technologies	Stage of Project Supported	Relevance to Geothermal	Key Gaps and Constraints
Contract for Difference (CfD)	Low Carbon Contracts Company (LCCC); Department for Energy Security and Net Zero (DESNZ)	Low-carbon electricity generation	Revenue support for operational projects	Provides long-term power price certainty	Does not fund pre-construction
Green Heat Network Fund (GHNF)	DESNZ	Capital grants supporting commercialisation and construction heat networks	Construction phase (heat source must be proven)	Can fund network integration of geothermal	Does not underwrite early-stage geological risk
National Wealth Fund (NWF)	UK government	Government investment vehicle providing debt/ equity to catalyse private capital in priority sectors	Construction, expansion, scaling; crowd-in private finance	Potential anchor investor/ co-investor for proven geothermal power/heat network assets	Not a resource-risk vehicle
Great British Energy (GB Energy)	UK government	State-owned energy developer to invest/develop clean energy	Exploration (where policy allows), development, construction, operation	Could take earlier-stage positions in geothermal if mandated	Mandate and scope currently unclear
British Business Bank (BBB); includes Growth Guarantee Scheme (GGS), Nations and Regions Investment Funds (NRIF), British Patient Capital (BPC)	BBB plc (UK government economic development bank)	SME finance via GGS debt guarantees; NRIF debt/equity for SMEs; BPC invests in venture/growth funds	Corporate/ supply-chain growth, working capital, and equipment finance; venture/growth rounds via BPC-backed funds.	Can support UK supply-chain companies serving geothermal projects; potential developer financing via equity funds	Not a project-finance/grant vehicle; no geological resource-risk; ticket-size limits
Geothermal Resource Insurance Facility (GRIF) (conceptual)	Perhaps DESNZ or HM Treasury via an appointed scheme manager	Insurance for exploration failure, initial under-performance; longer-term temperature/ pressure decline	Exploration drilling, appraisal/ flow-test, construction, and early operation (warranty period)	Caps downside for lenders/equity	Requires (i) actuarial data, monitoring and verification; (ii) deductibles/co-insurance and partial premium subsidy; and (iii) scheme design and state-aid compliance
Contracts for heat (conceptual)	Perhaps Ofgem	Long-term fixed-price heat purchase agreements	Post-resource-proving (bankable offtake)	Could provide bankable revenue stream for geothermal heat	Requires policy framework; not yet implemented

Figure 9.3: Current financing architecture and funding gaps at a glance. Source: author.

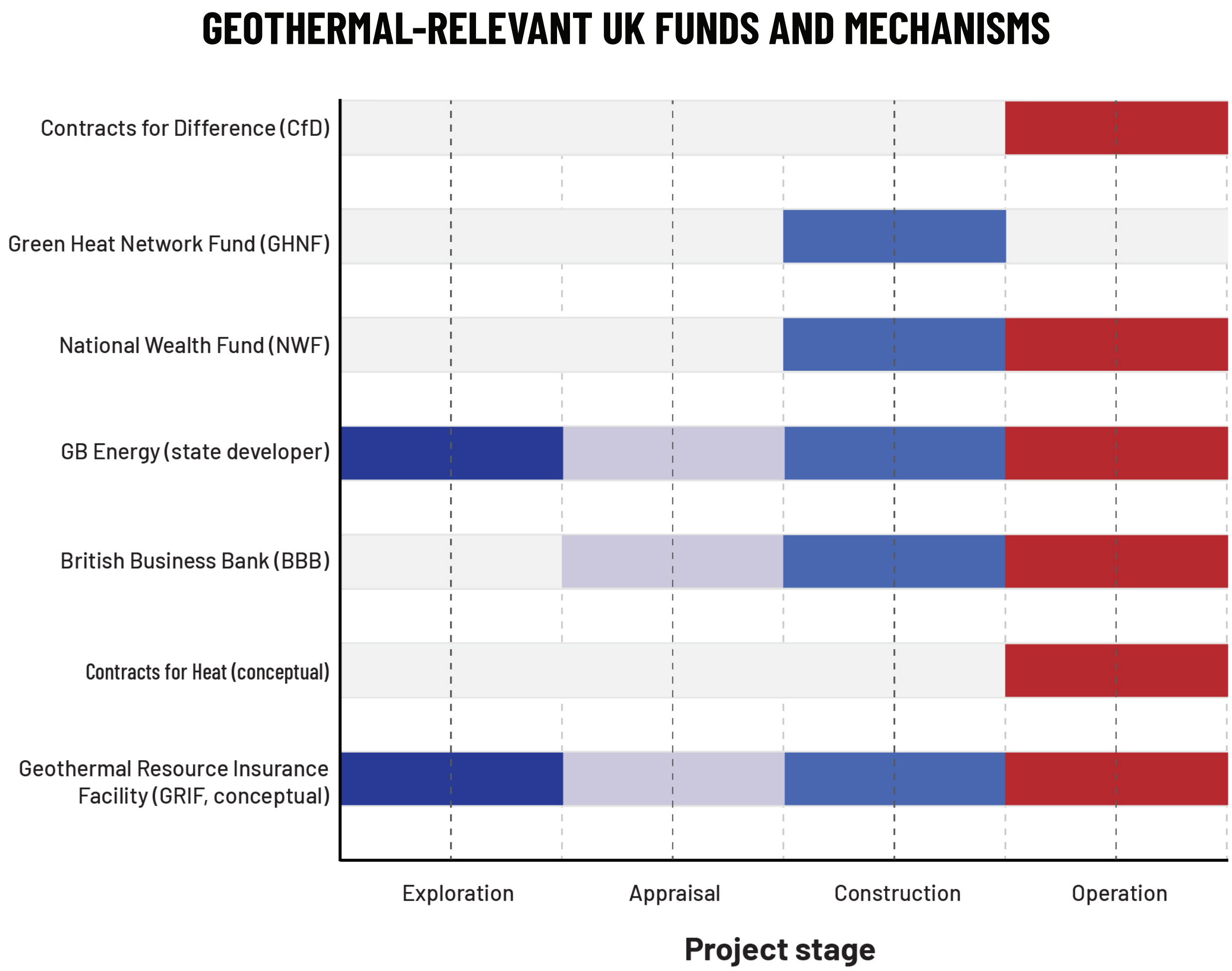


Figure 9.4: Summary of existing and conceptual UK funds and mechanisms relevant to geothermal. Source: author.

a-kind geothermal projects in the United Kingdom. A key new element is a philanthropic first-loss layer of between £3 million and £5 million per project to fund front-end studies and a slim-hole pilot. As a whole, these measures would let government-backed finance carry projects through the riskiest phases before handing off to institutional capital and project finance—allowing geothermal to scale in the United Kingdom. Taken together, these five steps fix the single biggest bottleneck the industry faces: early-stage subsurface risk.

Step 1: Integrate Geothermal into the Energy Plan and Build a Real Project Pipeline

Geothermal for heat and electricity must move from the margins of the UK energy strategy into the centre of delivery. Doing so means embedding geothermal in core planning frameworks and developing investable project lists that attract finance and speed delivery.

Actions

- **Add geothermal to scenarios and policies.** Explicitly include geothermal in National Energy System Operator scenarios, Department for Energy Security and Net Zero policies, and the Industrial Decarbonisation Strategy.[35] Taking this step would signal long-term demand for domestic, firm clean heat and dispatchable electricity, giving investors confidence. Additional policy ideas are discussed in Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential."
- **Maintain and expand subsurface resource data.** As detailed in Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface

Geology," subsurface characterisation and other technical and operational challenges must be addressed to unlock scalable deployment.

- **Launch a national demonstration programme.** The UK geothermal sector currently lacks an operational track record at commercial scale—no utility-scale deep geothermal plants currently operate in the UK for heat or power. The United States launched its FORGE project in Utah to help overcome a similar challenge and create a commercial pathway for new geothermal technologies.[36] At Utah FORGE, the programme has established standardised testing protocols and monitoring, and Fervo's nearby early projects demonstrate rapid learning-by-doing in drilling and reservoir performance.[37] This success illustrates how a similar demonstration programme in the UK focused on producing bankable data and repeatable delivery models could be catalytic. A modest UK demonstration programme would serve three critical functions: (1) generate performance data (flow rates, temperatures, decline curves, and operational costs) that will inform GRIF underwriting and reduce insurance premiums for subsequent projects; (2) establish standardised technical specifications and procurement frameworks that can be replicated, lowering costs industry-wide; and (3) create visible, bankable precedents that institutional investors can evaluate, addressing the "first-mover disadvantage" that has stalled UK geothermal despite successful deployment in comparable jurisdictions. In recognition of the UK's devolved governance arrangements—where energy policy is largely reserved to Westminster but planning and consenting are devolved—GB Energy will work with relevant national and devolved authorities to define clear, standardised project templates and a unified instruction set so that operational lessons can be consistently transferred across jurisdictions.
- **Standardise project front-end requirements.** Through the HNDU and the British Geological Survey, create a site information dossier for all candidates that includes desk geology, an appraisal plan, an anchor-load map (showing district heat, clusters, and data centres), indicative offtake pathways, and early-stage community engagement notes.

Who Leads

- National Energy System Operator and Department for Energy Security and Net Zero for scenarios and policy integration
- British Geological Survey and Geological Survey of Northern Ireland for atlas and classification
- Great British Energy, with the Scottish government's cabinet secretary for climate action and energy for national demonstration programme
- Heat Networks Delivery Unit for site dossiers and support for their development

All agencies coordinate for the national demonstration programme.

Why This Step Closes the Gap

A visible, standardised pipeline shortens diligence, concentrates support at the best sites, and prepares projects for risk transfer, laying the foundation for subsequent financing steps.

Step 2: Transfer Exploration Risk and Stack Public Capital Where It Has the Most Impact

In this step, the riskiest phase of geothermal development—exploration and drilling to appraise a site—is shielded from risk via early public anchors so projects can raise affordable capital before revenue contracts exist.

Actions

- **Establish a government-backed GRIF.** The GRIF would cover the risk of exploration failure, initial underperformance, and the early temperature decline. Re-insure global specialty markets so banks accept the transfer as credible. Similar public-backed drilling-risk and guarantee mechanisms already operate in Europe, providing workable precedents for a UK design. Existing UK bodies can administer this step. Design and regulatory oversight would reflect the UK's devolution settlement—energy policy and resource licensing remain reserved to the UK Parliament and the Department for Energy Security and Net Zero, but planning, local consenting, and heat policy are devolved in Scotland and Wales—so Great British Energy, the Department for Energy Security and Net Zero, and devolved administrations (such as the Scottish government) will agree on operating parameters and enforcement mechanisms.

- **Add a philanthropic or public first-loss layer.** Adding this layer of about £5 million per project to fund front-end studies and a slim-hole pilot well would generate the data needed for GRIF underwriting and de-risking transition to appraisal wells.
- **Capitalise Great British Energy for early equity.** Allocate an estimated £200 million for Great British Energy to co-invest in between 10 and 15 early-stage schemes, bridging projects from appraisal to shovel-ready. Statutory consent motions for Great British Energy investments in Scotland and Northern Ireland will be facilitated through intergovernmental agreement where required.
- **Create a geothermal sleeve within the National Wealth Fund.** Ring-fence £500 million to invest in early projects, crowding-in private equity and debt investors who would otherwise be reluctant to participate.
- **Deploy co-loans via the British Business Bank.** Offer senior or mezzanine tranches alongside commercial lenders, lowering the blended capital costs once insurance is in place.
- **Invite offtakers and the supply chain to participate.** Encourage minority equity stakes from district-heat operators, municipal energy companies, and large industrial heat users. Use oil and gas-style risk-sharing tools (for example, carried interests, service-for-equity, and multi-well structures) so drilling contractors share risks and rewards.

Who Leads

- Department for Energy Security and Net Zero and HM Treasury for GRIF design and re-insurance
- National Wealth Fund as aggregator and investor
- Great British Energy for early equity
- British Business Bank for co-lending
- Devolved administrations (such as Scottish government) and local authorities for planning and consenting alignment where projects sit within their jurisdictions
- Offtakers and service firms (voluntary participation)

Coordination Mechanism

A formal intergovernmental coordination forum will be established (Department for Energy Security and Net Zero, Great British Energy, devolved administration energy leads, and relevant regulators) to ensure clarity on devolved and reserved roles, mutual enforcement of standards and templates, and alignment of regulatory expectations across the UK's different energy governance frameworks.

Why This Step Closes the Gap

By combining insurance, first-loss support, and early public anchors, projects secure leverage and lower the cost of capital at the most finance-starved stage. De-risked wells become bankable resources, unlocking construction finance.

Step 3: Build Pilot Projects with Revenue Certainty, Not Bespoke Deals

Once resources are proven, pilot projects should be financed and built using standard revenue contracts and existing funds rather than bespoke negotiations.

Actions

- **Prioritise proven geothermal in the Green Heat Network Fund.** Once resources are confirmed via GRIF-compatible tests, the GHNF should finance network integration and customer connections. Align GHNF milestones with insurance verification to reduce timing risk.
- **Reform power contracts for geothermal CHP.** Establish a geothermal-specific budget line within Contracts for Difference, and make insurance-backed projects eligible early so electricity revenue is bankable before construction starts. Geothermal combined heat and electricity could be a subcategory of geothermal electricity only because its economics are more challenging.
- **Publish model contracts for heat.** Standardise long-term heat offtake agreements tied to zoning, with lender-friendly indexation, termination, step-in, and measurement and verification provisions that allow local councils and operators to adopt them off the shelf.
- **Encourage geothermal offtakers to be co-investors.** Create pathways for heat-network operators and

large users to take minority equity stakes—trading modest capital today for predictable heat prices tomorrow and helping unlock matched finance.

- **Bundle procurement across a demonstration portfolio.** Offer standardised
  - Well-design and stimulation workflows (leveraging oil and gas expertise);
  - Rig specifications to promote onshore rig construction and automation;
  - Organic Rankine Cycle specifications to aggregate orders to stimulate onshore production and cut lead times;
  - Engineering, Procurement, Construction, and Commissioning scopes and controls to compress schedules and reduce costs; and
  - Fast-tracked Health, Safety and Environment approvals on working organic fluids.

Who Leads

- Green Heat Network Fund for construction
- Low Carbon Contracts Company and Contract for Difference team for power contracts
- Department for Energy Security and Net Zero and Heat Networks Delivery Unit for heat contracts
- National Wealth Fund and Great British Energy for equity, debt, and bundled procurement
- Environment Agency to lead Health, Safety and Environment approvals on organic working fluids.

Why This Step Closes the Gap

Stable revenue frameworks and standard documents turn pilots into infrastructure, making them financeable and replicable.

Step 4: Align Demand and Mobilise Regional Finance So Projects Close Faster

New electricity demand can help fund local infrastructure, communities can co-finance networks, and regional institutions should establish explicit geothermal lanes.

Actions

- **Pilot a programme for large new electricity users.** In high-demand areas (such as data centres and energy-intensive plants), require the developers of large facilities to make contributions that can support local grid upgrades. These contributions should be standardised and tradeable, with reductions given for implementing on-site CHP and sharing surplus heat and electricity with nearby customers. This approach replaces blunt levies with a financeable asset and builds geothermal demand.
- **Enable local climate bonds.** Councils issue bonds for proven district-heating networks backed by contracts for heat, which lowers delivered heat prices and builds municipal ownership.
- **Mandate the Financial Conduct Authority to create a sandbox (a supervised, time-limited environment for live trials under tailored regulatory safeguards).** Conduct trials of geothermal-linked instruments such as geothermal gilts, local climate bonds, Emissions Trading System (ETS)–linked equity incentives, and tradeable infrastructure contributions.
- **Establish regional delivery lanes.** Require regional low-carbon investment funds to earmark geothermal allocations, accelerate offtake agreements with major heat-network operators, and leverage established infrastructure managers (such as Amber Infrastructure, Equitix, Schroders Greencoat, and Triple Point) to scale deployment.
- **Expand Salix Finance.** Use Salix for small, fast programmes in municipal and health-sector networks, which complements the GHNF's larger capital grants by providing rapid, interest-free public sector finance for connections and secondary-side upgrades (for example, heat interface units, controls, and metering); offering match funding; and de-risking GHNF schemes by firming near-term anchor loads.
- **Connect the workforce and supply chain.** Transition oil and gas workers via existing training frameworks, and attract oil and gas and power-equipment firms with bundling incentives such as investment zone relief, targeted capital grants, and streamlined planning. (See Chapter 8, "Beyond the North Sea: Leveraging the United Kingdom's Oil and Gas Expertise to Advance Geothermal," for more on this approach.)

Who Leads

- HM Treasury and local authorities for the local climate bonds and contribution pilots
- Financial Conduct Authority for financial instruments

- Regional funds and operators for frameworks
- Salix for municipal programmes
- Infrastructure managers for delivery

Why This Step Closes the Gap

Demand-side money and local capital reduce reliance on central funds, expedite closings, and keep tariffs affordable.

Step 5: Refinance into Low-Cost, Long-Tenor Capital and Recycle Public Money

Operating pilots are refinanced or bought out by project finance and institutional investors; government anchors recycle proceeds into the next round of wells.

Actions

- **Issue geothermal gilts and local climate bonds.** Use national gilts and local bonds to refinance proven geothermal assets at near-sovereign rates, typically 4 percentage points or 5 percentage points cheaper than private infrastructure debt.
- **Adopt reserves-based lending and portfolio finance.** Translate proven geothermal resources into collateral that banks recognise, using multi-well structures and service-for-equity models drawn from the oil and gas sector.
- **Deploy ETS-linked equity incentives.** Allocate a small, performance-linked share of anticipated lifetime carbon dioxide equivalent (CO_2e) savings, monetisable in the ETS market. At £45 per tonne of CO_2e,[38] a 40 megawatt electric and 80 megawatt thermal combined heat and electricity project avoids about 300,000 tonnes of CO_2e annually, yielding around £13.5 million in emissions value. Dedicating 10% of lifetime value could offset between £40 million and £50 million of equity without new grants.
- **Recycle the anchors.** Require the National Wealth Fund and Great British Energy to exit a project once it is refinanced, and re-deploy proceeds into the next set of appraisals and builds. This step creates a rolling programme and avoids stranded public investment.

Who Leads

- HM Treasury and UK Debt Management Office for gilts
- Local authorities for climate bonds
- Commercial banks and the British Business Bank for reserves-based lending and portfolio structures
- Emissions Trading System authority for performance-linked allocations
- National Wealth Fund and Great British Energy for reinvestment

Why This Step Closes the Gap

Low-cost take-out capital locks in affordability and frees public money to repeat the cycle—turning a handful of projects into a pipeline.

CONCLUSION

Geothermal can deliver reliable heat and truly dispatchable electricity while easing grid constraints and cutting whole-system costs. The obstacle is not the resource but the pre-construction appraisal risk that prevents otherwise viable projects from reaching build. The solution to this problem is implementing a disciplined, five-step pathway that uses existing institutions and adds a philanthropic first-loss funding step where capital is scarcest. Together, these steps turn system value into bankable cash flows.

The five steps tackle the bottleneck with insurance plus public anchors, focus each institution where it is most catalytic, bring in local and private capital, and recycle public money to fund future projects. With these steps and the institutions already in place, the United Kingdom can fund and remove early-stage risk and move projects from concept to bankable assets.

Geothermal can deliver reliable heat and truly dispatchable electricity while easing grid constraints and cutting whole-system costs. The obstacle is not the resource but the pre-construction appraisal risk that prevents otherwise viable projects from reaching build. The solution to this problem is implementing a disciplined, five-step pathway that uses existing institutions and adds a philanthropic first-loss funding step where capital is scarcest. Together, these steps turn system value into bankable cash flows.

POTENTIAL FUNDING PATHWAYS IN THE UNITED KINGDOM

Green Heat Network Fund (GHNF)

The GHNF is the main capital grant programme, covering up to 50% of eligible commercialisation and construction costs in England.[39] Launched in 2022 with £288 million, GHNF has already awarded more than £380 million.[40] In January 2026, the government announced[41] that the GHNF will receive £195 million per year in capital funding through 2030 for the commercialisation and construction of heat networks. The plan outlines the government's approach to heat network zoning, commits to publishing a national pipeline of district heating opportunities, and confirms its ambition for heat networks in England to double by 2035, providing at least 7% of England's total heat demand. While this is a welcome development for heat networks, it was also a missed opportunity to catalyse the supply of geothermal energy to those heat networks from minewater-fed heat pumps, direct heat, CHP, and aquifer thermal energy storage. Ground source heat pumps for buildings were also not incentivised. Geothermal schemes qualify only once the resource is proven and construction-ready. The GHNF does not fund exploration or appraisal drilling, so developers must raise early-stage capital elsewhere. Current rules cover "finalising contracts, procurement, planning, and technical investigations, including geological surveys and exploratory investigations." In practice, "exploratory investigations" has been applied narrowly (for example, to shallow geotechnical works), but the language could be broadened.

Heat Networks Delivery Unit (HNDU)

The HNDU provides early-stage grant support and technical guidance to local authorities for developing heat network pilots.[42] Since inception, it has distributed about £40 million to more than 300 projects.[43] HNDU funding can help position geothermal heat for integration into local network business cases—but again, it does not fund the subsurface resource risk phase.

Public Sector Decarbonisation Fund

More than £2.7 billion in grants have been awarded to support decarbonisation projects in public sector buildings between financial years 2020–21 and 2025–26.[44,45] Beneficiaries have included local authorities, schools, hospitals, and emergency services. The University of York was awarded £35 million to decarbonise multiple buildings across its main campus in York, most of which will be connected to an on-site geothermal heating network, while others will link to the existing district heating system.[46]

Contracts for Difference (CfD)

The CfD programme is the United Kingdom's flagship mechanism for providing long-term revenue certainty to low-carbon electricity generators.[47] The funding rounds for geothermal (Allocation Round [AR]5–AR7) are as follows:

- **AR5 (2023):** Three Geothermal Engineering Ltd projects—Manhay (5 megawatts electric), Penhallow (5 megawatts electric), and United Downs (2 megawatts electric)—secured 12 megawatts electric CfDs at £119 per megawatt-hour (2012 prices).
- **AR6 (2024):** The administrative strike price for geothermal rose to £157 per megawatt-electric-hour in 2012 prices (~£219 per megawatt-electric-hour in 2024 prices).[48] No geothermal projects were awarded CfDs in AR6.
- **AR7a (2025), Pot 2:** The administrative strike price for geothermal remained at £219 per megawatt-electric-hour in 2024 prices. The value of the pot was £15 million to allocate between all emerging technologies listed.[49]

The CfD structure does nothing to finance the pre-construction risk capital phase, when tens of millions of pounds per project may be needed for resource appraisal drilling before any revenue contract can be signed.[50]

National Wealth Fund (formerly UK Infrastructure Bank)

Now rebranded as a £28 billion sovereign-backed fund, the National Wealth Fund's mandate extends beyond infrastructure to include wider industrial strategy objectives.[51] While the fund can provide debt or equity for proven geothermal network projects—especially if linked to regional economic development and in association with private funds—it has a minimum £25 million ticket size, with a target of between £25 million and £50 million.[52]

Great British Energy (GB Energy)

GB Energy is planned as a state-backed investment vehicle with £8.3 billion over the parliamentary term.[53] Its remit is still under consultation, and equity stakes in early-stage geothermal would require an explicit mandate and allocation. The initial budget is modest: £100 million allocated for 2025–26, with significant scale-up not expected until after 2026.

British Business Bank (BBB)

The BBB channels capital via delivery partners such as Amber Infrastructure and Salix Finance. With £6.8 billion in deployable funds (2024–25)—including about £2.3 billion via Enterprise Capital Funds—BBB offers debt and limited equity (typically less than £5 million; range less than £1 million to £14 million[54]) at commercial rates. Its real value lies in financing small and medium enterprise supply-chain actors (for instance, drilling contractors, civils, fabrication, controls, and network installers) rather than direct project development.

Contracts for Heat (Conceptual/Proposed in This Chapter)

Not yet operational, contracts for heat would mirror the economic incentives of CfDs by offering long-term, fixed-price offtake. They could give geothermal projects bankable revenue certainty but would require statutory zoning and standard lender-friendly templates. Until then, projects remain dependent on ad hoc agreements.[55]

Geothermal Resource Insurance Facility (GRIF; Conceptual/Proposed in This Chapter)

Not yet operational, a GRIF could address the United Kingdom's main geothermal barrier: the tens of millions of pounds in appraisal drilling risk that block projects before GHNF or CfD support is viable. By underwriting this phase, the GRIF would shift risk into global re-insurance markets and unlock cheaper capital. Coverage would include the following:

- Exploration failure (dry wells)
- Underperformance (low flow and temperature)
- Early decline (first 5 years to 10 years)

Policies would use deductibles and co-insurance to limit moral hazard, with subsidised premiums. As mentioned in the summary, comparable public-backed geothermal risk guarantee and drilling-risk cover schemes already operate in Europe—including France's GEODEEP guarantee fund, the Netherlands' Garantieregeling Aardwarmte, and Germany's KfW geothermal drilling-risk cover—showing that this type of risk-transfer tool is an established way to catalyse private investment.[56,57,58] The Department for Energy Security and Net Zero and HM Treasury could administer GRIF, reinsured by firms such as Munich Re or Swiss Re. Precedents in France and Germany, as well as with the World Bank and European Investment Bank, show such schemes cut financing costs by around 20% and expand pipelines by more than 50% in five years.

GRIF should link directly to GHNF and CfD allocations so insured wells move seamlessly into bankable projects. Combined with GB Energy equity and NWF co-investment, taking this step would complete a UK geothermal financing chain.

PLAN OF ACTION

What departments can do in the next 12 months to 24 months:

1. **Publish and place GRIF.** Issue terms for a government-backed insurance facility covering exploration failure, underperformance, and early decline, and secure re-insurance in global specialty markets.

2. **Capitalise early-stage anchors.** Confirm a £500 million geothermal sleeve within the National Wealth Fund and £200 million for Great British Energy to co-invest in at least 10 early-stage schemes. Enable British Business Bank co-loans alongside insured projects.

3. **Standardise site data and contracts.** The British Geological Survey and the Heat Networks Delivery Unit should publish a site information and assessment dossier with due-diligence templates; the Department for Energy Security and Net Zero and the Heat Networks Delivery Unit should release model contracts for heat tied to zoning; and the Low Carbon Contracts Company and the Contracts for Difference team should confirm a geothermal budget line with early eligibility for insured projects.

4. **Launch the national demonstration programme.** Select a mixed portfolio of heat-only and combined heat and electricity generation sites in specific regions; bundle procurement; invite offtaker minority equity; and deliver quarterly reports on cost, schedule, test results, availability, and contracted revenues.

5. **Pilot demand-side and local finance.** Run infrastructure contribution pilots for large new electricity users with offset credits; enable local climate bonds on model terms.

6. **Prepare refinancing lanes.** Develop geothermal gilt templates, agree on reserves-based and portfolio finance structures with lenders, and implement Emissions Trading System–linked equity incentives with claw backs.

7. **Support the atlas and the workforce.** Fund the British Geological Survey to perform new data and atlas updates; expand oil and gas reskilling pathways and procurement frameworks to speed workforce transition.

CHAPTER REFERENCES

1 Climate Change Committee. (2020). *Sixth carbon budget*. https://www.theccc.org.uk/publication/sixth-carbon-budget/

2 National Energy System Operator (NESO). (2024). *Future energy scenarios*. https://www.neso.energy/publications/future-energy-scenarios-fes

3 BRGM. (2022, September 9). *Development of deep geothermal resources in France*. https://www.brgm.fr/en/reference-completed-project/development-deep-geothermal-resources-france

4 Project InnerSpace. (n.d.). *GeoMap*. https://geomap.projectinnerspace.org/geomap/

5 National Energy System Operator (NESO). (2024). *Clean power 2030: Advice on achieving clean power for Great Britain by 2030*. NESO. https://www.neso.energy/document/346651/download

6 Millard, R., & Pickard, J. (2024, November 5). Britain will need gas plants as "back-up" for wind in 2030, says grid operator. *Financial Times*. https://www.ft.com/content/2b3aff38-570c-4718-b26d-3fa346110b14

7 Linvill, C., Candelaria, J., & Elder, C. (2013). *The value of geothermal energy generation attributes: Aspen report to Ormat Technologies*. Aspen Environmental Group.

8 Department for Business, Energy and Industrial Strategy. (2021). *Opportunity areas for district heating networks in the UK: National comprehensive assessment of the potential for efficient heating and cooling*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/61371cdbd3bf7f05b166a517/opps_for_dhnnca_hc.pdf

9 Department for Energy Security and Net Zero. (2025). *UK geothermal platform*. Government of the United Kingdom. https://www.gov.uk/government/publications/uk-geothermal-platform

10 British Geological Survey (BGS). (n.d.). *UK geothermal platform*. https://ukgeothermalplatform.org

11 National Energy System Operator (NESO). 2024. *Summer outlook*. https://www.neso.energy/document/316126/download. Heat network cost = £3 per megawatt thermal per hour = £7.9 per kilowatt thermal per year at 30% capacity factor.

12 Ofgem. (2022). Appendix 1–Demand HCC development methodology. In *Access and forward-looking charges significant code review: Decision and direction*. Government of the United Kingdom. https://www.ofgem.gov.uk/sites/default/files/2022-05/Appendix%201%20%E2%80%93%20Demand%20HCC%20development%20methodology1651572982904.pdf. Grid reinforcement capital cost: £1720 per kilovolt-ampere (that is, kilowatt electric for 1.0 power factor) = £73–£173 kilowatt electric annualised.

13 British Geological Survey. (n.d.). *Geothermal energy*. https://www.bgs.ac.uk/geology-projects/geothermal-energy/

14 Calculated by the author based on various resources.

15 Historical well counts are derived from North Sea Transition Authority (NSTA). (2024).*Wells insight report 2024*. https://www.nstauthority.co.uk/news-publications/wells-insight-report-2024/

16 Data indicate that approximately 6,800 offshore wellbores and around 1,500 onshore wellbores spudded between 1980 and 2025. British Geological Survey (BGS). (2023, June 15). *A new open dataset to benefit onshore geoscience research*. BGS News. https://www.bgs.ac.uk/news/a-new-open-dataset-to-benefit-onshore-geoscience-research

17 Fervo Energy. (2025, June 10). *Fervo Energy drills 15,000-ft, 500°F geothermal well pushing the envelope for EGS deployment* [Press release]. https://fervoenergy.com/fervo-energy-pushes-envelope/

18 National Energy System Operator (NESO). (n.d.). *Constraint breakdown 2022-2023* [Database]. https://www.neso.energy/data-portal/constraint-breakdown/constraint_breakdown_2022-2023

19 Eastern Green Link. (n.d.). *Eastern Green Link 1: Torness–Hawthorn Pit*. https://www.easterngreenlink1.co.uk

20 Eastern Green Link. (n.d.). *Eastern Green Link 2*. https://www.easterngreenlink2.co.uk/

21 National Energy System Operator (NESO). (2024). *Beyond 2030: A national blueprint for a decarbonised electricity system in Great Britain—Web map*. NESO. https://www.neso.energy/publications/beyond-2030/web-map
22 Ofgem. (2023). *Accelerated strategic transmission investment guidance and submission requirements document*. Government of the United Kingdom. https://www.ofgem.gov.uk/sites/default/files/2023-08/Accelerated%20Strategic%20Transmission%20Investment%20Guidance%20And%20Submission%20Requirements%20Document.pdf
23 HM Treasury. (2022). Annex 6: Discounting. In *The green book*. Government of the United Kingdom. Last updated May 2024. https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government/the-green-book-2020
24 UK Power Networks. (n.d.). *Distribution network energy losses*. https://www.ukpowernetworks.co.uk/distribution-network-energy-losses. This reports that transmission and distribution totaled 7.2% of the total electricity consumed in Great Britain. These electricity-network losses were 21.4 terrawatt-hours in 2023.
25 Calculated by the author based on various resources.
26 National Energy System Operator (NESO). (2024). *Annual balancing services spend report 2023/24*. https://www.neso.energy/document/346086/download.This report shows approximately £1.01 billion total balancing services spend and ancillary services share.
27 National Energy System Operator (NESO). (2023). *Monthly balancing services summary 2023/24: June 2023*. https://storage.googleapis.com/dx-national-grid/national-grid/resources/251db6d5-6acd-40bd-ab64-f5b0ba760a19/mbss-june-2023.pdf. This report shows £52.82 million spent on ancillary services out of £115.23 million total (~45%).
28 Department for Energy Security and Net Zero. (2025). *UK energy in brief 2025*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/688890c3a11f859994409132/UK_Energy_in_Brief_2025.pdf
29 HM Treasury, 2022.
30 *The Green Book* uses a Social Time Preference Rate (STPR) for discounting.
31 Department for Transport. (2024). *Value for money: Supplementary guidance on categories*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/673e1cd02ff787d4e01b08d6/value-for-money-supplementary-guidance-on-categories.pdf. See Box 1.1 on page 4.
32 National Agency for Territorial Cohesion & the Ministry of Territorial Planning and Decentralization. (n.d.). *SA.48894 GEODEEP–Guarantee fund for geothermal projects*. Government of France. https://www.europe-en-france.gouv.fr/fr/aides-d-etat/regimes-d-aide/sa48894-sa48894-sas-geodeep-guarantee-fund-geothermal-projects
33 Netherlands Enterprise Agency. (2025, February 27). *Covering risks for geothermal energy (RNES Geothermal Energy)*.Government of the Netherlands. https://www.rvo.nl/subsidies-financiering/rnes
34 Richter, A. (2025, December 18). *Germany launches KfW geothermal loan and drilling risk cover*. ThinkGeoEnergy. https://www.thinkgeoenergy.com/germany-launches-kfw-geothermal-loan-and-drilling-risk-cover/
35 Department for Energy Security and Net Zero & Department for Business, Energy and Industrial Strategy. (2021). *Industrial decarbonisation strategy*. Government of the United Kingdom. https://www.gov.uk/government/publications/industrial-decarbonisation-strategy
36 Geothermal Technologies Office. (n.d.). *FORGE*. U.S. Department of Energy. https://www.energy.gov/eere/geothermal/forge
37 McClennan, J., Swearingen, L., & England, K. (2024). *Utah FORGE: Wells 16A(78)-32 and 16B(78)-32 Stimulation Program Report—May 2024* [Data set]. Geothermal Data Repository, Energy and Geoscience Institute at the University of Utah. https://doi.org/10.15121/2483880

38 Department for Energy Security and Net Zero. (2024). *Traded carbon values used for modelling purposes, 2024*. Government of the United Kingdom. https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2024/traded-carbon-values-used-for-modelling-purposes-2024. Central scenario values around £37 per tonne of CO_2-equivalent in 2024, increasing in later years.
39 Department for Energy Security and Net Zero. (2025). *Green Heat Network Fund (GHNF): Guidance on how to apply*. Government of the United Kingdom. https://www.gov.uk/government/publications/green-heat-network-fund-ghnf
40 Department for Energy Security and Net Zero, *Green Heat Network Fund*, 2025.
41 Department for Energy Security and Net Zero. (2026). *Warm homes plan*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/696f8a3ec0f4afaa9536a0c4/warm-homes-plan-standard-print.pdf
42 Department for Energy Security and Net Zero. (2017). *Heat Networks Delivery Unit*. Government of the United Kingdom. Last updated on January 19, 2026. https://www.gov.uk/guidance/heat-networks-delivery-unit
43 Department for Energy Security and Net Zero, 2017.
44 Department for Energy Security and Net Zero. (2024). *Public Sector Decarbonisation Scheme*. UK Parliament. https://questions-statements.parliament.uk/written-questions/detail/2024-05-07/25109
45 Department for Energy Security and Net Zero. (2024). *Public Sector Decarbonisation Scheme: Phase 4–projects awarded funding*. Government of the United Kingdom. https://www.gov.uk/government/publications/public-sector-decarbonisation-scheme-phase-4
46 Department for Energy Security and Net Zero. (2025). *Phase 4 Public Sector Decarbonisation Scheme: Project summaries*. Government of the United Kingdom. https://www.gov.uk/government/publications/public-sector-decarbonisation-scheme-phase-4/phase-4-public-sector-decarbonisation-scheme-project-summaries
47 Low Carbon Contracts Company (LCCC). (n.d.). *Contracts for Difference*. https://www.lowcarboncontracts.uk/our-schemes/contracts-for-difference/
48 Low Carbon Contracts Company (LCCC). (2024). *CfD Allocation Round Six (AR6) results*. https://www.lowcarboncontracts.uk/news/cfd-allocation-round-six-ar6-results/
49 Government of the United Kingdom. (2025, December 8). *Accompanying note to the contract budget notice for Allocation Round 7a (AR7a), 2025*. https://assets.publishing.service.gov.uk/media/6936af1070840a535475d3fd/cfd-ar7-second-contract-budget-notice-accompanying-note.pdf
50 GTW UK Ltd analysis of UK geothermal project pre-construction cost structures, September 2024. Unpublished internal document.
51 National Wealth Fund. (n.d.). *National Wealth Fund*. https://www.nationalwealthfund.org.uk/
52 National Wealth Fund. (n.d.). *Our products and terms*. https://www.nationalwealthfund.org.uk/private-sector-finance/our-products-and-terms
53 House of Commons Library. (2024, October 25). *Great British Energy Bill 2024-25*. UK Parliament. https://commonslibrary.parliament.uk/research-briefings/cbp-10088/
54 British Business Bank (BBB). (2024). *Small business equity tracker 2024*. https://www.british-business-bank.co.uk/sites/g/files/sovrnj166/files/2024-07/sbet-2024-report.pdf
55 Conceptual mechanism; no formal government documentation.
56 National Agency for Territorial Cohesion & the Ministry of Territorial Planning and Decentralization, n.d.
57 Richter, 2025.
58 Netherlands Enterprise Agency, 2025.

Chapter 10

A New Age of Innovation: The United Kingdom's Geothermal Start-Up Scene

Puja Balachander, UpGreen and former Carbon13

In interviews with more than 30 developers, technology providers, and investors, there was consensus that the UK start-up ecosystem is strong, but lacks the conditions needed to translate its advantages into a pipeline of reproducible projects. With the right regulatory signals and business-model innovations, UK companies are well positioned to deploy substantial geothermal resources.

The United Kingdom has the geology, skills, and customer demand for a more robust geothermal industry, with significant opportunities for economic development, jobs, and reduced costs. Yet the market remains constrained by policy friction, financing gaps, supply chain bottlenecks, and lack of awareness. Interviews with founders, investors, councils, and operators across the value chain confirm a consistent pattern: Technically, the sector is ready to move; commercially, however, the pieces are still being assembled.

For this case study, we interviewed 30 people working in the UK geothermal innovation ecosystem to gain an understanding of the significant challenges they face. The result was clear: The United Kingdom is missing necessary conditions to convert its advantages into a pipeline of bankable, reproducible projects. Today, because most investors are still warming to exploration or first-of-a kind risk—and because many customers (especially heat users) are still learning that geothermal is an option—projects tend to stall at feasibility, and technology companies often look abroad for early customers while they wait for the UK market to mature.

In the near term, momentum will hinge on zoning for district heat networks, financial vehicles for exploratory drilling that share and minimise risk, and business-model innovation that aligns with offtakers' needs. Developers are seeking patient capital and a way to fund exploration and deployment of technology that has been proven overseas. Technology providers need pilot projects, customers, and fit-for-purpose procurement. Investors want standardisation and scale. A pragmatic path forward is emerging: Bundle projects; de-risk early wells; pull proven tools and skill sets from oil and gas; and build the market around anchored, price-sensitive heat loads.

Still, multiple operators and councils believe that as district heat network zoning is integrated into local energy master plans, these systems will be catalysts for geothermal adoption, especially when paired with models that combine heat and power or otherwise improve possibilities for revenue. Near Newcastle in England, Gateshead Council is interested in proposals that use power generation to subsidise the cost of heat—which shows how the choice of business model can make the case for network expansion. With the right regulatory signals and continued model innovation, UK start-ups are well positioned to unlock domestic demand for geothermal deployment.

THREE PERSISTENT CHALLENGES

Policy

Interviewees describe fragmented policy, lack of incentives, and slower UK processes relative to continental peers. These hurdles stretch timelines and weaken projects' internal rates of return. Operators compare the unfavourable climate in the United Kingdom with markets where incentives and procedures are predictable, even if bureaucratic. Chapter 5, "Clearing the Runway: Policies and Regulations to Scale the United Kingdom's Geothermal Potential," provides policy recommendations that seek to overcome some of the following issues.

Karen Spenley, UK country director for Celsius Energy, which focuses on shallow geothermal energy, pointed to the abrupt cancellation in June 2025 of the Public Sector Decarbonisation Scheme (PSDS), a key UK government funding programme designed to help public sector organisations cut carbon emissions by improving the energy efficiency of their buildings and switching to low-carbon heat. This cancellation eliminates an important source of funding for demonstrating the viability of geothermal and raises questions about the stability of public sector incentives and therefore predictability around UK policy and funding.

Lack of public awareness across the ecosystem and policy issues are significant barriers to development. For example, shallow geothermal options are frequently dismissed in early project stages due to misconceptions about the space required to install a ground source heat pump and capital expenditures. As Spenley noted, consultants and installers often "discard ground source" early when guiding clients to choose energy saving and heat decarbonisation measures, and the recommendation goes unchallenged because the supply chain is not up-to-date on what shallow solutions can deliver.

It bears repeating that without practical and clear steps, an efficient planning process, grants that move at a reasonable pace, and greater recognition of heat's role in decarbonisation, many of the companies trying to move this resilient energy industry forward are at great risk of faltering.

Financing

All of the developers we spoke to said that the first "valley of death"—or the first big possibility of failure—comes after a project has been deemed feasible but before drilling has begun in earnest. The cost of establishing an exploration well can run to eight figures, yet financial returns accrue slowly, often more on utility company timelines than on venture capital timelines. Even with interest from councils and industrial clients for the offtake of the geothermal heat or energy, funding for this riskier stage of a project is difficult to find. Solid projects, in other words, get stuck at feasibility.

Current public financing mechanisms have not yet been able to bridge this gap. Most recently, this is because high-risk phases of geothermal development were not eligible for the once-promising PSDS.

An equally big hurdle for developers is that even though advanced geothermal projects in other countries have proven unit economics, execution, and technologies, companies have not been able to find the funding to build such a project in the United Kingdom. Infrastructure and growth investors still see tech proven in other countries as too risky for the United Kingdom because the technology is only recently proven, the projects have not yet scaled overseas, and the investors do not feel UK developers have a track record. The funding amounts needed and the time scales for returns do not pencil in. Investors are still weary of making a £30 million investment to drill on a single project.

It is a chicken-and-egg problem.

Technology providers face a similar challenge: first-of-a-kind performance risk. The only reliable way to prove technology is by advancing Technology Readiness Level steps with grants and early equity agreements and, at the same time, establishing a pilot program to prove their products (which then removes risks for investors). The problem is that there are not many opportunities for equity funding, as well as few pilot opportunities. Vasiliy Zbaraskiy of ZerdaLab works on advanced drilling technology. While he has been able to generate revenue from sales of drill bits, he said, "The bottleneck is not just the technology—it's finding someone willing to trial it in a real well." Developers, as mentioned, tend to be risk-averse because of the tenuous economics of each project.

Even early developers who have gotten funding for exploration and first-of-a kind deployments face challenges as they look for financing to scale. Early first-of-a-kind projects in the United Kingdom drilled under tight funding and timelines—and were successful. They achieved their targets. But according to Caroline Carroll of Cornwall Council, goalposts later shifted: Investors changed their expectations on cost, time, and output. The mismatch was caused at least in part by flaws in how early public financing for geothermal projects was structured, with requirements for rapid outputs in a short period of time with inflexible deliverables.

Consequently, there has been less opportunity for innovation and learning. As a result, early projects now face friction between grant-backed exploration funding and private capital for scale—despite customer demand.

Supply Chain

Developers also have a list of worries on the horizon. Once they get past feasibility and exploration to drilling, they are concerned about mobilisation costs and the availability of rigs. Kevin Gray, director of Black Reiver Consulting and an adviser to Stormhawk Energy (which sells circulation drilling technology), pointed out that for certain drilling operations, potentially only one rig is currently available in the United Kingdom, so equipment must be brought in from overseas and then returned after use. This process can cost between around £1 million and £1.5 million per project, a massive barrier for single-well projects. Indeed, Gray has seen the founders of Stormhawk Energy need to look outside the United Kingdom to test and prove new technology because of these issues and government skepticism of legacy projects. To help the rig supply chain, a number of wells in a sequence are needed; for example, the UK National Health Service (NHS) could procure 10 or more projects, which would keep a rig busy for three years. This approach would reduce the per-well burden of mobilisation or enable a drilling contractor to finance the building of a new rig.

Procurement is also fraught for some. Rob Stewart, the founder of GreenWeaver, which aims to decarbonise district heat, said he does not hear much about geothermal in his conversations with private district heat networks operators because district heat network operators are often backed by "patient, conservative capital" such as infrastructure funds and pension funds and are not typically risk-takers. The heat network industry could also benefit from increased education in civil engineering and deep geothermal development.

WHAT WORKS: MODELS THAT MOVE THE NEEDLE

Despite these barriers, founders and investors alike emphasised that the fundamentals for a strong UK geothermal market remain in place. In fact, many of the challenges slowing progress—policy gaps, financing friction, supply chain needs, and awareness—highlight the areas where innovation and coordination can have the greatest impact. The good news is that there are already models, markets, and technologies within the UK ecosystem that show how geothermal can scale, given the right conditions.

Market Opportunities Created by Public Sector and AI Revolution

While the PSDS is no longer taking new applications, NHS trusts and universities do have PSDS funding for geothermal projects, and these will continue to receive support. Star Energy was granted four out of the five NHS tenders it applied for and considers hospitals to be its most advanced counterparts. These kinds of public sector projects offer strong opportunities to demonstrate the potential of geothermal to provide affordable heat given an anchor load.

Many interviewees felt that district heat networks are a critical mechanism for achieving scale, driving demand, and improving project economics, especially for public sector decarbonisation. Gateshead Council is using its heat network plan to target the decarbonisation of 14,500 homes and public infrastructure. CeraPhi Energy, a UK-based geothermal developer that designs and deploys closed-loop wells and heat networks, is also working on heat network projects ranging from a few hundred kilowatts up to 10 megawatts, often through a heat-as-a-service (HaaS) model for anchor institutions such as swimming pools and government properties.

Interviewees also highlighted geothermal as a solution for data centres and the artificial intelligence (AI) revolution because it can provide a reliable source of cooling and, in select locations, electricity. Magma, a company retrofitting electric submersible pumps (ESPs) to withstand thermal and corrosive degradation, specifically targets data centres. Magma's technology enables the reliable extraction of high-temperature fluid for power generation, with residual heat driving absorption chillers for cooling. Magma's managing director, Andrew Milne, wants to see geothermal plants deployed near the affordable real estate where many data centres are built, unlocking a dual supply of resilient power and thermal management.

Utility-Style HaaS and Business Model Innovation

Kensa, a provider of shallow geothermal solutions in the United Kingdom, is developing a utility-like model for new-build housing. The company is betting on the UK's plans for 200,000 new homes per year—and the new requirement that all new homes use low-carbon heating systems by 2027. In Kensa's business model, housing developers would pay for in-unit heat pumps, Kensa would fund the shared subsurface and lateral infrastructure, and homeowners or tenants would pay for heating. The idea is to reduce up-front costs and simplify decision-making for housebuilders.

CeraPhi's business model aims to offer modular, off-grid, closed-loop geothermal systems to anchor load heat customers such as hospitals, schools, or public buildings, then build heat networks in the community around these customers, making the costs of energy predictable and bringing more customers in, with the aim of reducing the payback period on initial capital expenditures.

Tools Plus Aggregation: Reducing Costs, Risk, and Time

Underground Ventures, a European venture capital fund dedicated to geothermal, prioritises investing in the tools that cut costs, risk, and time, rather than projects directly. That approach is echoed by investors such as Sarah Black of alfa8, a UK-based family office. Black also looks for drilling, sensing, materials, and options that standardise and help scale geothermal production. The through-line is enabling technology and project aggregation that make the infrastructure for geothermal projects financeable by building a portfolio to reduce and diversify risk.

UK companies working on these types of technology tools can pursue a more traditional venture funding path than their peers who develop projects. ZerdaLab manufactures drill bits via machine-learning algorithms that optimise design and performance. To get started, the team bootstrapped its initial funding via a small grant and some private funding from the Middle East. It has since generated revenue from sales of drill bits to geothermal and oil and gas operators. The company's drill bits have improved project economics for clients.

Stormhawk Energy has developed a mobile continuous-circulation system that can be retrofitted to standard rigs. The team funded the development of the system itself and tested the prototype in Romania. As of the writing of this report, Stormhawk is raising a seed round from family offices and specialised investors to build three commercial units and deploy the system in two geothermal projects.

ZerdaLab and Stormhawk are illustrative of the UK ecosystem writ large: The founders of both companies came from oil and gas and bootstrapped their initial development. The business plan for both companies is to sell their technology to the oil and gas sector while waiting for the geothermal market to catch up. Both companies have also looked outside the United Kingdom for their early pilot sites.

These similarities point to three elements of the ecosystem that work and ought to be catalysed: the talent pool and experience of the UK oil and gas sector, the market in oil and gas for early-stage geothermal technology, and the bridge from UK technology to global markets.

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"IF YOU HAD £100 MILLION TODAY...": THE UK GEOTHERMAL WISH LIST

We asked how interviewees would use £100 million in funding. The following sections cover their responses.

Implementing Demonstrations

In interviews, there was consensus among developers, technology providers, investors, academics, and councils that £100 million could help fill the need for demonstration projects in the United Kingdom that would prove the feasibility, economics, and technologies of geothermal. In particular, interviewees such as Tim Lines of Geothermal Wells, a deep geothermal developer (and a consultant to Project InnerSpace), and Caroline Carroll of Cornwall Council called for the development of a National Geothermal Centre of Excellence. This centre would be a publicly owned demonstration site similar to the U.S. Frontier Observatory for Research in Geothermal Energy (FORGE) initiative in Utah that focuses explicitly on research and development. Such a project would provide a test bed for new technologies and ensure that all data and lessons learned would be open-source to support geothermal expansion.

Karen Spenley of Celsius Energy said that money could help her fund 100 demonstrators across the country to prove the performance of the technology, show unit economics, and showcase what is possible. Demonstration projects like these could show policymakers and the general public that taxpayer money can be put to good use and simultaneously show infrastructure investors that projects are bankable through repetition.

Multiple interviewees mentioned that £100 million would enable them to create an Exploration Fund so they could drill a set of exploration wells in different pockets of the United Kingdom to prove temperatures and flow rates and eliminate the exploration "valley of death" by catalysing more private financing. Tony Pink, chief technology officer of Eden Geothermal, noted that the Dutch are already drilling exploration wells systematically.

Moving Forward with Projects

Some interviewees—such as Stuart Sinclair of Consortium Drilling, a rig and drilling contractor—were impatient. With £100 million, they would move quickly, taking advantage of low-hanging fruit and existing incentives and momentum, such as approved PSDS-funded projects. As of the writing of this report, Sinclair is ready and waiting for a project to drill in the United Kingdom. Jeremy Wrathall and Michael King of Cornish Lithium are prepared to develop three or four sites that will commercially produce both lithium and heat, targeting locations where they see existing demand.

UK GEOTHERMAL START-UP ECOSYSTEM

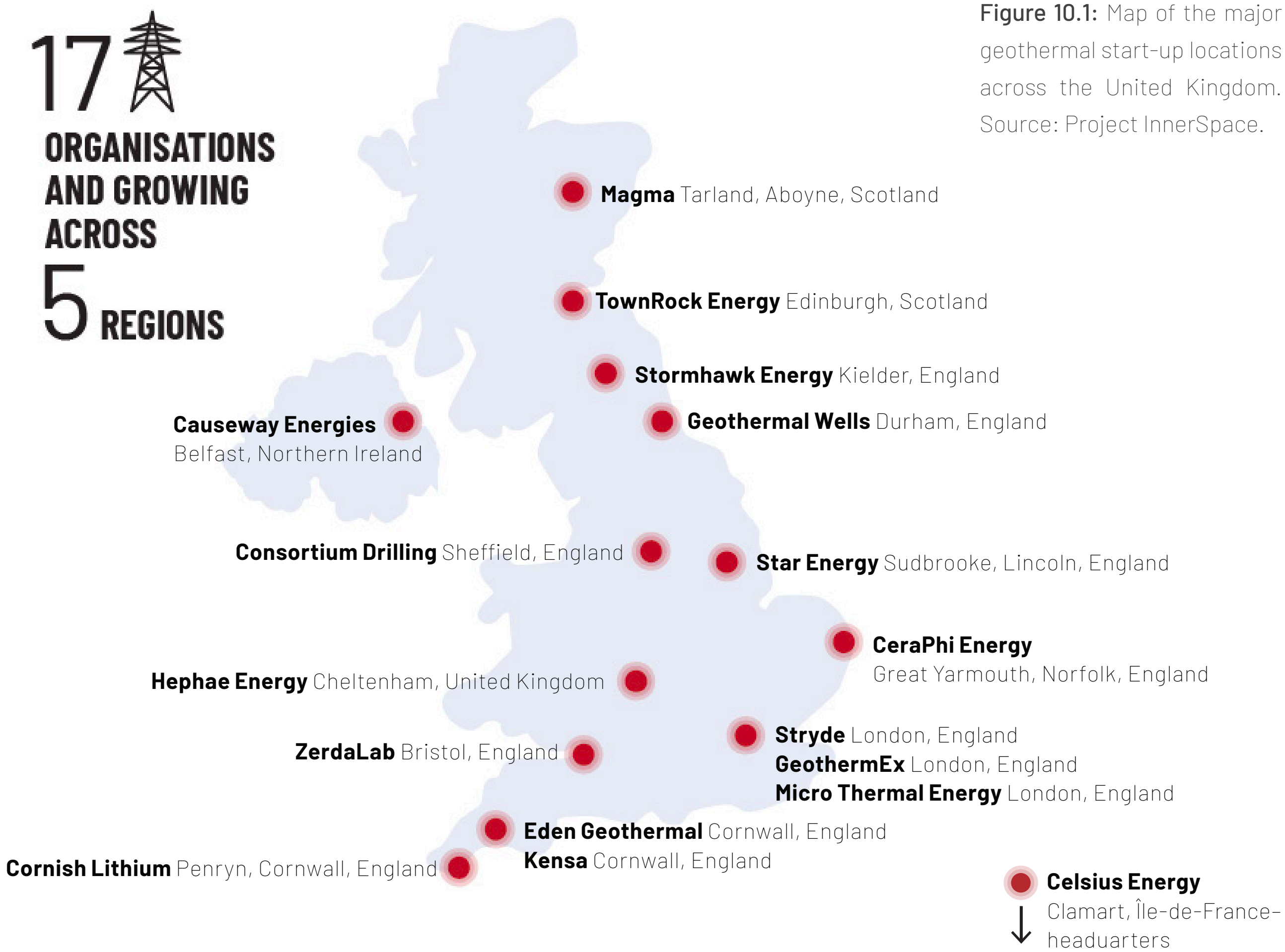

Figure 10.1: Map of the major geothermal start-up locations across the United Kingdom. Source: Project InnerSpace.

Building Portfolios

Investors said they would work to create efficiencies given supply chain challenges such as rig scarcity and to bring more aggregation to UK geothermal development. Sarah Black from alfa8 proposed putting together an umbrella special-purpose vehicle to bundle UK projects, standardise contracts, share rigs and teams, and secure infrastructure-style capital against a diversified risk profile.

In fact, Black maintained that technology is not the primary barrier for scaling geothermal in the United Kingdom. The problem is finding financial and operational models that make geothermal economical. She reiterated that aggregating projects and investing in the developers in those portfolios can bring infrastructure capital into the market.

In fact, Sarah Black from alfa8 maintained that technology is not the primary barrier for scaling geothermal in the United Kingdom. The problem is finding financial and operational models that make geothermal economical.

Deploying and Scaling up Building and Sensing Technology

Investors such as Torsten Kolind and advisers like Kevin Gray want to accelerate their backing of drilling, sensing, and materials companies that have a clear path to deployment. With £100 million, they would focus on technology that lowers the cost of producing heat per unit of energy and the cost of drilling per unit of annual energy output and that is transferable from the oil and gas sector.

Helle Ehrenreich of Micro Thermal Energy is working on a closed-loop single-well system with a downhole heat exchanger and a new turbine design. She said her company was at the design stage (Technology Readiness Level [TRL] 4) and needed to raise capital to conduct laboratory testing so it could reach TRL 6. Ehrenreich said just a small portion of that capital would facilitate the first pilot project. She was confident the results would be the tip of the iceberg for the development and scale the company could achieve.

Optimising Drilling Rigs

Many interviewees said that £100 million would allow them to invest in specialised rigs for their use cases. Sinclair from Consortium Drilling would invest in the design and construction of bespoke, urban-style rigs that could tackle issues such as pollution and noise. Karl Farrow of CeraPhi Energy mentioned that the gap between the rigs needed for shallow geothermal and the larger oil and gas rigs needed for deep (plus the need to create something for the medium-depth geothermal projects) is a focus of his work. Kensa, on the other hand, works with rigs that are highly specialised for shallow geothermal work.

Models that have been applied to other climate technologies can support geothermal technology companies as well, including seeding the ecosystem itself, helping early-stage technology become market-ready, and connecting more market-ready technology between the United States and the UK market.

Venture studios such as Marble have identified growth opportunities where they hope to fund solutions:

- **Geothermal heating and cooling:** reduced installation costs and times; innovations in working fluids, materials, heat pumps, and district heating integration
- **Geothermal electricity:** innovations in drilling and (especially) complementary technologies (e.g., materials, sensors, well integrity, modular power plants)
- **Risk mitigation:** data, AI, remote-sensing to reduce exploration risk and required up-front capital

THE PATH FORWARD FOR UK GEOTHERMAL

Developers have different support needs than technology providers. Ecosystem-wide interventions can knit the market together.

Biggest Support Needs

For developers: exploration-risk capital; policy backing and awareness; fit-for-purpose grant structures; access to skilled multidisciplinary teams (especially from oil and gas); project-bundling vehicles that de-risk at the portfolio level

For technology providers: access to pilot and demonstration sites; first-of-a-kind risk mitigation; customer education and adoption pathways; funding continuity from grants to early equity to growth to debt

Ecosystem-wide: coordinated market and policy push; better technology to address project matchmaking; a bridge to bring proven technology to the United Kingdom

FUNDING RAISED BY THE UK ECOSYSTEM

Since 2021, significant capital has flowed into the UK geothermal sector from multiple industry and investor sources, including Cornish Lithium (approximately £88 million), CeraPhi (approximately £15 million), Geothermal Engineering Ltd's United Downs project (about £15 million, in addition to being awarded a Contract for Difference by the UK government), Eden Geothermal (more than £20 million), Rendesco (£6 million), and Stryde (more than £30 million). According to Underground Ventures, several smaller, undisclosed investments have also taken place across early-stage UK geothermal ventures, highlighting increasing investor confidence in a market that has historically been undercapitalised.

Venture builders and accelerators such as Carbon13 could bring together founders with relevant backgrounds and intellectual property in this area to seed companies that are filling technology gaps and to support teams in getting to pilot projects, reaching global markets, and connecting to funding.

This approach could catalyse founders. Take Ben Adams, who earned a doctorate from Camborne School of Mines and developed his own model for heat flow in and out of a well. An Eden Geothermal project proved the technology's accuracy. Adams found that incorrect modelling could lead to an outlet temperature difference of up to 20 degrees, resulting in a project output of only 200 kilowatts instead of the quoted 500 kilowatts. He hopes to expand his model to include engineered geothermal systems and is debating whether to commercialise the model or release it as a free tool.

CONCLUSION

The United Kingdom is positioned to be an innovation engine for geothermal, but realising this potential requires a step change in policy, coordination, risk-sharing, and visibility for both developers and technology innovators.

UK GEOTHERMAL START-UP STAGES

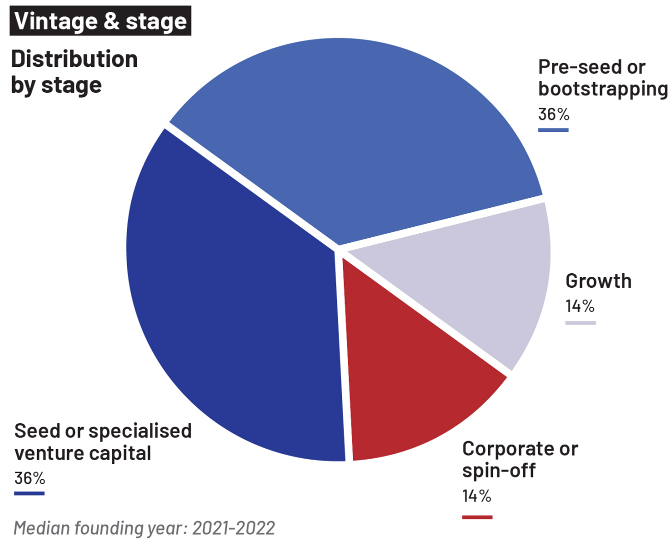

Figure 10.2: The geothermal start-up ecosystem is strongly weighted toward early-stage innovation, with more than 70% of companies at pre-seed, bootstrapping, or seed/specialist venture capital stages—highlighting a rapidly emerging sector and growing pipeline of companies positioned to scale into growth and commercial deployment. Source: author.

UK GEOTHERMAL START-UP FOCUS AREAS

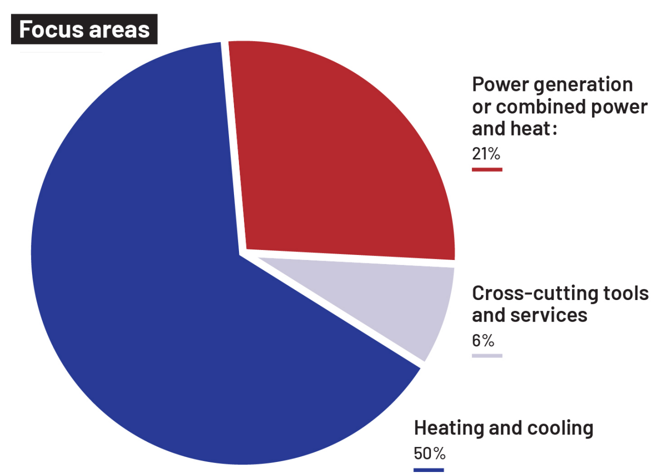

Figure 10.3: UK geothermal start-ups are primarily focused on heating and cooling applications, reflecting near-term deployment opportunities, while a growing share targeting electricity generation and combined heat and power highlights increasing ambition to scale geothermal solutions across the energy system. Source: author.

UK GEOTHERMAL START-UPS REPRESENTED IN INTERVIEWS

Value-Chain Role	Examples and Details
Exploration (EXP)	• **TownRock Energy:** consulting firm working across stages, including exploration • **Cornish Lithium:** company identifying and developing sites for lithium and geothermal co-production • **Star Energy:** geothermal project developer involved from exploration stage • **CeraPhi Energy:** geothermal project developer involved from exploration stage • **Geothermal Wells:** geothermal project developer involved from exploration stage • **Stryde:** seismic monitoring technology to de-risk subsurface • **GeothermEx** consulting firm working across feasibility, resource assessment, and due diligence • **Eden Geothermal:** geothermal project developer involved in heat and electricity projects from the exploration phase
Drilling & well construction (DWC)	• **ZerdaLab:** drill bit optimisation • **Stormhawk Energy:** continuous circulation system for cost and risk reduction • **Consortium Drilling:** rig contractor and onshore drilling services • **Kensa:** automated shallow drilling and casing processes • **Celsius Energy:** inclined drilling to minimise surface footprint • **Hephae Energy:** high-temperature downhole sensors and tools for well intervention • **Magma:** high-temperature electric submersible pumps for fluid lift • **CeraPhi Energy:** custom tracked geotechnic rigs and CeraPhi 1500 well design • **TownRock Energy:** well design and management consulting
Heat exchange (HX)	• **Kensa:** manufactures ground-source heat pumps (GSHPs) and systems • **Celsius Energy:** integrates GSHPs and waste heat recovery for thermal battery recharge • **CeraPhi Energy:** provides closed-loop systems and heat recovery via CeraPhi 1500 well • **Causeway Energies:** focuses on industrial heat pumps combining geothermal heat with industrial needs • **Micro Thermal Energy:** developing a closed-loop system with a downhole heat exchanger for fluid to surface
Organic Rankine Cycle/ Power (PWR)	• **Magma:** electric submersible pumps designed to pump supercritical or two-phase fluid to maximise power generation per well • **Micro Thermal Energy:** development of a new turbine design for surface conversion of heat to electricity • **Eden Geothermal:** deep geothermal project aiming to export power to the grid • **Geothermal Wells:** focus on power plus heat, using power revenue to subsidise heat costs • **Cornish Lithium:** potential to drill for deep geothermal power
Heat-as-a-service (HaaS)	• **Kensa:** deploys a utility-style HaaS model funding the shared subsurface infrastructure • **CeraPhi Energy:** offers turnkey geothermal-as-a-service using modular systems for B2B anchor customers • **Causeway Energies:** exploring HaaS and thermal purchase agreements for deployment
District integration (DI)	• **Kensa:** deploys systems linked together in the road to create small-scale heat networks • **Star Energy:** focuses on serving and decarbonising existing district heat networks (e.g., Southampton) • **Celsius Energy:** targets large projects and B2B customers seeking to integrate into heat networks • **Geothermal Wells:** works with councils to design heat networks requiring large heat and power output • **TownRock Energy:** provides consulting and feasibility studies for heat network integration • **Eden Geothermal:** works with councils and corporations to develop deep geothermal wells to large manufacturers and with hospitals to provide keystone customers to heat networks.

Figure 10.4: UK Geothermal ecosystem players represented in interviews. B2B = business-to-business. Source: Puja Balachander.

INTERVIEWEES AND AFFILIATIONS

Andrew Milne	Managing Director, Magma ESP
Ben Adams	Director and Head of Thermal Modelling, Geothermal Modelling Solutions
Caroline Carroll	Senior Trade and Investment Manager, Cornwall Council
Daniel Phillipson	Managing Partner and Founder, Deep Energy Capital
David Townsend	Founder, TownRock Energy
Eva Marquis	Postdoctoral Research Fellow, University of Exeter (adviser on technology metal)
Helle Ehrenreich	CEO and Founder, Micro Thermal Energy
Ingrid El Helou	Venture Science Associate, Marble Venture Studio
Ishan Sharma	Adviser, Project InnerSpace
Jeremy Wrathall	Founder and Executive Chairman, Cornish Lithium
Jim Gillon	Service Director for Design and Energy, Gateshead Council
John Clegg	President and Chief Technology Officer, Hephae Energy Technology, and Adviser, Project InnerSpace
Karl Farrow	Founder, CeraPhi Energy
Karen Spenley	UK Country Director, Celsius Energy
Kevin Gray	Adviser, Stormhawk Energy; Director, Black Reiver Consulting
Lisl Lewis	Geothermal Consultant and Project Manager, GeothermEx
Michael King	Vice President of Business and Government Relations, Cornish Lithium
Neil Edward	Principal Well Engineer, Well Safe Solutions
Nick Tranter	Head of Business Development, New Energy and Services, Stryde
Rob Stewart	Founder, GreenWeaver
Robin Shail	Associate Professor of Geology, Camborne School of Mines
Ross Glover	Chief Executive Officer, Star Energy
Sarah Black	Director, Geothermal and Energy Investments, alfa8
Simon Todd	Managing Director, Causeway Energies
Stuart Sinclair	Chief Executive Officer, Consortium Drilling
Timothy Lines	Chief Executive Officer, Geothermal Wells; Adviser, Project InnerSpace
Tony Pink	Director/Owner, Pink Granite Consulting; Chief Technology Officer, Eden Geothermal; Adviser, Project InnerSpace
Torsten Kolind	Co-founder, Underground Ventures
Vasiliy Zbaraskiy	Director, Chief Technology Officer, ZerdaLab
Wouter Thijssen	Commercial Director, Kensa

Chapter 11

The History of Geothermal in the United Kingdom

Helen Doran, Project InnerSpace; Gioia Falcone and David Banks, University of Glasgow;
Jon Gluyas, Durham University and National Geothermal Centre; and Mark Ireland, Newcastle University;
technical review by Cathy Hollis, University of Manchester

The United Kingdom has a long, proven record of geothermal exploration and deployment—from the 1977–1991 UK Geothermal Energy Programme to decades of reliable operation at the Southampton District Energy Scheme. Today, digitised national data sets; new screening and mapping tools; revitalised research funding; and a growing ecosystem of public, academic, and industry initiatives are translating that legacy into a practical pathway to scale geothermal heat, storage, and targeted electricity generation across the country.

In the wake of the 1973 oil crisis, concerns in the UK government about energy security drove a new interest in geothermal energy. The UK Geothermal Energy Programme (1977–1991)—led by the Department of Energy and the Institute of Geological Sciences (now British Geological Survey [BGS])—was the most comprehensive early national undertaking. It resulted in the drilling of seven deep geothermal boreholes, including three hot dry rock (HDR) wells at Rosemanowes,[1,2] near Cornwall, and four aquifer-targeted wells in Southampton and Marchwood (Hampshire), Cleethorpes (Lincolnshire), and Larne (Northern Ireland).[3,4,5] That work established a baseline understanding of the UK's heat flow and subsurface thermal gradients, but commercial uptake was constrained by low market interest, technical uncertainties, and the shift of national interest to the production of petroleum from the UK Continental Shelf.

A notable output of this period was the 1980s BGS *Catalogue of Geothermal Data for the Land Area of the United Kingdom*,[6] which recorded crucial information about subsurface temperatures, heat flow, and geochemical data. The first version was published

by the Department of Energy in 1978, and subsequent updates were made in 1982, 1984, and 1987. Although foundational, this catalogue has not been updated with any measurements since 1987. In 2024, BGS produced the first digitised version of the catalogue.[7]

Of the seven wells drilled on behalf of the UK government during the 1980s, the one in Southampton was developed for geothermal energy provision and heat distribution and forms the basis for the Southampton District Energy Scheme.[8] The three wells drilled into the granite at Rosemanowes Quarry, near Penryn, Cornwall, became research boreholes for testing geophysical equipment. They are now owned by Avalon Science Ltd and remain accessible.[9]

The Southampton District Energy Scheme uses a single-well abstraction system to produce water at around 75°C, delivering approximately 1.7 megawatts thermal from the Triassic Sherwood Sandstones as part of a combined heat and power network in central Southampton. The decision to retain and develop the well, rather than abandon it, was driven by Mike Smith, then an accountant with Southampton City Council who almost single-handedly championed and developed the scheme, which has been in operation since 1987.[10]

Despite the UK Geothermal Energy Programme and the publication of the BGS *Catalogue*, there was little interest from government, industry, or academia in the geothermal potential of the United Kingdom until the early 2000s. At that point, interest was reawakened by the late Paul Younger, who responded to a proposal from a regional development agency in the Northeast[11] to repurpose an abandoned quarry and cement works at Eastgate in Weardale County Durham as an eco-village. Younger suggested that heat could be provided to the proposed village using the proven geothermal resource of the area.[12] The village plan was not executed, but the Eastgate 1 well was drilled in 2003 through 2004 and designed to cross-cut the Slitt Vein, a major fault system within the Weardale Granite known from mining records to have substantial fracture-based porosity and permeability. The well was drilled to a terminal depth of 998 metres below rotary table and tested warm water at very high flow rates,[13] with solute ratios that suggested equilibration at temperatures well above 100°C.[14] A second well was drilled at Eastgate in 2010 by a partnership between Newcastle and Durham universities that was supported by the UK government's deep geothermal fund. The well was designed to confirm the fracture and fault permeability architecture in the Weardale Granite.[15]

Newcastle University partnered with Durham University and Newcastle City Council to drill the Newcastle Science Central Deep Geothermal Borehole in central Newcastle in 2011. It was planned to intersect the 90 Fathom Fault at the level of the Lower Carboniferous Fell Sandstone at a depth of around 1.8 kilometres. The well was executed on a very tight budget, resulting in few downhole data points being collected. The well reached the target as planned and demonstrated both high heat flow and a bottomhole temperature of 73°C at 1,740 metres, a little higher than projected. Heat flow was estimated at 88 milliwatts per square metre. However, the well failed to flow on test.[16,17]

This active geothermal exploration work led to the formation of BritGeothermal, a consortium including three universities (Newcastle, Durham, Glasgow) and the BGS with a mission to promote and develop geothermal energy in the UK. The two main outputs of BritGeothermal were the recognition of geothermal being distinct from shale-gas fracking in the UK Infrastructure Act and a revision to the UK geothermal resource base published by the BGS in the 1980s.[18]

Since the wells were drilled in Weardale and Newcastle, geothermal exploration and development in the UK have grown substantially, much of it driven by the work of Charlotte Adams, who recognised the potential for exploiting the tepid water that now occupies almost all of the 23,000 abandoned mines in the UK.[19] In particular, Adams reasoned that while the temperature was low, the permeability of mined areas is exceptionally high. (This reasoning ran counter to the view of geothermal skeptics in the UK who often cited the risk of encountering low-permeability rock as a reason not to undertake a project.) Adams further reasoned that UK councils needing to reduce greenhouse gases could become developers of low-grade, low-carbon, mine-water heat systems in their areas, which did in fact happen. Gateshead Council's initial 6 megawatt scheme became operational in March 2023, shortly after the first industrial minewater geothermal scheme became operational in the same council area for Lanchester Wines.[20] At a national level, the North East Local Enterprise Partnership (NE LEP) commissioned a white paper that assessed minewater geothermal potential across the UK and highlighted key regulatory and economic constraints.[21]

Building on its success, NE LEP went on to oversee a UK-wide deep geothermal reevaluation for the Department of Business, Energy and Industrial Strategy, extending the work of Gluyas et al. (2018) with contributions from BGS and Arup.[22]

In 2024, the UK National Geothermal Centre (NGC) was created by a partnership between Durham University (Durham Energy Institute), the Net Zero Technology Centre, and Shift Geothermal Ltd, with financial support provided by the Reece Foundation. The centre aims to facilitate the development of the United Kingdom as a geothermal nation, with its work covering four areas of activity: (1) policy, regulation, and investment; (2) technology and innovation; (3) infrastructure; and (4) research and knowledge. The centre has been appointed to manage the Department for Energy Security and Net Zero's (Deep) Geothermal Task Force. The NGC announced in September 2025 that it had signed a memorandum of understanding with the Renewable Energy Association to promote geothermal energy in the United Kingdom.

In addition to the NGC, several other initiatives and organisations are contributing to the growth of the geothermal sector in the United Kingdom. The Geothermal UK Coalition, led by Anne Murrell, plays an important role in advocating for geothermal's strategic integration into the national energy mix and raising its profile across government and industry.[23] Industry associations such as Offshore Energies United Kingdom's Geothermal Energy Forum, the Heat Pump Association,[24] and the Renewable Energy Association's newly formed Geothermal Energy Advancement Association[25] are driving awareness, technical standards, and policy engagement across both shallow and deep geothermal applications. Regional collaborations such as the London Geothermal Consortium[26] further highlight the growing momentum behind geothermal deployment in specific urban and infrastructure contexts. Together, these initiatives reflect a diverse and complementary ecosystem that is helping position geothermal energy as a vital component of the United Kingdom's transition to secure energy.

In 2025, *UK Geothermal Energy Review and Cost Estimations*[27] was published alongside the launch of the UK Geothermal Platform,[28] a new BGS-developed hub showcasing geothermal potential across the United Kingdom. Commissioned by the Department for Energy Security and Net Zero and led by Arup, the report provides the most detailed assessment of UK geothermal costs to date, including the first levelised cost of heat and power estimates, while the department has also issued a cover note outlining the research's purpose, scope, and intended use.[29]

EVOLVING DATA INFRASTRUCTURE AND SCREENING TOOLS

Recent years have seen major improvements in digital data availability. The 2024 release of the UK Geothermal Catalogue in digital form represents a significant step forward in accessibility. Building on this catalogue, BGS is developing a new digital portal, the UK Geothermal Platform, to unify geothermal data sets and models. A precursor to this system includes a set of legacy geothermal models such as depth-to-top Sherwood Sandstone aquifer maps.[30]

For shallow systems, BGS maintains the Open-Loop GSHP Screening Tool, which supports preliminary assessments of groundwater suitability for heating and cooling across England and Wales.[31] This tool is critical for enabling developers and local authorities to identify viable sites for open-loop geothermal installations.

BGS has also played a leading role in synthesising strategic assessments, including the white paper *The Case for Deep Geothermal Energy*,[32] which provides an overview of resource potential, barriers, and recommendations.

CURRENT NATIONAL AND REGIONAL STUDIES

Heat-demand mapping conducted by the former Department for Business, Energy, and Industrial Strategy and the Department for Energy Security and Net Zero has informed spatial planning of low-carbon heating infrastructure. These maps focus on surface heat demand density rather than subsurface resource quality and thus must be interpreted in conjunction with geological models for geothermal targeting.

Multiple researchers have conducted deep geothermal resource assessments of the Lower Carboniferous limestones across central and southern Great Britain, providing updated estimates of temperature, reservoir thickness, and thermal capacity.[33,34,35] These studies are three of the most rigorous basin-scale assessments to date and underpin much of the recent planning for geothermal heat networks.

Gluyas and colleagues evaluated the capacity of the UK's deep saline aquifers for heat storage,[36] and Imperial College London is now leading two major geothermal research projects: (1) ATESHAC (Aquifer Thermal Energy Storage for the Decarbonisation of Heating and Cooling),[37] which further explores the role of aquifers in seasonal heat storage, and (2) SMARTRES (Smart Assessment, Management and Optimisation of Urban Geothermal Resources),[38] which addresses technical and regulatory challenges in subsurface thermal resource development.

Regional studies in Northern Ireland by Geological Survey of Northern Ireland (GSNI) have focused on the Lough Neagh Basin and northeast Antrim, identifying thermal gradients, aquifer potential, and resource confidence levels.[39] In 2022, Northern Ireland's Department for the Economy announced that it would make available £3 million in funding to deliver geothermal demonstrator projects as part of the GeoEnergy NI project in two separate locations in Northern Ireland to investigate both shallow and deep geothermal potential.[40]

Exploratory geothermal drilling and testing took place at the first of these two sites between 2024 and 2025 on the grounds of Stormont Estate in Belfast. The investigations at Stormont examined the shallow geothermal opportunities and their potential to provide sustainable, low-carbon, renewable heating and cooling to several pre-identified buildings on the estate. Investigations consisted of the drilling and testing of five boreholes, which ranged between approximately 100 metres and 300 metres deep and were used to examine open-loop and closed-loop potential and gather stratigraphic information about the local geology in the area using rotary coring. A series of downhole geophysical and pumping tests and analyses were carried out to ascertain the optimal numbers and depths of boreholes required to deliver low-carbon, renewable heat to the estate.

In parallel, the GeoEnergy NI project completed a feasibility study at the College of Agriculture, Food and Rural Enterprise (CAFRE) Greenmount Campus near Antrim to assess the viability and plan for the drilling of a deep geothermal borehole doublet. During summer 2023, the GeoEnergy NI team conducted detailed geophysical surveys (including of gravity, magnetotelluric, and seismic reflection) around CAFRE to assess deep geothermal potential. Data from this survey have been used to inform a 3D geological model to approximately 2 kilometres deep, evaluating the area's suitability for a geothermal district heating network. A planning application supported by an Environmental Impact Assessment was lodged in June 2025. The work was supported by local stakeholders and forms part of a wider project exploring geothermal demonstrators in both Antrim and Belfast, led by the Department for the Economy, with scientific support from GSNI.

Numerous organisations—including the Ministry of Defence, housing developers, industrial heat users, and leisure centres—have evaluated the use of shallow and deep geothermal, and many city and local councils across the UK have also commissioned feasibility studies (such as Newcastle City Council,[41] Durham County Council,[42] and Glasgow City Council[43]). Such studies are commonly integrated with decarbonisation planning and urban planning and housing development schemes. These studies may also assess the practicality of ground source heat pump (GSHP) deployment in residential and commercial zones. Other unique public sector partnerships have helped raise the profile of geothermal potential across the United Kingdom. For example, the Ministry of Defence has evaluated the feasibility of geothermal energy production at numerous sites since 2020; in 2022, in partnership with Newcastle University as a first-of-its-kind effort for the United Kingdom, the ministry acquired a high-density 3D seismic survey.[44] While less work has been done on the environmental impact of geothermal development,[45] one significant study was commissioned by the Environment Agency to evaluate the risks associated with repurposing petroleum industry infrastructure for geothermal energy (see the section on onshore activity).[46] This report followed an analysis of the potential for heat generation from the end-of-life Welton Oil Field in Lincolnshire, as well as the geothermal potential of the whole of the East Midlands Oil Province.[47,48,49]

INDUSTRIAL DEPLOYMENT AND DEMONSTRATION PROJECTS

The most recent deep geothermal developments are located in Cornwall and are the first developments since the Southampton District Energy Scheme in 1987. The Eden Geothermal Project, supported by multiple stakeholders (including the University of Exeter), has completed a well that is 4,871 metres deep (measured depth or total length of 5,277 metres) and is now supplying direct heat to the Eden Eco Park.[50] Geothermal Engineering Ltd. (GEL) operates the United Downs Deep Geothermal Project, with a production well drilled to 5,275 metres measured depth and a re-injection well to 2,393 metres measured depth, targeting the radiogenic Cornubian granite batholith.[51] GEL has the first-ever Contract for Difference issued in the United Kingdom for electricity generation from geothermal energy.[52] The United Downs project also aims to deliver a second revenue stream from lithium extraction of produced water.[53]

These projects mark the first commercial-scale demonstrations of deep geothermal in the United Kingdom. They have also yielded valuable thermal and geochemical data sets that support wider national geothermal assessments. The involvement of universities in Cornwall, notably the Camborne School of Mines at the University of Exeter, has been critical to the interpretation of subsurface data and fault system characterisation.[54]

ACTIVITY FOR REPURPOSING EXISTING OIL AND GAS WELLS

Onshore

The United Kingdom has a significant legacy of onshore oil and gas drilling, with 2,135 exploration, appraisal, and development wells recorded by the North Sea Transition Authority.[55] This extensive subsurface infrastructure has sparked growing interest in whether these wells could be repurposed for geothermal energy production unlocking access to deep, hot formations without the cost of drilling new wells, although not without risks.[56]

In the United Kingdom, the idea of repurposing onshore oil and gas wells for geothermal use was first proposed for heat storage applications by Westaway,[57] with several studies following suit. Globally, interest in this approach has accelerated,[58] and the UK is beginning to see tangible steps being taken.

To date, the only UK well actively undergoing repurposing for geothermal demonstration is Kirby Misperton-8 (KM-8) in North Yorkshire. Exploration for natural gas in this area began in the 1970s, resulting in three gas fields in the Vale of Pickering, Kirby Misperton, Marishes, and Pickering[59] all produced from the Upper Permian Zechstein dolomite reservoir. KM-8 also yielded gas from Namurian sandstones, sourced from Lower Carboniferous organic-rich shales, as identified in the original exploration well KM-1.

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In 2015, KM-8 was drilled to a total vertical depth of 3,068 metres to test a tight gas play within the Lower Carboniferous section.[60] At the time, operator Third Energy intended to hydraulically fracture the reservoir, but plans were halted due to local protests and, later, the withdrawal of financial backing. The well remained suspended for nearly a decade.

In 2023, CeraPhi Energy acquired the rights to KM-8 and announced plans to recomplete the well as a closed-loop, coaxial geothermal demonstrator.

Since 2006, a range of geoscience and engineering research projects, totalling around £90 million, have been publicly funded, principally through UK Research and Innovation (UKRI) schemes.

Research Projects

Since 2006, a range of geoscience and engineering research projects, totalling around £90 million, have been publicly funded, principally through UK Research and Innovation (UKRI) schemes. Of that, about £22 million has been provided by Innovate UK to support business-led innovation. These projects, awarded to more than 30 different research organisations, have supported developing knowledge, understanding, and capability despite the lack of commercial uptake, and they play a crucial role in UK geothermal research. Organisations including BGS, the University of Glasgow, Durham University, Newcastle University, Imperial College London, the University of Leeds, and the University of Manchester have all led multiple research projects on geothermal energy, such as thermo-physical properties (THERMOCAL[61]), assessment and management of geothermal resources (SmartRes[62]), the acquisition and processing of novel seismic data for exploration (Project VITAL),[63] integration of minewater geothermal into energy systems (GEMS[64]), and quantitative understanding of fluid flow in granitic rocks (GWatt[65]). A full list of funded projects can be found by searching on the UKRI website (gtr.ukri.org).

Uniquely, the UK has two subsurface observatories designed for shallow geoenergy studies, called the

UK Geoenergy Observatories. These facilities were funded in 2017 by the UK's Department for Business, Energy and Industrial Strategy, now the Department for Energy Security and Net Zero, and are owned by UKRI's Natural Environment Research Council. They are being operated by BGS. They were delivered through an initial £31 million investment from the 2014 UK government plan for the growth of science and innovation. Glasgow, Scotland, is home to one observatory, a fully instrumented minewater geothermal research site providing real-time temperature and fluid data from a network of boreholes.[66] A second site in Cheshire is home to a field-scale laboratory for research and innovation in aquifer underground thermal energy storage, rock volume characterisation, and subsurface process monitoring. The facilities can be used by research institutes and industry.

Industry, academia, and regional stakeholders are proposing a UK programme similar to the Frontier Observatory for Research in Geothermal Energy (FORGE) programme in the United States that could establish two next-generation geothermal test and demonstration hubs in the southwest and northeast parts of England. Building on the success of the U.S. FORGE programme, the initiative aims to unlock stalled projects, reduce drilling costs, and accelerate UK geothermal growth, delivering up to 300 gigawatt-hours per year of baseload power and 230 gigawatt-hours per year of heat per site. With a projected £250 million investment (70% public and 30% private), the programme would drive innovation, attract private capital, create high-value jobs, and enable the North Sea oil and gas transition while supporting the United Kingdom's clean energy goals.[67]

In addition, the University of York has secured a £35 million grant from the UK government's Public Sector Decarbonisation Scheme, delivered by Salix Finance, with an additional 12% matched funding from the university. Located on the university's Campus East site in York, the initiative is a deep geothermal energy project designed to tap into the geothermal heat beneath the campus to provide a low-carbon heating solution—and, in later phases, potentially generate electricity. The first phase, spanning approximately three years, will focus on supplying geothermal heat to most campus buildings, reducing fossil fuel consumption by an estimated 78%. Over a total project timeline of around six to seven years, subsequent phases will explore electricity generation and the potential to expand heat provision to the wider York community. The project is also envisioned as a "living laboratory," supporting research, education, and community engagement around renewable energy and decarbonisation.[68]

In September 2025, the United Kingdom's National Wealth Fund announced a £31 million commitment to geothermal developer Cornish Lithium to advance its projects to the next stage of development, following an earlier £24 million investment in 2023, when the fund operated as the UK Infrastructure Bank.[69] The new funding will support two key initiatives: the Trelavour Lithium Project, which focuses on hard-rock lithium extraction, and the Cross Lanes Geothermal Lithium Project, which uniquely combines geothermal drilling with lithium recovery. The latter is particularly significant because it integrates renewable energy and mineral extraction—using geothermal heat and fluids to extract lithium—thereby demonstrating a hybrid model that leverages shared subsurface infrastructure. This approach not only strengthens Cornwall's role in the United Kingdom's critical minerals supply chain but also positions the region as a dual-asset hub for both geothermal energy and lithium production.

Finally, Star Energy is applying its onshore oil and gas experience to the development of geothermal heat projects in the UK. Its Salisbury Geothermal Project in Wiltshire aims to provide heat to Salisbury District Hospital by drawing from deep aquifers, using adapted drilling techniques and existing supply chains.[70] The company has undertaken geological assessments, early stakeholder engagement, and risk-reduction measures to evaluate the project's feasibility.

GEOTHERMAL RESOURCE REPORTING

Historically, the geothermal sector (both globally and in the United Kingdom) has suffered from ambiguity in the terminology and approaches used to report quantities of geothermal energy, which has left too much latitude in geothermal assessment, thereby leading to less confidence in development. In addition, with no bespoke regulation of the geothermal industry in the UK currently in place,[71] no single organisation has the remit to manage the reporting of geothermal energy resources.

With a diverse range of geothermal opportunities, a major challenge is the inherent difficulty in defining what the appropriate metric actually is when assessing geothermal energy resources. Should it be the primary resource, the reservoir, fluids, stored heat, recoverable volume, recoverable heat, recoverable power, or net profit? This challenge is further complicated by changing environmental, policy, and regulatory constraints nationally and around the globe.

The amount of energy that can be dynamically extracted over a project's lifetime (for example, 30 years) ultimately depends on the specific technologies and system designs employed. Rybach already highlighted the progression needed to go from theoretical to developable geothermal potential.[72]

As shown in Chapter 3, "Where Is the Heat? Exploring the United Kingdom's Subsurface Geology," Heat-in-Place figures can be further converted into estimates of recoverable quantities. For electric power generation projects, for example, the latter are a function of the thermal energy stored in the reservoir, the rate of thermal energy recovery at the wellhead, and the efficiency with which the latter can be converted into electric power. Electric power generation can be estimated from a stored heat estimate through the application of a recovery factor, an energy conversion factor, a power plant capacity factor, and power plant life. (See Chapter 3, Appendix B, for more detail.)

A consistent assessment framework for geothermal energy resources is needed by investors, regulators, insurers, governments, and consumers as a foundation for a comprehensive overview of current and future energy sustainability scenarios at the project, company, country, region, or world levels and to offer greater confidence in development.

CHAPTER REFERENCES

1 Parker, R. (1999). The Rosemanowes HDR project 1983–1991. *Geothermics, 28*(4–5), 603–615. https://doi.org/10.1016/S0375-6505(99)00031-0

2 Parker, R. H. (Ed.). (1989). *Hot dry rock geothermal energy: Phase 2B final report of the Camborne School of Mines Project*. Pergamon Press. https://openlibrary.org/books/OL2190432M/Hot_dry_rock_geothermal_energy#overview

3 Downing, R. A., & Gray, D. A. (Eds.). (1986). *Geothermal energy: The potential in the United Kingdom*. HMSO. https://nora.nerc.ac.uk/id/eprint/537257

4 Downing, R. A., & Gray, D. A. (1986). Geothermal resources of the United Kingdom. *Journal of the Geological Society, 143*(3), 499–507. https://doi.org/10.1144/gsjgs.143.3.0499

5 Barker, J. A., Downing, R. A., Gray, D. A., Findlay, J., Kellaway, G. A., Parker, R. H., & Rollin, K. E. (2000). Hydrogeothermal studies in the United Kingdom. *Quarterly Journal of Engineering Geology and Hydrogeology, 33*(1), 41–58. https://doi.org/10.1144/qjegh.33.1.41

6 Rollin, K. E. (1987). *Catalogue of geothermal data for the land area of the United Kingdom: Third revision, April 1987*. British Geological Survey. Unpublished. https://nora.nerc.ac.uk/id/eprint/537114

7 British Geological Survey (BGS). (2024). *UK digital geothermal catalogue, version 1* [Data set]. BGS. https://www2.bgs.ac.uk/nationalgeosciencedatacentre/citedData/catalogue/05569ed5-db0e-4587-807c-58e39ee240fa.html

8 Gearty, M. (2008). *Southampton District Energy Scheme: A story of collaboration and steady ambition*. University of Bath. https://people.bath.ac.uk/mnspwr/doc_theses_links/pdf/dt_mg_APPDXGSouthampton_case_issue_vws_A5.pdf

9 Avalon Sciences Ltd. (n.d.). *Avalon borehole test facility*. https://avalonsciences.com/services/avalon-borehole-test-facility/

10 Gluyas, J. G., et al. (2018). Keeping warm: A review of deep geothermal potential of the UK. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 232*(1), 115–126. https://doi.org/10.1177/0957650917749693

11 Government of the United Kingdom. (n.d.). *One North East*. https://www.gov.uk/government/organisations/one-north-east

12 Dunham, K. C., Johnson, G. A. L., Bott, M. H. P., & Hodge, B. L. (1961). Granite beneath the Northern Pennines. *Nature, 190*(4782), 899–900. https://doi.org/10.1038/190899a0

13 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

14 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

15 Gluyas, J. G., Adams, C. A., Narayan, N. S., & Hirst, C. M. (2020). The geothermal potential of the fractured Weardale granite and associated aquifers of County Durham and adjacent areas, northern England. In *Proceedings of the World Geothermal Congress 2020*. Reykjavik, Iceland. https://www.worldgeothermal.org/pdf/IGAstandard/WGC/2020/16046.pdf

16 Younger, P. L., Manning, D. A. C., Millward, D., Busby, J. P., Jones, C. R. C., & Gluyas, J. G. (2016). Geothermal exploration in the Fell Sandstone Formation (Mississippian) beneath the city centre of Newcastle upon Tyne, UK: The Newcastle Science Central deep geothermal borehole. *Quarterly Journal of Engineering Geology and Hydrogeology, 49*(4), 350–363. https://doi.org/10.1144/qjegh2016-053

17 Sutton, R. (2022). *Assessing the geothermal potential of the Lower Carboniferous Fell Sandstone* [Doctoral dissertation, Durham University]. Durham E-Theses Online. http://etheses.dur.ac.uk/14692

18 Gluyas et al., 2018.

19 Adams, C. A., Monaghan, A. A., & Gluyas, J. G. (2019). Mining for heat. *Geoscientist, 29*(4), 10–15. https://nora.nerc.ac.uk/id/eprint/523186/

20 Adams, C., Gordon, J., & Parker, K. (2022). *The Gateshead mine water heat scheme: Coal mining in Great Britain*. Coal Authority. https://www.spe-aberdeen.org/uploads/1115-SPE-Aberdeen-Feb23-Adams.pdf

21 Kirkup, W., Cavey, A., Lawrence, D., Crane, M., Gluyas, J. G., & Handley, W. (2021). *The case for mine energy—unlocking deployment at scale in the UK*. North East Local Enterprise Partnership. https://www.midlandsnetzerohub.co.uk/media/cw0hj5q1/mine-energy-white-paper_final.pdf

22 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

23 Geothermal UK. (n.d.). *Geothermal UK*. https://www.geothermaluk.org

24 Heat Pump Association. (n.d.). *Heat Pump Association*. https://hpauk.org.uk/

25 Renewable Energy Association. (2025, October 17). *Renewable Energy Association and the Geothermal Energy Advancement Association come together to drive forward the growth of geothermal energy in the UK*. https://www.r-e-a.net/renewable-energy-association-and-the-geothermal-energy-advancement-association-come-together-to-drive-forward-the-growth-of-geothermal-energy-in-the-uk

26 London Geothermal. (n.d.). *London Geothermal Consortium*. https://londongeothermal.com/

27 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

28 British Geological Survey. (2025). *UK geothermal platform*. https://ukgeothermalplatform.org/

29 Department for Energy Security and Net Zero. (2025). *Cover note: UK geothermal energy review and cost estimations*. Government of the United Kingdom. https://assets.publishing.service.gov.uk/media/6891e217e8ba9507fc1b0a20/geothermal-energy-review-cover-note.pdf

30 British Geological Survey. (n.d.). *Legacy BGS geothermal models: Depth to the top Sherwood Sandstone Group in the Permo-Triassic Cheshire, Worcester, Wessex and East Yorkshire-Lincolnshire basins* [Vector contour data set]. Derived from Rollin, K. E., Kirby, G. A., & Rowley, W. J. (1995). *Atlas of geothermal resources in Europe: UK revision* (British Geological Survey Technical Report WK/95/7, Regional Geophysics Group) and the European Geothermal Atlas. https://hosted-metadata.bgs.ac.uk/geonetwork/srv/api/records/0ba977bd-62a5-4e3b-8fac-d568f413fe9e

31 British Geological Survey. (n.d.). *Open-loop GSHP screening tool (England and Wales)*. https://www.bgs.ac.uk/geology-projects/geothermal-energy/geothermal-technologies/open-loop-gshp-screening-tool/

32 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 & British Geological Survey.

33 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.

34 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

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 Gluyas, J. G., Adams, C. A., & Wilson, I. A. G. (2020). The theoretical potential for large-scale underground thermal energy storage (UTES) within the UK. *Energy Reports*, *6*(Suppl. 7), 229–237. https://doi.org/10.1016/j.egyr.2020.12.006

37 Department of Earth Science and Engineering. (n.d.). *Project: ATESHAC*. Imperial College London. https://www.imperial.ac.uk/earth-science/research/research-projects/ateshac

38 Department of Earth Science and Engineering (n.d.). *Project: SMARTRES*. Imperial College London. https://www.imperial.ac.uk/earth-science/research/research-projects/smartres

39 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

40 GeoEnergy NI. (n.d.). *The demonstrator projects*. Department for the Economy. https://geoenergyni.org/demonstrator-projects

41 Newcastle City Council. (2022). *Net zero Newcastle: Priority actions update April 2021-August 2022*. Newcastle City Council.

42 City Science. (n.d.). *Unlocking heat network potential in County Durham*. https://cityscience.com/case-study/unlocking-heat-network-potential-in-county-durham

43 Hilley, S. (2022 August 12). Glasgow energy crisis could get lifeline with 6km geothermal well in Clyde. *Glasgow News*. https://www.glasgowlive.co.uk/news/glasgow-news/glasgow-energy-crisis-could-lifeline-24741071

44 https://geoscientist.online/sections/unearthed/seismic-for-geothermal/

45 Environment Agency. (2024). *Environmental impacts of teperature changes from ground source heating and cooling systems: Summary*. Government of the United Kingdom. https://www.gov.uk/government/publications/environmental-impacts-of-temperature-changes-from-ground-source-heating-and-cooling-systems/environmental-impacts-of-temperature-changes-from-ground-source-heating-and-cooling-systems-summary

46 Daniels, S. E., Gluyas, J. G., Hartgill, D., & Jones, R. (2022). *Specific environmental risks from repurposing oil and gas wells*. Environment Agency. https://www.gov.uk/government/publications/specific-environmental-risks-from-repurposing-oil-and-gas-wells

47 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.

48 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

49 Hirst, C. M. (2017). *The geothermal potential of low enthalpy deep sedimentary basins in the UK* [Doctoral dissertation, Durham University]. Durham E-Theses Online. http://etheses.dur.ac.uk/11979

50 Eden Geothermal. (n.d.). *About the Eden Geothermal Project*. https://www.edengeothermal.com/the-project/phase-1

51 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. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2022/Farndale.pdf

52 Cariaga, C. (2023, September 8). *GEL awarded the first-ever Contracts for Difference for geothermal*. ThinkGeoEnergy. https://www.thinkgeoenergy.com/gel-awarded-the-first-ever-contracts-for-difference-for-geothermal

53 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*. Stanford, CA, United States. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2025/Olver.pdf

54 University of Exeter. (n.d.). *Geothermal power generated from UK granites (GWatt)*. UK Research and Innovation. https://gtr.ukri.org/project/4EA2E71D-D45A-4ABC-8F22-3D6B05B0BDBA

55 Watson, S. M., Falcone, G., & Westaway, R. (2020). Repurposing hydrocarbon wells for geothermal use in the UK: The onshore fields with the greatest potential. *Energies, 13*(14), 3541. https://doi.org/10.3390/en13143541

56 Daniels et al., 2022.

57 Westaway, R. (2016). Repurposing of disused shale gas wells for subsurface heat storage: Preliminary analysis concerning UK issues. *Quarterly Journal of Engineering Geology and Hydrogeology, 49*, 213–227. https://doi.org/10.1144/qjegh2016-016

58 Santos, L., Dahi Taleghani, A., & Elsworth, D. (2022). Repurposing abandoned wells for geothermal energy: Current status and future prospects. *Renewable Energy, 194*, 1288–1302. https://doi.org/10.1016/j.renene.2022.05.138

59 Harrison, D., Haarhoff, M., Heath-Clarke, M., Hodgson, W., Hughes, F., Ware, D., & Mortimer, A. (2020). The Vale of Pickering gas fields: Kirby Misperton, Malton, Marishes and Pickering, North Yorkshire, UK onshore. In G. Goffey & J. G. Gluyas (Eds.), *Geological Society, London, Memoirs* (vol. 52, pp. 82–93). Geological Society of London.

60 Hughes, F., Harrison, D., Haarhoff, M., Howlett, P., Pearson, A., Ware, D., Taylor, C., Emms, G., & Mortimer, A. (2019). The unconventional Carboniferous reservoirs of the Greater Kirby Misperton gas field and their potential: North Yorkshire's sleeping giant. In M. Bowman & B. Levell (Eds.), *Petroleum geology of NW Europe: 50 years of learning–Proceedings of the 8th Petroleum Geology Conference*. Geological Society of London. https://doi.org/10.1144/PGC8.5

61 University of Glasgow. (n.d.). *THERMOphysical properties of CALedonian rock materials to de-risk geothermal development (THERMOCAL)*. UK Research and Innovation. https://gtr.ukri.org/projects?ref=EP%2FU536878%2F1

62 Imperial College London. (n.d.). *Smart assessment, management and optimisation of urban geothermal resources (SmartRes)*. UK Research and Innovation. https://gtr.ukri.org/projects?ref=NE%2FX005607%2F1

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

64 Durham University. (n.d.). *Geothermal Energy from Mines and Solar-Geothermal Heat (GEMS)*. UK Research and Innovation. https://gtr.ukri.org/projects?ref=EP%2FV042564%2F1

65 University of Exeter, n.d.

66 Monaghan, A. A., Starcher, V., Barron, H. F., Shorter, K., Walker-Verkuil, K., Elsome, J., Kearsey, T., Arkley, S., Hannis, S., & Callaghan, E. (2022). Drilling into mines for heat: Geological synthesis of the UK Geoenergy Observatory in Glasgow and implications for mine water heat resources. *Quarterly Journal of Engineering Geology and Hydrogeology, 55*(1), qjegh2021–033. https://doi.org/10.1144/qjegh2021-033

67 Caroline Carroll, personal communication, August 2025

68 University of York. (n.d.). *Deep geothermal energy project*. https://www.york.ac.uk/about/sustainability/campus-operations/climate-action/geothermal-energy

69 National Wealth Fund. (2025, September 23). *National Wealth Fund announces a £31m commitment to Cornish Lithium to advance projects to next stage of development*. https://www.nationalwealthfund.org.uk/news/national-wealth-fund-announces-ps31m-commitment-cornish-lithium-advance-projects-next-stage

70 IGas Energy PLC. (2023, June 12). *IGas selected as preferred contractor for Salisbury NHS Trust geothermal scheme*. Investegate. https://www.investegate.co.uk/index.php/announcement/rns/star-energy-group-plc—star/igas-preferred-contractor-for-geothermal-scheme-/7569259

71 McClean, A., & Pedersen, O. W. (2023). The role of regulation in geothermal energy in the UK. *Energy Policy, 173*, 113378. https://doi.org/10.1016/j.enpol.2022.113378

72 Rybach, L. (2010). The future of geothermal energy and its challenges. *In Proceedings of the World Geothermal Congress 2010*. Bali, Indonesia. Classification of geothermal potentials—from theoretical through technical and economic to developable—is described therein.

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