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Keeping warm: a review of deep geothermal potential of the UK

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Abstract

In 2015, the primary energy demand in the UK was 202.5 million tonnes of oil equivalent (mtoe = 848 EJ). Of this, about 58 mtoe (2.43 EJ) was used for space heating. Almost all of this heat was from burning fossil fuels either directly (50% of all gas used is for domestic purposes) or indirectly for power generation. Burning fossil fuels for heat released about 160 million tonnes of carbon dioxide in 2015. The UK must decarbonise heating for it to meet its commitments on emissions reduction. UK heat demand can be met from ultra-low-carbon, low enthalpy geothermal energy. Here we review the geothermal potential of the UK, comprising a combination of deep sedimentary basins, ancient warm granites and shallower flooded mines. A conservative calculation of the contained accessible heat in these resources is 200 EJ, about 100 years supply. Presently only one geothermal system is exploited in the UK. It has been supplying about 1.7MW_T (heat) to Southampton by extracting water at a temperature of 76 °C from a depth of 1.7 km in the Wessex Basin. Like Southampton, most of the major population centres in the UK lie above or adjacent to major geothermal heat sources. The opportunity for using such heat within district heating schemes is considerable. The consequences of developing a substantial part of the UK's geothermal resource are profound. The baseload heating that could be supplied from low enthalpy geothermal energy would cause a dramatic fall in the UK's emissions of greenhouse gases, reduce the need for separate energy storage required by the intermittent renewables (wind and solar) and underpin a significant position of the nation's energy security for the foreseeable future, so lessening the UK's dependence on imported oil and gas. Investment in indigenous energy supplies would also mean retention of wealth in the UK.

Keywords

Baseload, climate change, CO_2 emissions, geothermal, geothermal energy, granite, heat, heat flow, low carbon, sedimentary basin

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Introduction

Currently, geothermal energy provides only 0.3% of global power production.[1] Although the total power production from geothermal energy is tiny, there has been steady growth in the quantity supplied each year for the past decade or so. During the period from March to September 2016, the construction of 44 new geothermal power plants began in 23 countries around the world. These will add 1,562.5 MW of developed capacity[2] and by the end of 2016, 440 MW_E (3.4% increase) was on stream.[1] Total geothermal power capacity is at the end of 2016 was 13,000 MW.[3]

The global use of direct geothermal heat is not as well reported. The most up to date figures appear to be from 2015 and these indicate that 70,329 MW_T was installed globally at that time with 50% of global capacity shared equally between China and the US.[4] Thus, the installed capacity for geothermal heat is about five times greater than that for installed geothermal power.

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The use of geothermal energy whether directly for heat (and cooling) or for power generation is a well established and stable technology. Considered in terms of the energy trilemma, sustainability, equity and security, geothermal energy is able to address each. It has a distinct advantage over many renewable forms of energy usage in that it has good base load properties. Unlike intermittent wind or sunshine, geothermal energy is always available. Geothermal energy also compares very favourably against fossil fuels and nuclear insofar as its emissions are near zero for both greenhouse gases and radioactive waste (minor and low level). In addition, geothermal energy is highly equitable. Unlike the heterogeneous distribution of fossil fuels and fissile material, every part of the Earth gets hotter with depth. Although resources will vary depending upon geothermal gradient, every nation on Earth could develop geothermal energy for heat. Where geothermal energy loses out to nuclear and fossil fuels is in terms of energy density. A kilogram of uranium will deliver 80 million MJ of energy, 1 kg of petroleum about 50 MJ of energy, 1 kg coal about 24 MJ of energy and cooling 1 kg of water by 30 °C about 0.126 MJ of energy. Despite the low energy density, low enthalpy geothermal energy is ideal for space heating and hot water requirements, greenhouses and aqua-culture amongst other applications.

The aim of this paper is to examine the potential for geothermal heat to replace fossil fuels as the main source of space heating in domestic and industrial premises and the impact that could have on reducing the UK's emissions of greenhouse gases in line with the UK government's commitments on climate change mitigation. Heat from industrial processes could also be used to lessen that use of fossil fuels but this will not be considered in this paper.

Background

Total primary energy demand in UK in 2015 was 202.5 million tonnes of oil equivalent (mtoe = 8.48 EJ), slightly up on the warm year of 2014 but well down from about 240 mtoe a decade earlier.[5] About 28% of this energy was lost in energy transformation and distribution or used by the energy industry itself. Of the remaining 145.7 mtoe about 40% (58 mtoe, 2.43 EJ) of energy is used on an annual basis for space heating;[6] the percentage is higher in the colder north of the UK and lower in the warmer south. The heating demand dominates our use of gas in the UK. Over 50% of the total gas consumption is for domestic heating and cooking and a further 25% is used by industry (51.75 mtoe[5]). Domestic heating also accounts for about 25% (6.25 mtoe) of coal use and 4% (2.96 mtoe) of oil use in the UK. The heat is produced from these fossil fuels by combustion with the resultant release of carbon dioxide and other greenhouse gases.

The temperature at which coal, methane and heating oil burn varies considerably depending upon the fuel air mixtures, but in broad terms it is between about 1500 °C and 2000 °C. These high temperatures contrast with domestic radiators, which run at a temperature of 60–80 °C and domestic hot water which, typically, is stored at 60 °C. A considerable portion of the heat generated is lost through a flue or chimney. The efficiency of condensing boilers, which recover heat from the flue gases may be as high as 90%, and that of non-condensing boilers is lower at around 70% while for open fires, possibly as little as 30% of the generated heat is transmitted to the building and the air it encloses.

If we take the optimistic view that the UK has only gas fired condensing boilers and an energy industry which is 72% efficient (28% losses above), then at best, the conversion of primary energy to home heating is 65% but at the same time every molecule of gas, oil or coal combusted produces carbon dioxide. In 2014, the UK produced achieved a ten-year low in carbon dioxide emissions of 404 million tonnes[7] of which 40% or 162 million tonnes of carbon dioxide was produced from combusting fossil fuels for heat.

The UK Climate Change Act (2008) contains a binding commitment to reduce emissions of greenhouse gases in the UK by 80% by 2050. To date, progress has been good with a significant proportion of the UK's power generation having been decarbonised by mid-2017. Offshore wind and photovoltaic electricity production continue to deliver success in this regard. On 22 April 2017, UK news agencies reported that no coal had been burned for power production on that day and on 25 May 2017, a particularly sunny day in the UK, enabling delivery of 23% of the nation's power requirement was met by solar photovoltaics. In July 2017, the UK government announced that petrol and diesel-powered cars would not be sold in the UK after 2040,[8] marking another significant step in the decarbonisation of the transport sector. However, The UK Committee on Climate Change[9] stated that only decarbonisation of heating in the UK could deliver the major reduction in emissions needed to meet the 2050 target.

In addition to the role that geothermal energy can play in reducing greenhouse gas emissions in the UK, it also has the potential to increase energy security. About half of the UK's current energy supply is from natural gas (methane) of which around about 55% is imported from: Norway (36%), Qatar as LNG (12%), Belgium and The Netherlands via the Interconnector (6%), Algeria as LNG (0.5%) and elsewhere as LNG (0.5%).[5] Within Europe and hence affecting the Interconnector, Russia controls about 35% of gas supply. In recent years, Russia has used its dominant position within the European gas markets to its political advantage. Qatar has in 2017 had its own political issues that could affect UK gas supply and the single pipeline from Norway to the UK (Langeled) has had technical problems. Given that there have been several occasions in the past few winters when gas supply in the UK has only been 1% above gas demand, it is clear that gas security for the UK is a major issue; one which would be eased considerably if geothermal energy replaced gas as a major source of heat for domestic and industrial properties in the UK.

UK onshore geology – basins, granites, heat flow and thermal gradients

The geology of the UK is both diverse and complex, a product of its position on the margin of the Eurasian continental mass; a position it has occupied for much of the last billion years or more. Repeated rifting from and collision with, the North American and African continents has produced an array of sedimentary basins, many of them partially exhumed, and plutonic rock masses (granites). Both basins and granites have geothermal potential, albeit modest when compared with the geothermal energy systems developed in tectonically active countries such as Iceland, Italy and New Zealand.

The surface geology of the UK is extremely well known, not least because it has been mapped in great detail by the officers of the British Geological Survey, since the Survey was founded in 1835 (as the Ordnance Geological Survey). However, we know much less about the deep geology of the UK onshore, particularly compared with those areas of the North Sea and Atlantic Margin that have been explored for petroleum. Much of the UK onshore is covered by 2D seismic data (of variable vintage and quality) but such data do not contain information on temperature or heat flow. Temperature, and hence heat flow, can be measured in mines and boreholes. Heat flow can also be measured at the surface although it is possible that many such measurements do not give a true picture of heat flow at depth because of near surface chilling during the last Ice Age.[10] Many areas in the UK were mined for coal, minerals and stone and temperature data are available for some of these mines. The UK also has more than 2000 onshore (compared with about 9000 offshore wells) petroleum exploration wells drilled since the beginning of the twentieth century.[11] Most of these were drilled in the proven petroleum provinces of the East Midlands, Wessex, Hampshire and the Weald. Fewer wells have been drilled in the minor petroleum provinces of the Scottish Midland Valley and Cheshire areas and a few wells have been drilled elsewhere in the UK. Most of the onshore wells terminate at depths of between 1 km and 2 km beneath the land surface. A few penetrate to depths of greater than 2 km. This contrasts with the offshore where most wells have been drilled to depths of around 3 km and many in excess of 5 km.

A suit of maps illustrating the main geological elements, heat flow, thermal gradient and data coverage for deep wells and 2D seismic lines for the UK are presented in Figure 1. In broad terms, seismic and well data density is greatest in the sedimentary basins because of their perceived or real potential for hosting fossil fuel resources (coal, gas, oil). While such areas can be of interest for geothermal prospecting, potential geothermal resources are more widespread and include areas between these basins, where there are often radiothermal granites.

There are several deep sedimentary basins in the UK in which the thickness of sedimentary and thus likely porous, water bearing, sedimentary, rock fill exceeds 2 km. The geological age of these basins is typically older in northern England and Scotland and younger

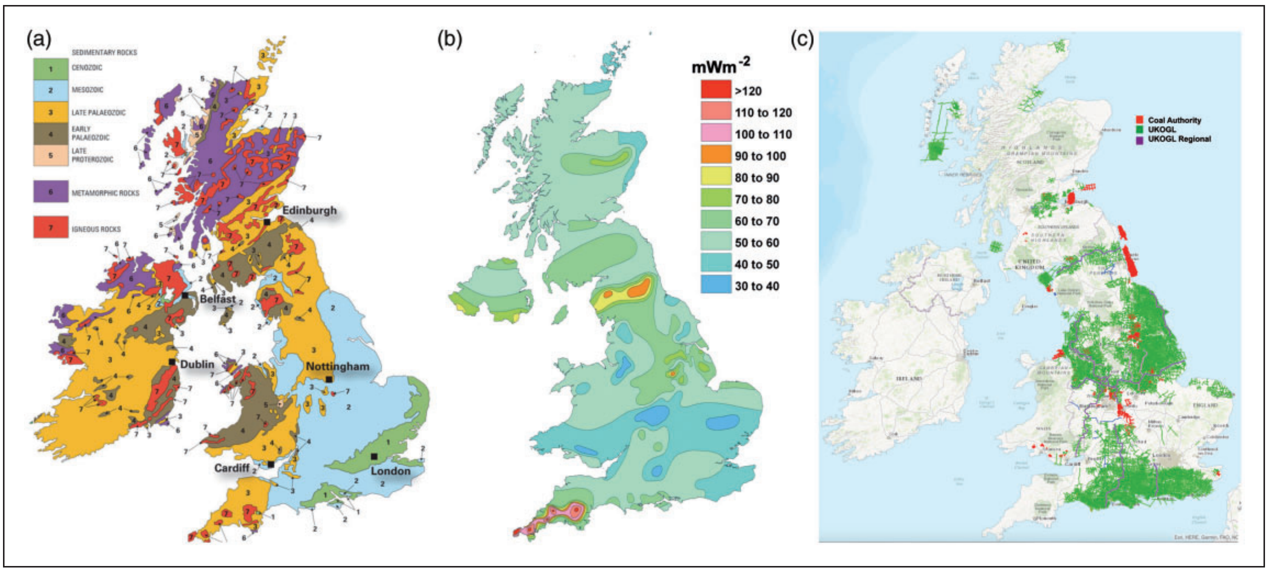

Figure 1. (a) Simplified geology of the UK (from the British Geological Survey); (b) heat flow across the UK (from the British Geological Survey); (c) seismic data coverage of the UK (from the UK Onshore Geophysical Library).

in the south of England (Figure 2, Table 1). Although these sedimentary basins will certainly contain porous sedimentary rocks (sandstones, limestones, dolomites) we cannot be sure without drilling that the pore spaces will be interconnected, so that the rock will be permeable enough to transmit fluid.

In addition to the sedimentary basins, the UK also hosts several suits of granite batholiths (Table 2). Granites typically contain small quantities of thorium and uranium. Both elements are radioactive. They decay over periods of billions of years and in doing so produce heat. This means that even very ancient granites are likely to be significant heat sources hundreds of millions of years after emplacement. Unlike sedimentary rocks, granites are not porous (typically <1% pore space) and therefore unlikely to be permeable unless fractured. Some of the UK granites are naturally fractured as a result of earth movements that have occurred since their emplacement, while others could be stimulated to transmit fluids after thermal fracturing.

Review geothermal exploration and previous studies

Miners in the UK had long realised that below ground it could be warm long before anyone considered the geothermal potential of the UK. Temperatures were recorded in mines initially because of health and safety concerns rather than an interest in the sub-surface thermal gradient,[28] although as far back as 1869, Lord Kelvin measured elevated temperatures down shallow boreholes. Similarly, the hot springs at Bath and rather more tepid springs, elsewhere in the UK, have attracted bathers since at least Roman times.[29] The first successful oil well in the UK was drilled at Hardstoft in Derbyshire, striking oil at 3070 ft (936 m) in May 1919[30] but no mention was made of the temperature at depth. The same was true when Falcon and Kent[31] summarised the results of the search for petroleum in the UK from Hardstoft until the late 1950s; again no mention of temperature. It was however in 1961 that the UK science community was awakened to the fact that hot rocks exist at depth when the Department of Geology at Durham University drilled a well at Weardale in County Durham. The aim of the well was not to discover petroleum but rather to prove the hypothesis advanced by Martin Bott that the negative gravity anomaly he had mapped in Weardale was caused by the presence of a cryptic granite, buried at depth and not exposed anywhere at surface.[32] The Rookhope well did indeed find granite at a depth of 385 m below the surface but in what was a surprise at the time the granite was found to be both eroded and hot.[33] Three further wells were drilled for research purposes on or adjacent to the Weardale Pluton.[34]

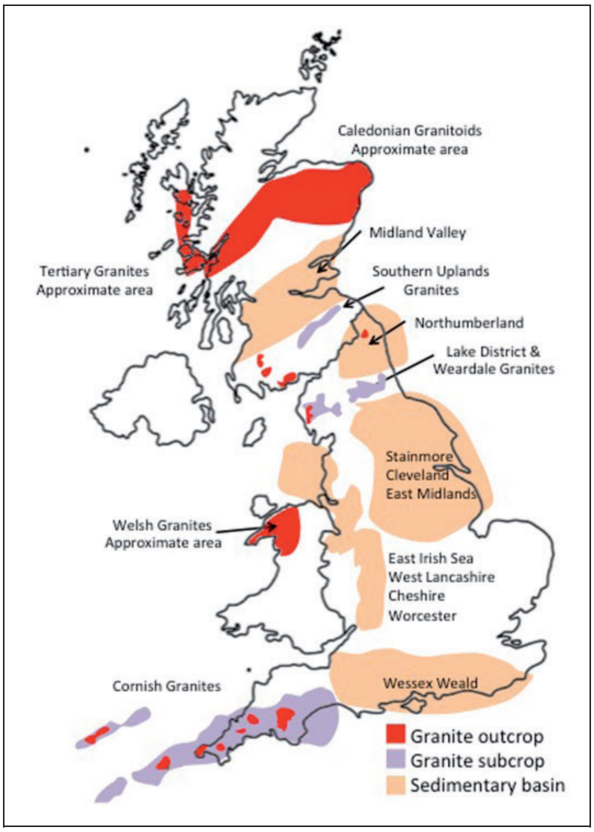

Figure 2. UK sedimentary basins and granite batholiths. The offshore extensions of onshore sedimentary basins are omitted for clarity.

The deliberate search for geothermal energy in the UK began in the 1970s in response to the global oil crisis and at a time when the petroleum resource in the UK lay largely undiscovered. A total of seven deep boreholes were drilled on the basis of the studies done in the 1970s, although all these wells were drilled in between 1980 and 1985 by which time the UK was a petroleum exporting country and oil was selling at around \$30 per barrel in money of the day (Table 3). Four of these wells were targeted at deeply buried, saline aquifers (Antrim, Lincolnshire and Hampshire), while three wells targeted radiothermal granite (Cornwall). The three wells drilled at Rosemanowes, Cornwall became known as the hot, dry rocks programme and received much attention.[35] However, none of the three wells drilled made it into production. Success was delivered by the Southampton borehole which was put on production and has supplied water at 75 °C and 1.7MW_T since 1987 and forms the basis for the Southampton District Energy Scheme, which supplies heat and power to a hospital, university and commercial buildings in central Southampton. The Southampton geothermal scheme was not, however, developed by the UK government, but was the result of the foresight of the accountant at Southampton Council, Mike Smith, who rescued the well from premature abandonment as the UK government programme was closed.[36]

Table 1. The main onshore, sedimentary basins of the UK.

Basin	Approximate thickness of strata (km)	Stratigraphic age of strata	Average thermal gradient (°C/km)	Possible maximum temperature in basin centre (°C)	Reference
Orcadian Basin	3–4	Devonian	40 inferred	>100	12
Scottish Midland Valley	4 estimated	Devono-Carboniferous	30 calculated from data in 14	130	13, 14
Northumberland Trough	>3	Carboniferous and possibly older	35	140	15, 16, 17
Stainmore Trough	2.5	Carboniferous and possibly older	40	125	16, 18
Cleveland/ Lincolnshire Basins	3.5	Triassic to Cretaceous	32	107	19, 20
East Midlands Basin	2.5	Devono-Carboniferous	29	81.4 recorded in Pre-Cambrian basement at 2.5 km in Welton A1 well	21
Cheshire Basin	4.7 to base of Permian	Carboniferous to Triassic	>80	21	22, 23
South Wales Basin	2 to base of Coal Measures	Devono-Carboniferous	60	25	19
Worcester Graben	>3	Permo-Triassic	18	63 measured in basement below Permian	20
Wessex Basin	3	Permian to Cretaceous	34.5	76.6 measured in Southampton bore hole at 1.818 km	20
Northern Ireland	2.5	Triassic to Jurassic	85	58	19

Table 2. Granite batholiths of the UK.

Name	Age of emplacement	Average thermal gradient (°C/km)	Average heat production (μW/ m^3)	Reference
Caledonian – Cromarty suite	Devonian	Not available	2.5–4	24, 25, 26
Caledonian – Great Glen suite	Devonian	Not available	2	24, 25
Caledonian – Cairngorm suite	Silurian/ Devonian	24[26]	5-7	24, 25, 26
Caledonian – Argyll suite	Devonian	Not available	2	24, 25
Caledonian – South of Scotland suite	Devonian	Not available	2	24, 25
Weardale (Durham)	Devonian	38	3.7	19, 27
Cornwall	Permian	39.5	3.1 (Bodmin) to 6.5 (Lands End)	19

Twenty years elapsed before the next geothermal borehole was drilled in the UK and it was a return to Weardale in County Durham where the first accidental discovery of hot geothermal water had been made in 1961. The well was drilled at Eastgate (Table 4) on the site of a former cement works that had been designated as the hub for a possible eco-village development led by the then Regional Development Agency for the region, One North East. Embryonic plans were made by One North East for the village to be powered by wind and photovoltaics. The opportunity to add geothermal energy to this mix of renewables planned for the village was identified by Paul Younger, then a professor of hydrogeology at Newcastle University. The village never was developed because of the combination of the global economic downturn at the end of the first decade of the twenty-first century and the demise of the Regional Development Agencies at about the same time. However, the well at Eastgate was drilled in 2004. Manning et al.[27] reported on the

Table 3. Summary of deep boreholes drilled during the UK 1980s geothermal campaign (modified from Younger et al.[25]).

Location	Completion	Well depth (m)	Bottom hole temperature (°C)	Main aquifer depth (m)	Temperature of aquifer (°C)
Rosemanowes RH11, Cornwall	December 1981	2175	90	2100	55–70
Rosemanowes RH12, Cornwall	October, 1981	2143	90	Not identified	Not applicable
Rosemanowes RH15, Cornwall	January 1985	2652	100	Not identified	Not applicable
Marchwood, Hampshire	February 1980	2609	88	1672–1686	74
Larne, N. Ireland	July 1981	2873	91	960–1247	40
Southampton, Hampshire	November 1981	1823	77	1725–1749	76
Cleethorpes, Lincolnshire	June 1984	2092	69	1093–1490	44–55

Table 4. Summary of deep boreholes drilled in the UK during the 2000s and 2010s (modified from Younger et al.[17,25]).

Location	Completion	Well depth (m)	Bottom hole temperature (°C)	Main aquifer depth (m)	Temperature of aquifer (°C)
Eastgate (1)	December 2004	995	46	411	27
Eastgate 2	July 2010	420	–	Not present	No flow
Science Central	July 2011	1821	73	1418.5–1795	No flow

plan to drill Eastgate and its execution. The well was a stunning success. Drilled to a depth of 998 m, the mid to deep part of the well encountered naturally fractured Weardale Granite as planned. The bottom hole temperature was 46 °C and the well flowed saline water from a zone at 411 m and at a temperature of 27 °C. The Eastgate No1 borehole as it became known proved capable of producing water at a rate of 140 m^3/h (39 L/s) from per meter of drawdown and the heat flow was measured at 111 mW/m^2. An appraisal well, Eastgate 2, was drilled in 2010 some 700 m from Eastgate 1 to determine whether the fractures were pervasive throughout the granite or were limited to the bounding fault to the granite, known locally as the Slitt Vein. The granite at Eastgate 2 proved the same thermal gradient as Eastgate 1, but also proved to be impermeable, confirming that the fracture permeability in Eastgate 1 is associated with the bounding fault.[37]

The most recent geothermal exploration well to be drilled in the UK followed on from Eastgate 2 and targeted the same fracture system as Eastgate 1. The well, called Newcastle Science Central, was drilled in central Newcastle by a consortium headed by Newcastle University, that included Durham University, the British Geological Survey and Newcastle City Council. The well was drilled to a depth 1.8 km and targeted Lower Carboniferous Fell Sandstones in an area close to what is known as the Ninety Fathom Fault (equivalent to the Slitt Vein). The well proved the high thermal gradient but failed to flow water to surface.[17] The reasons for the failure are not entirely clear.

No new geothermal wells have been drilled in Cornwall since the 1980s but recently funding has been obtained from the European Regional Development Fund (ERDF) to drill two deep geothermal wells at United Downs near the town of Redruth and to the original Rosemanowes borehole. The wells will penetrate to depths of 2.5 km and 4.5 km, respectively. Assuming the injected water descends through the artificially created fracture system and is heated, the deeper well is expected to produce water at 175 °C and so deliver 1 MW of power.[38]

Downing and Gray[19] provided the first comprehensive nationwide assessment of geothermal potential for production of hot water from Permian and younger strata in the UK. Their work has formed the basis for two more recent reviews by SKM[39] and Atkins.[40] Busby[20] provided a summary of the geothermal heat resource potential for the UK (Table 5) and indicated that, at a minimum, the resource potential is 200 EJ. Such a resource, if exploited could, supply the current annual UK heating requirements for about 100 years.

The total heat resource in a basin or granite is clearly an important parameter to calculate and to balance against energy needs. However, it is the rate at which heat can be extracted determines whether the use of the geothermal energy is economically viable. Such flow rate tests are few in the UK, at least for boreholes drilled for geothermal exploration. However, it is possible to supplement the few tests from geothermal wells with data from petroleum fields and from the small number of hot or tepid springs known in the UK. In some areas, it may also be valid to use analogue data from (nearby) offshore petroleum producing fields (Table 6). Of particular note in Table 6 is that most the data that are available come from petroleum fields within Carboniferous reservoirs, an interval which was not part of the quantitative

Table 5. Summary of the UK's low-enthalpy geothermal resources above 40°C.[44]

Basin	Aquifer	Area (km^2)	Geothermal resource (at>40°C, EJ)	Identified resource (EJ) reject temperature 25°C, recovery factor 33%	Maximum temperature (°C)	Maximum thermal store (GJ/m^2)
Eastern England	Triassic Sherwood Sandstone	4827	122	24.6	65	60
Wessex	Triassic Sherwood Sandstone	4188	27	6.5	95	18
Worcester	Triassic Sherwood Sandstone	500	8	1.5	55	35
Worcester	Permian Collyhurst Sandstone	1173	60	11.8	65	110
Cheshire	Triassic Sherwood Sandstone	677	36	7.6	80	75
Cheshire	Permian Collyhurst Sandstone	1266	38	9.1	100	60
Northern Ireland	Triassic Sherwood Sandstone	1618	35	4.7	60	25
Total			326	65.8		

Table 6. The UK's flow-tested geothermal systems and analogue petroleum systems.

Unit name/type	Location	Stratigraphic age/reservoir	Temperature (°C)	Flow rate (L/s)	Heat delivery (MW_t)	Notes
Southampton Single geothermal well	Southampton, Hampshire	Triassic Sherwood Sandstone	75	12	1.7	
Wytch Farm Oilfield	Dorset and Poole Harbour	Triassic Sherwood Sandstone, Jurassic Bridport Sandstone	66	450	35	53
Liverpool Bay fields, Cheshire Basin	East Irish Sea Basin, Cheshire	Triassic Sherwood Sandstone, Permian Collyhurst Sandstone	30 at 2140 m (Douglas Field, Triassic)	140 (32 oil, 108 water)	Not calculated	Temperature gradient is 27°C/km
Welton Oilfield	Lincolnshire	Upper Carboniferous sandstones, Lower Carboniferous Limestone	52.5 (at 1.5 km)	18 (8.4 oil, 9.88 water)	1.6	30°C temperature depletion at maximum flow rate
East Midlands oilfields	Lincolnshire and Nottinghamshire	Upper Carboniferous sandstones, Lower Carboniferous Limestone	2–50 from 23 fields	15 water 15 oil	2.6 midpoint of range covering 0.78% of East Midlands area	42
Bath hot spring	Avon	Carboniferous limestone	45	17	Not calculated	
Eastgate geothermal well	Weardale, County Durham	Devonian granite	27	39	Not calculated	

geothermal resource assessment of Downing and Gray.[19] There are two reasons for this: Upper Carboniferous sandstones are the most common petroleum bearing reservoir intervals onshore UK[41,42] and karstified Lower Carboniferous limestones form the primary reservoir for the UK's hot and tepid springs[43] as well as hosting a small number of oilfields.

UK geothermal plays

In petroleum terms, a play describes a paired system of reservoir rock and associated seal, the latter preventing the petroleum from leaking to surface. This same approach can be used to describe geothermal systems. A geothermal play will comprise a water-bearing reservoir rock overlain by a sealing rock. The quality of the resource (hotter or cooler water) is not part of the play but of the prospect, that is the area to be drilled. Our approach here is the same as that adopted by the UK Department of Trade and Industry[45] in dividing the UK into its natural component geological parts (Figure 3). The DTI[45] only addressed areas that might have petroleum potential. We have extended their work

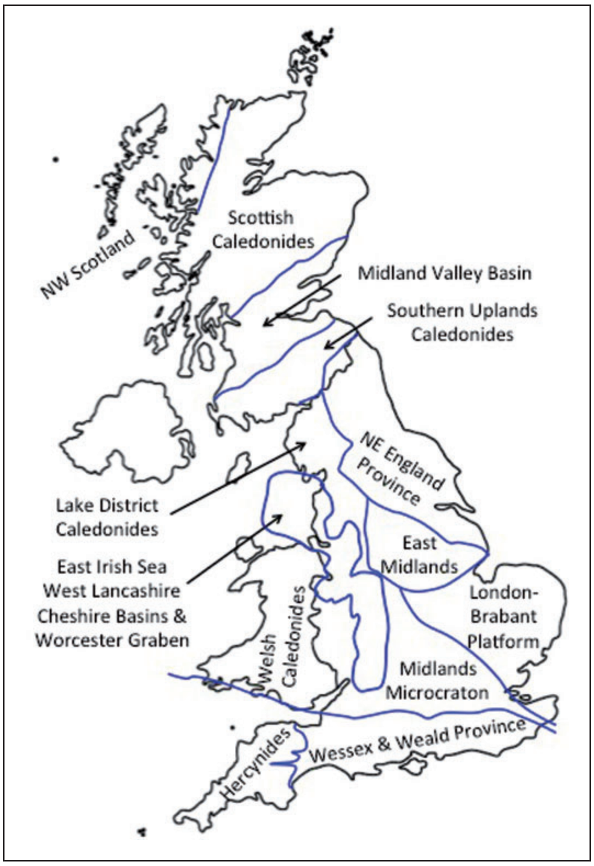

Figure 3. Potential UK onshore, proven and potential geothermal provinces.

to include other areas that have geothermal potential.

Hercynides – including the area of SW England containing the Permian granites (Isles of Scilly to Dartmoor), this is the area associated with the Hot Dry Rock project of the 1980s and the current United Downs geothermal power project. The play comprises the largely uncapped Permian granites that were intruded into Carboniferous strata, which act as partial lateral heat seals. The United Downs project is based on an exploration paradigm that the mineralised 'cross courses' are deep fractures with some existing natural permeability that may or may not need to be enhanced by hydraulic fracturing. The mineralisation in the area demonstrates that there has been hydrothermal activity in the geological past. No other plays have been evaluated in this area although abundant flooded mine workings in Devon and Cornwall have potential as a geothermal energy resource.

Wessex and Weald Province – comprises a single proven geothermal play and several possible plays. The Southampton District Energy Scheme produces water at 75 °C from Triassic (Sherwood) sandstones overlain by a Triassic (Keuper) mudstone seal. From petroleum exploration and production data, other transmissive reservoirs are known to exist within the Triassic (Rhaetic limestone, Liassic seal), Jurassic (Bridport sandstone, Liassic Seal; Frome Clay and its laterally equivalent Great Oolite limestone, Middle Jurassic Oxford Clay seal; Upper Jurassic sandstones and seals) and Cretaceous (Lower Cretaceous, Greensand and Wealden sandstones and seals; Upper Cretaceous Chalk, sealed by Tertiary mudstones). However, the shallow depth of all but the Triassic Sherwood Sandstone makes it likely that these reservoirs will be too cool for them to be of direct use resource for domestic heating. Karstified Lower Carboniferous Limestones have been penetrated below the Humbly Grove (former) oilfield in Hampshire and similar limestones are known to exist beneath the abandoned (Upper Carboniferous) coal mining area in Kent. The coalfields of Kent were mined to depths between 0.6 and 1.5 km[46] and known to suffered from significant water inflow at rates measured at around 60 L/s from Cretaceous Greensand and Chalk.[47]

Welsh Caledonides – comprise tectonised Lower Palaeozoic meta-sedimentary and igneous rocks for which no geothermal play has been defined. Some very low enthalpy geothermal potential may exist in the many abandoned, flooded mineral mines of which there are many in Wales. Similar flooded mine potential may exist in the now abandoned South Wales Coalfield.

Worcester Graben – the plays in the Worcester Graben, Cheshire Basin, West Lancashire Basin and its extension into the East Irish Sea Basin are all similar and will be discussed in the section below devoted to the Cheshire Basin.

Midlands Microcraton – comprises a shallow Pre-Cambrian and Lower Palaeozoic basement with thin Mesozoic cover. No geothermal plays have been defined.

London Brabant Platform – no geothermal plays have been defined for the area.

West Lancashire Basin – this area is also discussed below within the following Cheshire Basin section.

Cheshire Basin – together with the Worcester Graben, West Lancashire Basin and East Irish Sea Basin has significant geothermal potential (noted above in Table 5). The main evaluated plays are the Triassic (Sherwood) sandstone sealed by Triassic shales and evaporites and the Permian (Collyhurst) sandstone, partially sealed by the Permian Manchester Marl. Both intervals are exploited as potable aquifers at shallow depth and both are proven, productive petroleum reservoirs in the East Irish Sea Basin between depth of 1 km and 2.6 km.[48,49]

Older plays include Carboniferous (Westphalian, Namurian and uppermost Dinantian) sandstones each sealed by Carboniferous mudstones.[45] Karstified, Lower Carboniferous limestones, sealed by a variety of younger mudstones are an additional play system, evaluation of which is currently underway by Nadia Narayan of Durham University. This play is proven, in the southern end of the

Worcester Graben by the Bath Hot Springs and by three oil discoveries in the adjacent East Midlands Province. Evaluation of seismic and well data in the West Midlands indicates this play may well exist at depth, beneath Permian and Triassic strata. As with South Wales, opportunities exist for exploiting the warm water in abandoned, flooded coal mines.

East Midlands Province – hosts most of the UK onshore oil and gas fields. Productive intervals occur in Upper Carboniferous sandstones sealed by mudstones and Lower Carboniferous limestones also sealed by mudstone.[20] Each of these proven petroleum plays could also constitute a working geothermal play. Hirst et al.[20] evaluated the geothermal potential of the depleted (Carboniferous reservoir) Welton Field. Triassic sandstones sealed by Triassic mudstones are also a potential play in the eastern part of the province where buried to depths in excess of 1.5 km.[50] Devonian coarse grained, sedimentary rocks have also been proven to exist beneath the Carboniferous strata in a few wells[51] and are inferred from seismic data to be extensive in the East Midlands Province. These too could form a viable play with lowermost Carboniferous mudstones acting as the seal horizon.

Lake District Caledonides – do not contain an identified geothermal play.

NE England Province including the Cleveland Basin – has much in common with the East Midlands Province insofar as the Carboniferous is concerned with additional plays associated with the naturally fractured Weardale Granite[27] and possibly the Cheviot granites.

In addition Permian (Lower Permian Yellow Sands; Upper Permian Zechstein carbonates), Triassic and possibly Jurassic reservoirs with contemporaneous mudstone seal plays occur in the Cleveland Basin.

Southern Uplands Caledonides – do not contain an identified geothermal play.

Midland Valley Basin – contains proven petroleum systems, flowing oil from Carboniferous sandstones with Carboniferous mudstone seals.[52]

Scottish Caledonides – includes Caledonian (Devonian) granites[25] and locally developed Devonian sedimentary cover.

NW Scotland – includes fractured Archean basement and the North Atlantic Tertiary Igneous Province.

Details of the successfully tested geothermal plays and tested analogue (petroleum) plays are given in Table 6.

UK potential geothermal resource and utilisation

The UK's geothermal heat resource is substantial. Figure 4 shows a map of the UK with areas of high thermal resource annotated. This compares very favourably with the heat demand (Figure 4). For many areas of the UK it would be technically feasible to use low enthalpy geothermal heat for space heating using district energy schemes.

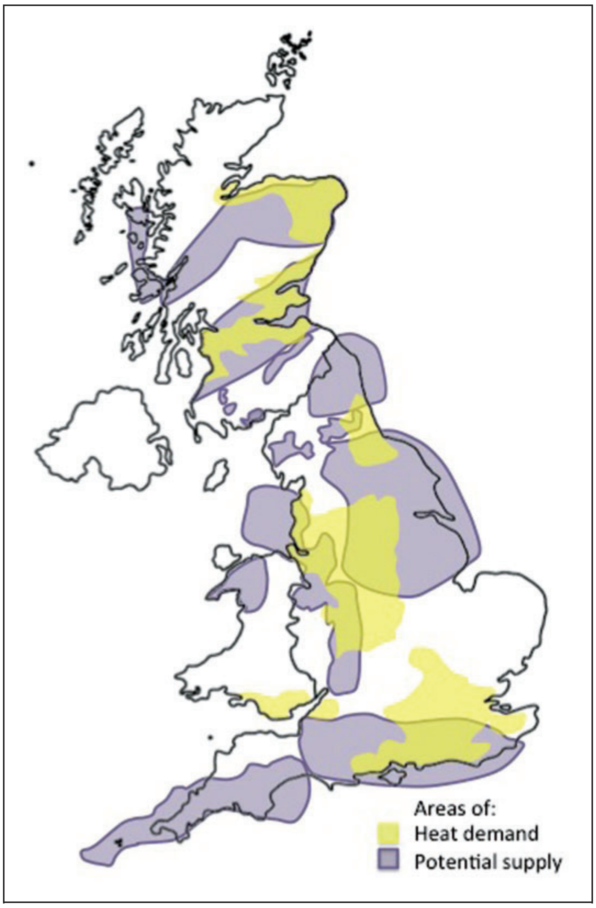

Figure 4. Comparison of estimated geothermal resources (purple) and heat demand (yellow). Data sources for heat demand are the English, Welsh and Scottish heat-maps published by the UK and devolved governments.

The UK government has already crated a suitable mechanism for helping develop low-carbon electrical power generators and the same could be utilised to help develop low-carbon heat sources such as geothermal. The Contract for Difference (CFD) is a contract between a low-carbon electricity generator and the Low Carbon Contracts Company (LCCC), a government-owned company. A generator party to a CFD is paid the difference between the 'strike price' – a price for electricity reflecting the cost of investing in a particular low-carbon technology – and the 'reference price' – a measure of the average market price for electricity in the GB market. It would be a simple matter to extend this concept to heat.

Exploitation of low-carbon heat needs to be developed now in order that the UK meets its next carbon budget and it could be achieved using CFD alongside the low-cost option of reusing oilfield assets (so deferring abandonment costs). The geothermal developments would also require the skills developed by staff within the petroleum industry and currently available from an oversupplied skills market for petroleum.

Conclusions

In order to meet its emissions reduction commitments, the UK must decarbonise its heating. The emissions associated with domestic, commercial and industrial heating in the UK are about 150 million tonnes per annum of carbon dioxide equivalent. A switch from burning fossil fuels (largely gas) to produce the required heat to use of naturally heated geothermal water can play a major role in reducing such emissions. District energy schemes, similar to that developed by Southampton Council would replace gas boilers in individual properties. There is enough accessible geothermal heat resource adjacent to major population centres in the UK for this to be a technically feasible option and the resource base is such that at least 100 years supply could be delivered at present consumption rates. It would provide a good level of base load energy supply for heating, so lessening the need for the (wasteful) energy storage that is required by renewable, but intermittent, energy supply from wind, solar photovoltaics and solar thermal.

The time to make this change to geothermal from gas is now. Skills and know how from the petroleum industry could be used to drill wells and produce hot water from deep below our major cities and towns and the spent cold water reinjected to be rewarmed by the rock below. Similarly the aging and non-productive infrastructure used for petroleum production in the UK could be upcycled and repurposed for hot water production, so utilising existing facilities and deferring abandonment costs.

The last three UK governments have sequentially and successfully assisted development of an offshore wind industry that has led the way in decarbonising power production. The commercial device used to effect this change has been the Contract for Difference. It has ensured stability of income for developers and costs for consumers. Applied to heat CFDs could help ensure a warm and secure energy future for the UK.

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