Ground source heating and cooling: status, policy, and market review

Chief Scientist's Group report

September 2024

Version: SC220017/R3

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Published by:

Environment Agency
Horizon House, Deanery Road,
Bristol BS1 5AH

www.gov.uk/environment-agency

Further copies of this report are available from our publications catalogue: www.gov.uk/government/publications or our National Customer Contact Centre: 03708 506 506

Email: research@environment-agency.gov.uk

Keywords:
Geothermal, ground source heating and cooling, industry, market, projections

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Project number:
SC210017/R3

Citation:
Environment Agency (2023) Ground Source Heating and Cooling (GSHC): Status, Policy, and Market Review. Environment Agency, Bristol.

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Dr Robert Bradburne
Chief Scientist

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Acknowledgements

This report was primarily written and researched by David Banks of Holymoor Consultancy Ltd. under contract to Mott MacDonald. The author wishes to thank David Birks of Birks Geothermal Ltd., Chris Davidson of Genius Energy Lab, Andy Howley of Ground Source Consult Ltd. and HEX Energy Ltd., John Findlay of Carbon Zero Consulting, Andy Louth of Groundtherm Ltd. and Dan Roberts, Alister Henderson and Amy Featherstone of Kensa for providing opinions and information on the state of the Ground Source Heating and Cooling (GSHC) industry. He also wishes to thank Corinna Abesser (British Geological Survey) and Robin Curtis (GeoScience Ltd) for helping to understand the background to previous estimates contained in International Energy Agency / World Geothermal Congress / European Geothermal Congress country geothermal reports. Finally, the author thanks Stephen Bielby and Andrea Ellison of the Ground Source Heat Pump Association for facilitating contacts with industry representatives.

While acknowledging the assistance provided by the above-named organisations and persons, the conclusions and tentative prognoses contained in this report are those of the author(s) and should not necessarily be construed as representing those of the UK GSHC industry or the Environment Agency.

The project benefited from expertise offered by the Environment Agency's steering group, Danielle Ashton, Natalie Kieboom, Judy England, Alison Futter, Tim Johns, Sarah Scott and Catherine Bayliss. The Mott MacDonald project team consisted of Aidan Foley and Suzanna Fairbairns.

Executive summary

As part of its Net Zero strategy, the UK Government has set ambitious targets to increase the numbers of heat pumps installed from 55,000 a year to 600,000 per year by 2028 (HM Government 2020a, 2021a, 2021b). Ground source heat pumps (GSHP) are a type of heat pump that use the ground's relatively stable ambient temperature to provide heating or cooling. The above and below-ground parts of the heat pump can be referred to as a ground source heating and cooling (GSHC) system[1]. Some open-loop GSHC systems[2] are regulated by the Environment Agency through the Water Resources Act and Environmental Permitting Regulations (EPR)[3], and since October 2023 closed-loop GSHC systems[4] are also regulated through the EPR[5]. In addition, amendments to the EPR mean that heat is now recognised, and can be regulated, as a pollutant in groundwater[6].

GSHC systems can alter the temperature of the ground and groundwater. In particular, larger GSHC systems, or high densities of smaller systems, could potentially have impacts on the subsurface or connected environments. While comprising only 9% of the current UK heat pump market in England currently, it is important that we understand if the numbers are likely to increase and the potential impacts of GSHC systems on the wider environment, so that we can regulate these appropriately.

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[1] A "system" refers to a network of consumers or consumptive processes, heat pumps and subsurface heat exchangers (for example, closed-loop boreholes) connected by a circuit of heat transfer fluid (or in the case of open-loop systems, connected to an abstraction - heat exchange – discharge circuit of groundwater). A system may thus include multiple boreholes, multiple heat pumps and multiple consumers or households.

[2] Open loop GSHC systems are those that actively abstract groundwater and use this to transfer heat. They may provide heating and "active" cooling via the use of a heat pump, or "passive" cooling without the use of a heat pump. Open loop GSHC systems that abstract > 20 m^3 per day are licensed by the Environment Agency.

[3] https://www.gov.uk/guidance/open-loop-heat-pump-systems-permits-consents-and-licences

[4] Closed loop GSHC systems are those that use a heat transfer fluid circulating within a pipe in the ground to transfer heat to the surface. The pipes can be horizontal or vertical.

[5] https://www.gov.uk/guidance/closed-loop-ground-source-heating-and-cooling-systems-when-you-need-a-permit

[6] Heat, as a pollutant, is already recognised and able to be regulated in surface water.

This report is part of a series of reports completed as part of the same project undertaken in 2023/2024 that will improve our understanding of the possible environmental impacts from GSHC:

- "Identifying potential receptors to temperature changes to ground source heating and cooling (GSHC) systems" (Environment Agency, 2024a).
- "Temperature changes in the environment around ground source heating and cooling (GSHC) systems: Thermal plume modelling and literature review" (Environment Agency, 2024b).

This report summarises the current state of the GSHC industry, including the past and existing drivers and barriers to its development. It provides an assessment of the likely developments of the industry over the next 5 years from an industry perspective. This information will contribute to our understanding of how the market may change in the future so that we can better judge the scale and timing of any necessary regulatory intervention.

This work found that the GSHC market is highly dependent on policy and so the figures presented in this report are associated with a high degree of uncertainty. It should be noted that at the present time the UK Government's Net Zero policies are evolving rapidly, therefore, it is important that policy details are checked at the time of reading. Important policy developments include the implementation of the 2025 Future Homes Standard, amendment to the Boiler Upgrade Scheme (BUS) or other subsidy framework, the place of hydrogen in the future UK energy economy and decoupling electricity price from gas price.

As there is no single register of installed GSHC systems in England, an overview of the current state of the GSHC industry has been constructed from several data sources. These data sources use different metrics for registering GSHP/GSHC, for example, some are based on sales figures of GSHP heat pump units, some (renewable heat incentive (RHI)) are more likely to be based on GSHC systems, while others are based on household installations (microgeneration certification scheme (MCS)). These data sources do not typically record failed / decommissioned systems or replacement heat pumps. Therefore, GSHC installation figures in this report must be regarded as best estimates. In addition, many of these figures apply to the UK and so a combination of UK and England based figures are used in the report. To convert UK figures to England figures, a multiplier of 78 to 80% is recommended.

The most recent estimate of GSHP installations in the UK is that of Abesser & Jans-Singh (2022), who cite a cumulative total of 43,700 GSHP units installed in the UK by late 2021, based on GSHP sales figures. This figure may represent around 30,000 to 38,000 operational GSHC systems (UK). Over the period 2009-2021, the UK rate of GSHP installation has likely fluctuated between about 1000 and 4000 GSHP per year with an average of 3,200 units per year (based on sales figures). During 2022, a further 5,584 ground source heat pumps are reported to have been sold in the UK.

During the year April 2022-March 2023, only 493 MCS-accredited domestic GSHP installations were registered in the UK. This is lower than previous years and most likely reflects the replacement of the RHI by the BUS which has resulted in fewer retrofit installations. However, the MCS data do not capture all installations at new build properties.

Planned implementation of the Future Homes Standard (that effectively bans the installation of gas boilers in new homes) in 2025 could increase the demand for domestic GSHP in England to about 20,000 per year within 5 years. Much of this demand would be for new-build dwellings; a proportion could be met by networks of individual domestic heat pumps on shared ground heat exchange loops. If the Standard is not implemented as anticipated, and under current BUS conditions, growth in the domestic GSHP market might be more limited; maybe reaching around 5,000 GSHP installs per year (UK) over the next 5 years.

Installation rates of commercial, industrial, and public sector GSHC systems in the UK are estimated to be around 500 to 1000 smaller (<100 kW) systems per year, of which about 200 to 300 are in the range 45 to100 kW, and at least 60 to 80 larger (>100 kW) systems. According to industry interviewees, this market is growing moderately at present, both in the commercial and public sectors and in the social housing (for example, shared loop) sector. It is possible that within 5 years, UK installation rates could reach 1,000 to 2,000 smaller (<100 kW) systems per year and over 150 larger (>100 kW) systems per year.

Annual installation rate	Current (per year)	5 year prognosis (per year)
Total number of GSHP units (UK)	5584 (2022) 3200 (decade average) 1838 (MCS-accredited*)	
Domestic GSHP (UK)	about 2000 (total) 493 (MCS accredited*)	20,000 (high growth) about 5000 (moderate growth)
Smaller (<100 kW) non-domestic / public sector systems (UK)	500 to1,000, of which 200 to300 in 45-100 kW range	1000 to 2000, of which about 600 in 45-100 kW range
Larger (>100 kW) non-domestic / public sector systems (UK)	60 to 80	>150
Groundwater-sourced open-loop GSHC systems (licensed, England)	16	30

Executive summary table. Summary of estimated current and future (5 year) installation rates for GSHC in the UK and England. * April 2022 to March 2023, see

Section 3.2. To convert UK figures to England figures, a multiplier of 78 to 80% is recommended.

There are currently 149 active Environment Agency abstraction licences (required for abstractions >20 m^3/day) with “heat pump” listed as a usage. The median heat exchange capacity of these open-loop systems is estimated to be around 208 kW. Additionally, there are 174 licences listing “low loss” or non-evaporative cooling as a use – which could relate to “passive” cooling. There is a perceived regulatory burden for selecting open-loop GSHC systems that is unlikely to change in the immediate future, therefore current trends will likely continue at around 16 new open-loop GSHC systems licensed per year in England, or grow modestly to around 30 new open-loop GSHC systems licensed per year, within the next 5 years.

1. Introduction

1.1 Background

As part of its Net Zero strategy, the UK Government has set ambitious targets to increase the numbers of heat pumps installed from 55,000 a year to 600,000 per year by 2028 (HM Government 2020a, 2021a, 2021b). Ground source heat pumps (GSHP) are a type of heat pump that use the ground's relatively stable ambient temperature to provide heating or cooling. The above and below-ground parts of the heat pump can be referred to as a ground source heating and cooling (GSHC) system[7].

EA2025 sets out the Environment Agency's ambition to create better places for people, wildlife and the environment (Environment Agency 2022). The plan sets out 3 long term goals:

- a nation resilient to climate change
- healthy air, land and water
- green growth and a sustainable future

It is therefore important that Net Zero technologies are regulated to prevent environmental harm, but that these regulations are proportionate to avoid being a barrier to sustainable development. To achieve this, it is important to understand the possible impacts that these technologies might have on the environment.

GSHC systems can alter the temperature of the ground and groundwater. In particular, larger GSHC systems, or high densities of smaller systems, could potentially impact the subsurface or connected environments. While comprising only 9% of the current UK heat pump market in England currently, it is important that we understand if the numbers are likely to increase and the potential impacts of GSHC systems on the wider environment, so that we can regulate these appropriately.

While larger open-loop systems (that abstract > 20 m^3 groundwater a day) have been regulated for some time (Environment Agency 2016), heat has now (October 2023) been recognised as a pollutant in groundwater under the Environmental Permitting Regulations (EPR) (The Environmental Permitting (England and Wales) (Amendment) (England)

[7] A "system" refers to a network of consumers or consumptive processes, heat pumps and subsurface heat exchangers (for example, closed-loop boreholes) connected by a circuit of heat transfer fluid (or in the case of open-loop systems, connected to an abstraction - heat exchange – discharge circuit of groundwater). A system may thus include multiple boreholes, multiple heat pumps and multiple consumers or households.

Regulations 2023)[8] bringing closed-loop systems under EPR and providing the Environment Agency with the ability to apply appropriate risk-based controls to prevent heat pollution.

This report summarises the current state of the GSHC industry, including the past and existing drivers and barriers to its development. It provides an assessment of the likely developments of the industry over the next 5 years from an industry perspective. This information will contribute to our understanding of how the market may change in the future so that we can better judge the scale and timing of any necessary regulatory intervention.

This report is part of a series of reports completed as part of the same project undertaken in 2023/2024 that will improve our understanding of the possible environmental impacts from GSHC systems:

- "Identifying potential receptors to temperature changes to ground source heating and cooling (GSHC) systems" (Environment Agency, 2024a).
- "Temperature changes in the environment around ground source heating and cooling (GSHC) systems: Thermal plume modelling and literature review" (Environment Agency, 2024b).

1.2 Report objective and methods

The objective of this report is to provide an overview of the state of the GSHP and GSHC industry in England. It will review barriers and drivers to growth of the industry to date and assess possible development of the industry over the next 5 to 10 years, from an industry perspective. This will contribute to the Environment Agency's understanding of the scale of the potential thermal impacts of GSHC systems and of the potential numbers of GSHC systems that might be included in environmental regulation.

The report:

- Provides a background to the GSHP / GSHC industry in England (Chapter 1)
- Reviews the evolution of UK Government policy and subsidies within the GSHP sector (Chapter 2).
- Provides a summary of the current (2023) state of the GSHP and GSHC industry in England, including numbers and geographical distribution of systems (Chapter 3).
- Provides an assessment of the potential for growth of the GSHP and GSHC industry in England over the next 5-10 years, including a review of previous Environment Agency prognoses (Chapter 4)

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[8] The Environmental Permitting (England and Wales) (Amendment) (England) Regulations 2023 (legislation.gov.uk)

To achieve these objectives, the following methodology was used:

1. An internet-based review of the development of government policy and subsidy frameworks for GSHP from the year 2000 until the recent Boiler Upgrade Scheme (BUS) uplift in summer 2023. Where mainstream media opinion of these schemes has been identified, it has also been included within this review.
2. Construction of a timeline of the cumulative numbers of GSHP installed in the UK since 1985. As there is no single register of installed GSHC systems in England 3 sources of data were used:
   i. UK country reports on the state of the geothermal industry. These are submitted regularly to either the International Energy Agency (IEA), the World Geothermal Congress (WGC) or the European Geothermal Congress (EGC) and report UK sales of GSHP.
   ii. The Microgeneration Certification Scheme (MCS). This MCS registers a large proportion of newly installed and smaller GSHP schemes for quality assurance and to gain access to subsidies.
   iii. The Renewable Heat Incentive (RHI). While now closed, the RHI holds records of GSHP schemes receiving RHI funding and data on larger systems but overlaps with the MCS database.
3. Examination of the Environment Agency database of groundwater abstraction licences related to GSHP and passive cooling, to ascertain the numbers of open-loop GSHC systems in England that abstract >20 m^3/day of groundwater.
4. A comparison of the growth of the UK GSHP industry with that in selected European countries that share geological, cultural or energy-economic similarities with the UK (Netherlands, Denmark, Norway, Poland).
5. Structured interviews with a number of industry representatives, including those responsible for the design of the majority of the UK's larger closed-loop GSHC installations, to understand the current status of the industry in the UK and the likely drivers or barriers to industry growth in the near future.

It should be noted that the lack of data results in a level of uncertainty in the estimates provided in this report. Assessment of the state of the industry, likely drivers and barriers to its growth, and its possible future growth are thus reliant on informed interpretation. The report was written in the summer of 2023 and the UK Government's Net Zero policies are evolving rapidly and changes in this could impact future developments in the market.

The Environment Agency is the environmental regulator in England, however, some sets of statistics refer to the UK as a whole (country reports, Section 3.1) and MCS data (Section 3.2). RHI data refer to England, Wales and Scotland whereas the Environment Agency abstraction licence data only refer to England. The ratios between English installation rates and UK installation rates are typically 78 to 80% (see Appendix A), so this factor is tentatively used to convert between English and UK data.

1.3 What is a ground source heat pump?

A heat pump is a mechanical device, usually comprising a refrigerant fluid that circulates through a compressor and heat exchangers, absorbing heat from a lower temperature source (at low pressure) and rejecting it to a higher temperature sink (at higher pressure). It "pumps" heat *up* a temperature gradient, in much the same way that a water pump moves water against gravity.

Another way of thinking of a heat pump is that it is a kind of thermal "vacuum cleaner". It can suck heat out of the environment (river water, air, the ground), even in winter, and deliver it as useful space heating in a home or building.

The heat pump's compressor is powered by electricity. A well-functioning heat pump system should be able to extract at least 2 units of heat from the environment for the expenditure of only 1 unit of electricity. As very little energy is lost in the process, all 3 units of energy are delivered as useful heat to the home. The ratio of heat delivered to electrical energy expended is often referred to as the coefficient of performance of the heat pump, or COP_H. In this example, the heat pump COP_H would be 3.

Because the electrical energy used can be generated by low carbon technologies (solar, wind, nuclear), and the remainder of the heat is drawn from the environment, heat pumps are one of very few space heating technologies that are energetically efficient and low carbon.

A ground source heat pump (GSHP) is a heat pump that draws heat from the ground. They are particularly efficient, as the ground in England has a relatively constant temperature of at least 10°C at around 10 m depth. This means that, in winter, the ground is usually warmer than the air, and heat can be extracted from it more efficiently than an air-source heat pump (ASHP).

The most common way of extracting heat from the ground is by drilling a borehole or excavating a trench and installing a heat exchanger in the borehole or trench. The heat exchanger is usually a loop of polyethylene pipe. A heat transfer fluid circulating within the pipe conveys heat from the ground to the heat pump. A borehole installed with such a loop is termed a "borehole heat exchanger" or BHE. These borehole-based GSHP systems are also referred to as a "closed-loop borehole" or "vertical closed-loop" GSHP systems. A trench-based system is referred to as a "horizontal closed-loop GSHP" system.

An alternative way of extracting heat from the ground is to pump groundwater (normally at a temperature of at least 10°C) from a water well or borehole and pass the water through a heat exchanger, connected to the heat pump, at the surface. In this case, heat is extracted directly from the groundwater. This is commonly referred to as a groundwater-based "open-loop GSHP" system. After the heat has been extracted, the cool groundwater must be returned to the environment, most often to the aquifer from which it was abstracted, by means of an injection borehole, thus also preserving groundwater resources.

While domestic properties will often use a single heat pump and maybe a single closed-loop borehole, larger commercial properties may obtain heat from a GSHP 'system'. These comprise a network of several heat pumps and multiple boreholes or trenches sharing a single closed-loop of heat transfer fluid (or a joint set of abstraction/reinjection wells). Thus, the numbers of GSHP systems in England will be somewhat less than the number of individual GSHP installed – this will become an important distinction later in this report.

The rate of heat extraction from the ground, or of supply to a building, is measured in kilowatts of thermal energy (kW). A small, well-insulated house or apartment may require a heat supply of 4-6 kW on a cold winter day. A larger, poorly-insulated house may require 10-12 kW. The heating and cooling requirements of large commercial buildings may run into hundreds of kW.

The direction of a heat pump can be reversed to provide space cooling, air conditioning or refrigeration by pumping surplus heat from a building back into the ground, or groundwater. This application is especially important in many large commercial buildings or data centres. Because the ground (about 10-12°C) is cooler than the preferred temperature in living spaces (about 20°C), a heat pump is not strictly necessary to provide ground source cooling. Surplus heat can be rejected, via simple heat exchange, to cold circulating groundwater or to a cluster of closed-loop boreholes. This is called passive cooling.

The all-inclusive term "ground source heating and cooling" (GSHC) is used to describe both passive (without heat pump) and active (with heat pump) heat exchange processes that are coupled to the ground or groundwater. GSHPs are thus a subset of GSHC.

If heat is extracted from the ground by a GSHP, the ground (and the groundwater it contains) cools down. If surplus heat is put into the ground, the ground and groundwater heat up. There is a potential for the changes in ground temperature to have environmental impacts – or to cause thermal pollution (Abesser & Walker 2022).

A GSHC system (whether open-loop or closed-loop) can reject surplus heat from cooling to the ground in summer. If there is relatively little natural groundwater flow and if the system is well-designed, much of that heat will be retained in the rocks or sediments and can be re-extracted in winter for space heating. This is referred to as underground thermal energy storage (UTES). In the case of open-loop, groundwater-based systems, it is named aquifer thermal energy storage (ATES); in the case of closed-loop borehole heat exchangers, it is referred to as borehole thermal energy storage (BTES). Such UTES systems operate optimally if the heat rejected (from cooling) in summer approximately balances the heat extracted in winter.

1.4 The first UK ground source heat pumps

The Anglo-Irish engineer Sir Charles Parsons described a fantasy GSHP scheme – the "Hellfire Exploration Company" - based on circulating refrigerant within a deep mine shaft, as early as 1904. Parsons' ideas likely influenced the thinking of T.G.N. "Graeme" Haldane who constructed a heat pump to heat his home in Auchterarder, Perthshire around 1927 to 28. The heat was extracted from a water tank fed by the Estate's water supply, most likely derived from springs – if so, Haldane could claim to have constructed the UK's first groundwater-sourced heat pump (Haldane 1930, Banks 2015).

After Haldane, the UK's pioneering ground source heat pumps were installed by John Sumner and Miriam V. Griffith in the 1940s and 1950s, including Sumner's water-source heat pump based on the River Wensum in Norwich in 1945. In 1948, Lord Nuffield commissioned them to install twelve domestic closed-loop ("ground coil") systems for testing in selected houses, with an output of around 9 kW each (Sumner 1976, Curtis 1995, Banks 2012).

Little further interest was shown in GSHP in the UK until the mid-1990s, although Curtis (1995, 2001) notes the installation of up to a dozen Swedish heat pumps coupled to horizontal ground loops in southern England during the 1960s and 1970s. 1994 saw the first "modern" vertical closed-loop borehole GSHP installed at a house in Devon (Curtis 1995). By this time, however, GSHP had become an accepted technology in several European nations, most notably Sweden (Banks 2012).

Text Box 1.1. Miriam Griffith – UK ground source heat pioneer

As early as 1948, Miriam Griffith was already considering the optimal conditions and environmental impacts of ground source heat pumps in the UK (Griffith 1948).

The soil "should have as high a thermal conductivity as possible. We need to know also the effect of moisture movements under sharp temperature gradients and of natural cyclic variations of temperature. If the soil freezes round the buried pipes, how will this affect the crops, should the heat be taken from 4 feet down in a kitchen garden? What effect will the soil surface conditions have on the heat transfer? What length and size of pipe will be necessary?"

Since around 2000, the GSHP market has grown steadily in the UK. Section 2 provides a background to the more important policies and subsidy systems that have affected the GSHC industry, both positively and negatively, during this period. The progress in numbers of installed GSHP and ground source heating / cooling systems are examined in more detail in Section 3.

2. A review of UK GSHC policy and subsidy

Section 2.1 provides an overview of Government policy for heat pumps in low carbon heating, Sections 2.2 onwards describe the most important subsidy schemes for heat pump installation since 2003 in more detail.

2.1 The evolution of UK GSHC policy

Heating accounts for over one third of the UK's greenhouse gas emissions (BEIS 2018). The Climate Change Act (2008)[9] committed the Government to reducing greenhouse gas emissions by 80% by 2050 and mandated the setting of regular carbon budgets to systematically achieve this. Heat pumps[10] have long featured in the UK Government's energy decarbonisation strategy, being one of a few technologies that allow for the cost-efficient decarbonisation of space heating, especially in a domestic context. This is because heat pumps use electrical energy which can be decarbonised by using wind, nuclear, hydroelectric or solar technologies (among others).

In the Climate Change Committee's[11] (CCC) outline of the first 3 carbon budgets (CCC 2008), heat pumps are mentioned 26 times, but biomass was widely regarded as the major source of renewable heat. However, in the 4th Carbon Budget, heat pumps are mentioned 107 times (see Section 4.1) (CCC 2013) and envisioned as heating 13% of homes by 2030, with annual sales of 400,000.

More recently, the UK Government's (2017) Clean Growth Strategy pointed out the need to fully decarbonise home heating by 2050 as a crucial component in meeting emissions targets. In the Strategy, the use of heat pumps is cited alongside hydrogen (via a gas grid) and district heating as pathways to achieve this. The Strategy focuses on ensuring that all

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[9] https://www.legislation.gov.uk/ukpga/2008/27/contents

[10] Heat pump targets discussed in this section refer to air, water and ground source heat combined, not only GSHP/GSHC systems.

[11] Although discussed in this Section, it should be noted that the Committee on Climate Change (CCC) is not a government organisation. It is an executive, non-departmental public body set up under the Climate Change Act (2008) to advise government. It is currently sponsored by the Department for Energy Security and Net Zero (DESNZ) - https://www.gov.uk/government/organisations/committee-on-climate-change. It should not be confused with the Parliamentary House of Lords Environment and Climate Change Committee.

new homes not on the gas grid are heated by a heat pump or other low-carbon heating by the mid-2020s.

BEIS's (Department for Business, Energy and Industrial Strategy, now DESNZ (the Department for Energy Security and Net Zero)) 2018 "Clean Growth – Transforming Heating" paper provided more detail on the strategy to decarbonise heating. This included reducing heat demand by improving the thermal efficiency of buildings, growing heat networks, and increasing the uptake of low or no-carbon heating solutions, including heat pumps (together with biomethane). Hydrogen gas (possibly blended with natural gas) supplied through the gas grid is also discussed. The report emphasises that "there is no consensus on which technologies will be able to achieve this [i.e. heat decarbonisation] most economically and effectively at the scale required". BEIS (2018) also announced the intention to review Part L of the Buildings Regulations[12] to discourage use of fossil fuels in new homes, and the Heat Networks Investment Project (HNIP)[13].

In the 2019 Spring Statement (HM Treasury 2019), the Government announced its intention to introduce a new Future Homes Standard by 2025. The performance standards would ensure that "new homes will not be built with fossil fuel heating, such as a natural gas boiler" (Ministry of Housing, Communities and Local Government 2021). To help achieve this goal, the Government amended Parts F (Ventilation[14]) and L (Conservation of fuel and power) of the Buildings Regulations 2010[15] in 2021. This will ensure that new homes built to the Standard will produce 75-80% less carbon emissions than current homes; the likely implication is that it will not be feasible to install gas and other fossil fuel space heating infrastructure in new homes from 2025 (Woodfield & Pullen 2022).

Also in 2019, Parliament amended the Climate Change Act (2008) with a 2050 Target Amendment Order (2019)[16], to commit to a "Zero Emissions" target by 2050, rather than an 80% reduction.

In 2020, CCC (2020) recommended that the 6th Carbon Budget (which would run from 2033-37) target a 68% reduction in greenhouse gas emissions by 2030 and 78% by 2035, relative to a 1990 baseline. The latter (2035) target implies a 63% reduction from 2019.

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[12] https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l

[13] https://www.gov.uk/government/collections/heat-networks-investment-project-hnip-overview-and-how-to-apply

[14] https://www.gov.uk/government/publications/ventilation-approved-document-f

[15] https://www.legislation.gov.uk/uksi/2010/2214/contents/made

[16] https://www.legislation.gov.uk/ukdsi/2019/9780111187654

The document focusses heavily on heat pumps and heat networks for space heating and remains open to the place of hydrogen. To achieve a balanced net zero pathway, CCC (2020) foresees 1 million annual heat pump sales, and a total of 5.5 million heat pumps installed in the UK, by 2030 (Figure 1).

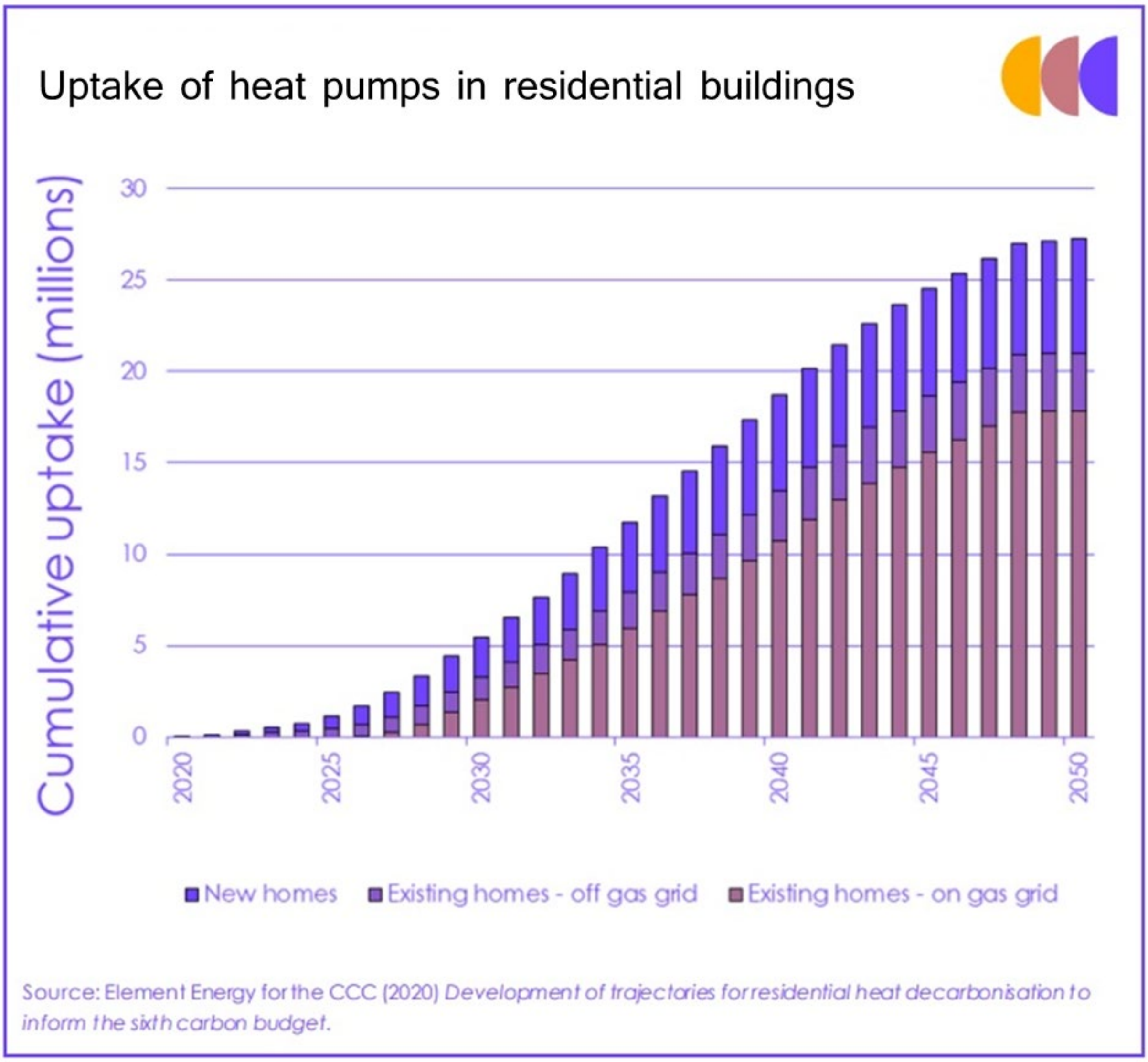

Figure 1. Projected uptake of heat pumps in residential buildings in the UK, according to the decarbonisation pathway envisaged by CCC (2020). © Committee on Climate Change, reproduced under terms of https://www.theccc.org.uk/copyright-terms-conditions/

In November 2020, HM Government (2020) published its "10 Point Plan for a Green Industrial Revolution". Point 7 of the plan focussed on greener buildings, confirming the intention to move away from fossil fuel boilers over the next 15 years and introducing the Government's ambition to see 600,000 heat pumps installed annually by 2028. It confirmed the intention to implement the Future Homes Standard at the earliest opportunity, to make new homes 'zero carbon ready', reducing carbon dioxide emissions by 75–80% compared to current emissions. It affirmed the Government's support for the:

- Recently created Green Homes Grant[17] voucher scheme, which ran from September 2020 until March 2021 and provided support to households and landlords wishing to improve home energy efficiency or to install low carbon heating technology, including heat pumps. The scheme was heavily criticised as "underperforming" by the renewable energy industry (SEA 2021) and indeed by the UK Parliament's Public Accounts Committee (House of Commons 2021).
- Public Sector Decarbonisation Scheme[18], launched in September 2020, and providing grant support to energy efficiency and decarbonisation measures in public sector buildings (schools, hospitals etc.), including installation of heat pumps. Funding is currently delivered via DESNZ's delivery body Salix Finance[19].
- Social Housing Decarbonisation Fund (SHDF), launched in October 2020, with a demonstrator scheme[20], and with the first wave of funding in August 2021[21], aimed at retrofitting energy efficiency measures, including low carbon heating technologies (with a "focus on low temperature heat pumps as the lead technology") in the social housing sector[22].
- Homes Upgrade Grant (HUG)[23], commencing in 2022 and delivered through local authorities, the scheme is designed to provide funding for energy efficiency upgrades and installation of low carbon heating technologies to low-income households without a gas boiler and with poor existing energy performance (SEA 2021).

The Government's overall Net Zero Strategy (HM Government 2021a) and the specific Heat and Buildings Strategy (HM Government 2021b) were published in October 2021. Key points relating to heat pumps include:

- An "ambition" that no new or replacement gas boilers will be sold after 2035.

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[17] https://www.gov.uk/guidance/apply-for-the-green-homes-grant-scheme

[18] https://www.gov.uk/government/collections/public-sector-decarbonisation-scheme

[19] https://www.salixfinance.co.uk/public-sector-funding-schemes

[20] https://www.gov.uk/government/publications/social-housing-decarbonisation-fund-demonstrator-successful-bids

[21] https://www.gov.uk/government/publications/social-housing-decarbonisation-fund

[22]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1114571/shdf-wave-2.1-competition-guidance.pdf

[23] https://www.gov.uk/government/publications/home-upgrade-grant-successful-local-authorities, https://www.gov.uk/apply-home-upgrade-grant

- Announcement of a £450 million funding over 3 years for the BUS.
- Although the strategy does not discount hydrogen as a contributor to low carbon heating, the heat and buildings strategy focusses heavily on heat pumps and heat networks, affirming the ambition of 600,000 heat pumps installed annually by 2028.
- Reducing the price of electricity by shifting the burden of levies from electricity to gas.
- A commitment to taking a decision on the future role of hydrogen in heating by 2026.
- Reaffirming the intention to ensure that all new buildings in England are ready for Net Zero from 2025, through implementation of the Future Homes Standard.

One of the main concerns of Government policy from within the heat pump industry is the persistence of the concept of a gas-grid based on hydrogen for domestic heating. Many studies have found that widespread use of hydrogen for heating is less efficient than alternatives (Rosenow 2022), and that postponing the final decision until 2026 (see above) will lead to potential heat pump customers deferring decisions until that date. Moreover, recent trials of hydrogen heating have been cancelled due to objections within the affected communities (BBC News 2023).

The Locating Resource Efficiency at the heart of Future Industrial Strategy “UK FIRES” (2019) group (an Engineering and Physical Sciences Research Council (EPSRC)-funded consortium of academics) supports the idea that the main viable future space heating technology will be electrically driven heat pumps. However, they suggest that a zero-carbon energy solution will require the closure of the fossil fuel supply chain by 2050 and a threefold expansion of zero-carbon electricity provision.

A 2021 report from UK FIRES (2021) examined the Government’s proposed pathway to a 45% reduction in greenhouse gas emissions between 2018 and 2030 (the Government’s Nationally Determined Contribution submitted under the Paris Agreement for COP26). It calls for a ban on new gas boilers as early as 2028, with the installation of 7 million heat pumps by that date, a massive growth in building retrofit and a stamp duty structure that encourages householders to invest in energy efficiency.

In the same year, the Committee on Climate Change (CCC 2021) issued its own independent assessment of the UK Government’s Net Zero Strategy. While the assessment is broadly supportive of the Strategy, the CCC does raise some concerns regarding lack of detail on mechanisms to deliver policy goals, and lack of emphasis on necessary change in consumer behaviour. It underlines the need to take urgent action on “standards and market mechanisms for driving low-carbon heat uptake”. In the space heating sector, it notes that “significant delivery risks remain, notably for energy efficiency in the 60% of UK homes which are owner-occupied but not fuel poor”. The report notes that the UK Government Net Zero Strategy does not meet the CCC’s preferred pathway, which calls for 900,000 heat pumps installed annually by 2028 and 25 TWh_{th} of low carbon district heating by 2030 (as opposed to the Government target of 15 TWh_{th} and 600,000 heat pumps).

The UK Energy Research Centre (an independent research centre, founded in numerous academic institutions and funded by UK Research and Innovation (UKRI)) also cast doubt on the Government's ambitious heat pump roll-out described in the Net Zero Strategy (UK ERC 2021), by pointing out the flawed assumption that there is scope for a dramatic reduction in the cost of heat pumps (in the same way that has, for example, been seen for solar PV). The UK ERC (2021) also notes that the £450 million BUS package over 3 years only equates to the installation of 30,000 heat pumps annually, far lower than the ambition of 600,000 per year by 2028. Lowes et al. (2021) agree, stating that "existing and proposed policy is currently insufficient to drive the market at anything near the required deployment levels". Lowes et al. (2021) proposed a programme of capital grants for heat pump deployment peaking at £3 billion per year to achieve significant change, together with a clear "end date" for fossil fuel heating systems. Importantly, Lowes et al. (2021) point out that electricity sales are subject (as of March 2021) to around 22.9% "legacy" environmental and social obligation levies, while gas is subject to 1.9%, despite recent rapid electricity decarbonisation. Lowes et al. (2021) note that if there were changes to these levies then the uptake of heat pumps might be greater.

2.2 The Clear Skies programme

The Clear Skies Programme[24],[25] ran from 2003 to 2007, with funding of up to £12.5 million for householders and community/public sector organisations to claim capital grants of up to £100,000 or 50% of total project cost (whichever is the lower) for renewable energy installations including solar thermal, wind, small-scale hydroelectric, biomass, micro-CHP and GSHP. Its major success, according to the review by industry authors Curtis & Pine (2016), was to raise awareness of GSHP technology amongst architects and developers.

2.3 The Low Carbon Building Programme (LCBP)

The Clear Skies Programme was succeeded by the LCBP, which was open both to domestic and non-domestic applicants for capital grants covering a portion of the total cost of renewable energy schemes, including GSHP. The scheme was administered by the Department for Trade and Industry (subsequently BERR, the Department for Business, Enterprise and Regulatory Reform) and ran from April 2006 and closed to new applications in May 2010.

Eligible schemes needed to either comply with "Clear Skies" requirements or meet the new MCS standards. Funding was split into two phases:

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[24] https://www.building.co.uk/clear-skies-scheme-provides-10-million-boost/1027977.article

[25] https://www.bre.co.uk/news/Clear-Skies-ahead--255.html

1. Phase 1 was for domestic applicants and businesses and administrated by the Energy Savings Trust.
2. Phase 2 was launched in 2007 for public sector, charitable and not-for-profit organisations.

Funding of the order of several tens of millions of pounds was provided, although grant tranches (especially for the domestic scheme) were often oversubscribed within hours of being announced. Despite being widely regarded as underfunded, the scheme was also regarded as moderately successful and, in the opinion of Curtis & Pine (2016), together with the Clear Skies initiative, contributed to the growth of the UK GSHP market to around 4000 installations per year by 2009.

2.4 The Microgeneration Certification Scheme (MCS)

The MCS is a certification, rather than a subsidy, scheme. It was founded in 2007 by the then Department of Energy and Climate Change (DECC) to allow, "for the certification of products, installers and their installations"[26,27] of a number of different low-carbon energy technologies – including GSHP. It was initially developed to provide quality control for the Clear Skies and LCBP subsidy schemes (Curtis and Pine 2016). In April 2018 the Scheme was transferred to MCS Service Company Limited, and the MCS Charitable Foundation.

MCS accreditation has been a precondition of receiving several different forms of government subsidy, including the RHI and the BUS subsidy. The MCS scheme applies to individual GSHP with a thermal capacity of up to 45 kW, and GSHP systems (using multiple heat pumps) of thermal output up to 70 kW. This means that:

- Many GSHC schemes larger than 45 kW are unlikely to be registered in MCS databases.
- GSHC schemes that have not applied for government subsidy (RHI or BUS) will not necessarily be registered in MCS databases (but should be if the installer was MCS-certified).

The MCS issues a number of guidance documents with which MCS-approved installers must comply. Among the key documents for GSHP design are:

- MCS (2019). Heat emitter guide for domestic heat pumps.
- MCS (2020). Domestic heat pumps – a best practice guide.

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[26] https://mcscertified.com/about-us/ ,

[27] https://www.hvnplus.co.uk/archive/clear-skies-successor-charges-massive-registration-fee-01-04-2007/

- MCS (2021a). Heat Pump Standard - Design.
- MCS (2021b). Heat Pump Standard - Installation.
- MCS (2021c). Heat Pump reference information and tools (including ground loop sizing tables).
- MCS (2022). Specification for ground source closed-loop drilling.

2.5 Renewable Heat Payment Premium (RHPP)

Between the closure of the LCBP (August 2011) and the introduction of the Domestic RHI in March 2014 (see Section 2.7), a RHPP householder voucher scheme[28] was operated as an interim measure. The RHPP made one-off payments to householders for renewable heating technologies – including solar thermal and heat pumps (Lowe et al. 2017). It made grants of £1250 to £2300 for GSHP and £850 to £1300 for ASHP. These grants were considered too small to have a major impact, but around 2229 ground or water source heat pumps are believed to have been installed under the RHPP[29] (i.e. less than 1000 per year; DECC 2014a).

2.6 Green Deal

The Green Deal was a scheme launched by DECC, running from 2012/13 through to 2015. It allowed homeowners to make improvements to the energy efficiency of their homes by taking out a loan, provided this was assessed as being able to be paid back via subsequent savings in energy expenditure. The scheme was later modified to provide lump-sum grants rather than loans to qualifying householders. GSHP installation was one of a wide range of eligible energy efficiency technologies.

The scheme was widely perceived to be unsuccessful (BBC News 2015), due to poor awareness of the scheme amongst the public, unattractive interest rates, poor quality of assessments for Green Deal eligibility, and a high burden of administration and bureaucracy resulting in a lack of uptake.

[28] https://www.gov.uk/guidance/renewable-heat-premium-payment-scheme

[29] https://www.icax.co.uk/Renewable_Heat_Premium_Payment.html

Lowes et al. (2021) record that only 270 heat pumps were installed under the combined Green Deal and the Energy Company Obligation[30].

2.7 Renewable Heat Incentive (RHI)

In 2007 the rate of GSHP installation in the UK was 2400, rising to almost 4000 GSHP installations in 2009 (Rees & Curtis 2014, Curtis & Pine 2016)[31]. At around this time, the UK adopted the European Renewable Energy Sources (RES) directive 2009/28/EC[32] and the LCBP was abruptly withdrawn, with a new Domestic[33] and Non-Domestic[34] (RHI) being announced (2008/09), based on "per kWh_{th}" tariffs for renewable heat production (Curtis & Pine 2016). Eligible technologies included biomass combustion, solar thermal, ASHP and GSHP.

The RHI had two strands:

- a Non-domestic RHI, which was launched in November 2011 (but applicable to equipment installed after July 2009), typically for larger systems, where production of renewable heat had to be metered on-site and a tariff paid against meter readings. Eligible technologies have included: solid biomass, biogas, GSHP, ASHP, geothermal, solar thermal and energy from waste. GSHP with capacities less than 45 kW had to be MCS accredited. The Non-domestic RHI closed on 31st March 2021.
- A Domestic RHI, which began in 2014 (but applicable to legacy systems installed since the announcement of the scheme in 2009) (OFGEM 2022a). For most installations under the domestic RHI, heat was not metered, but "deemed" based on

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[30] This scheme, running from 2013, placed an obligation on medium-to-large energy suppliers to improve the ability of vulnerable households to heat their homes; measures implemented could include upgrades to heating systems (https://www.ofgem.gov.uk/environmental-and-social-schemes/energy-company-obligation-eco).

[31] It is acknowledged that this relatively high reported (albeit short-lived – Curtis & Pine 2016) upturn in installation rate does not fully accord with other reported data sources: see for example Figure 3.

[32] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (europa.eu)

[33] https://www.gov.uk/domestic-renewable-heat-incentive

[34] https://www.gov.uk/non-domestic-renewable-heat-incentive

the likely heat requirements of the building and an assumed COP_H. In properties with a “bivalent” system (where the heat pump only meets part of the heat demand) or in second homes, heat metering was required. The domestic RHI closed to new applicants on 31st March 2022. As of 2023/24 (OFGEM 2023a), GSHP schemes accredited after December 2016 are eligible for a tariff of 24.8 p per kWh_{th} (adjusted by the Consumer Price Index[35]). MCS accredited installation is a precondition for approval for domestic RHI funding.

The tariff-based RHI system for heat was an idea paralleling the popular feed-in tariff (FIT) scheme for home electricity generation (for example, by solar PV). However, while an electricity tariff FIT was relatively straightforward to implement and administer (due to connection to a universal electricity grid, allowing consistent national pricing and straightforward export metering) it was more difficult for renewable heat. As well as the technical challenges of metering generation of heat:

- Heat networks were not widespread and thus heat would largely be consumed locally;
- the appropriate tariff levels for differing forms of heat production (and for much of the lifetime of the RHI there was disquiet that the tariff for heat from GSHP did not adequately reflect the investment costs in heat pumps and ground loops);
- the challenge of how to apply tariffs to systems that provided both heating and heat rejection (cooling), and how to differentiate renewable heat (from the ground or air) from heat produced by a heat pump compressor (OFGEM 2012).

Formulation of the tariff system took around 3 years, creating a hiatus in the GSHP industry while potential customers waited to find out what the final form of the RHI would be. This hiatus coincided with the aftermath of the worldwide global financial crisis of 2008/2009, a slowdown in the construction industry and competition from a successful solar PV FIT tariff. As a result, the UK GSHP installation rate dropped to less than 500 per year in 2010 and 2011 and several GSHP consultants and contractors downsized or went out of business (Curtis & Pine 2016).

Lowes et al. (2021) noted (in March 2021) that the UK’s RHI was “set to deploy less than one-sixth” of the 491,000 “domestic heat pumps it intended by its original end date of April 2021”.

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[35] The Consumer Price Index is a measure of inflation or deflation that measures the overall change in consumer prices over time based on a representative basket of goods and services.

As of May 2023, 114,634 heat pump installations had been made under the domestic RHI, of which 77,826 were ASHP and 15,290 were GSHP[36]. Annual domestic RHI accreditations for ASHP had been around 9000 to 10,000 in around 2020 (rising to over 21,000 in 2021-22), with around 1000 per year for GSHP between 2016 to 2021 (Ofgem 2022a) (Figure 2).

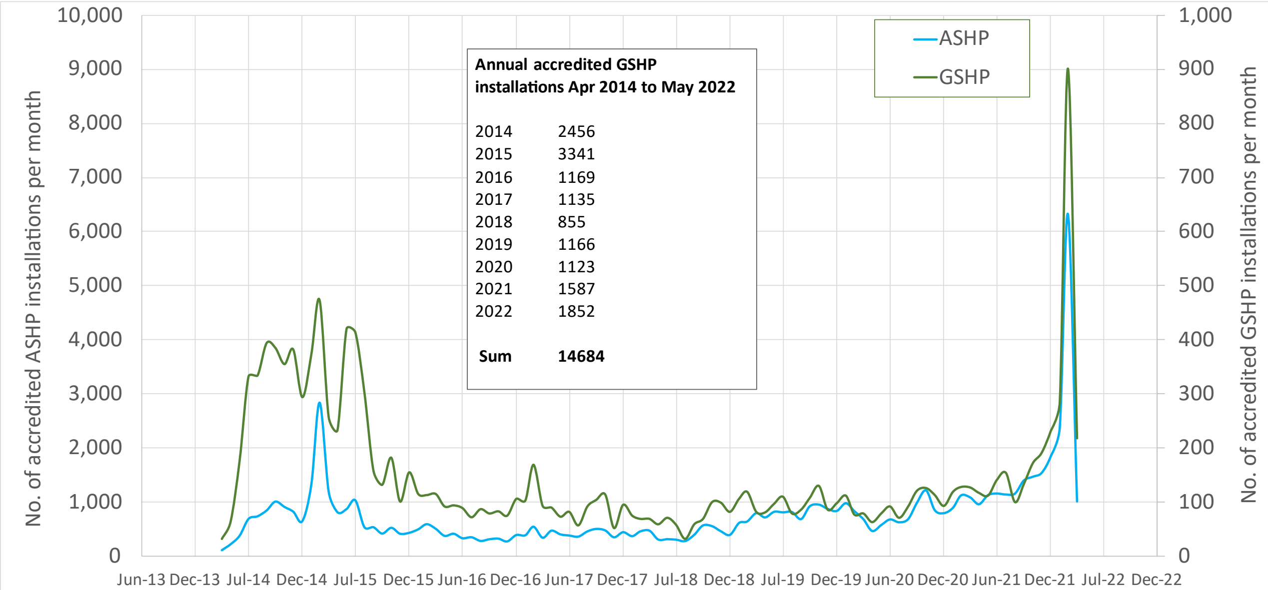

Figure 2. Numbers of Domestic Renewable Heat Incentive accredited ASHP (left axis) and GSHP (right axis) installations per month, based on BEIS deployment numbers contained in "RHI monthly deployment data: May 2022" at https://www.gov.uk/government/statistics/rhi-monthly-deployment-data-may-2022 and reproduced under terms of Open Government Licence 3.0.

As of 2023, over 60% of total domestic installations made under RHI are ASHP, and the majority of Domestic RHI funding has gone to ASHP.

For the Non-domestic RHI (BEIS 2022), between November 2011 and May 2022 there were:

- 2098 accredited full applications for small (<100 kW) ground or water source heat pumps;
- 456 accredited full applications for large (>100 kW) ground or water source heat pumps.

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[36] https://www.ofgem.gov.uk/environmental-and-social-schemes/domestic-renewable-heat-incentive-domestic-rhi/contacts-guidance-and-resources, online graph of approved renewable heating systems by technology type, accessed 16/6/23.

2.8 Boiler Upgrade Scheme (BUS)

The BUS has replaced the Domestic RHI. It subsidises replacement of fossil fuel (gas, oil, electrical resistance) heating systems with either an ASHP, a ground- or water-sourced heat pump or a biomass boiler.

To be eligible for the BUS, the system must have a capacity of less than 45 kW, be MCS accredited, the property must not have outstanding actions on its (valid) Energy Performance Certificate (EPC) certificate, and the system must have been installed on or after 1st April 2022 (the date of closure of the domestic RHI).

The subsidy levels as of spring 2024 are[37]:

- £7,500 towards an ASHP,
- £7,500 towards a GSHP (including water source heat pumps and those on shared ground loops)
- £5,000 towards a biomass boiler

Almost all industry respondents interviewed (Section 4.2) cited the BUS as the reason for recent increased uptake of ASHP, at the expense of the "flatlining" growth of the domestic GSHP market (see Merrett 2022). Given that a typical domestic ground source heat installation can cost £20,000 to £25,000, the level of subsidy is not perceived to be making a substantial contribution to the initial capital outlay for GSHP. On the contrary, the subsidy for ASHP is a substantial fraction of the initial cost (ASHP can cost £8,000 to £12,000 within a domestic setting[38]).

The GSHP industry argue that the subsidy level does not reflect:

- the generally shorter lifetime of ASHP relative to GSHP[39];
- the typically higher operational efficiency of GSHP relative to ASHP[41]
- the long-term investment in a GSHP ground collector (which might endure for over 100 years and represents a significant portion of the initial capital investment).

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[37] https://www.gov.uk/apply-boiler-upgrade-scheme/print.

[38] The costs suggested here are highly indicative and will depend strongly on how much effort is needed to upgrade heat delivery systems within the house.

[39] See for example Wu, R. (2009) Energy Efficiency Technologies – Air Source Heat Pump vs. Ground Source Heat Pump. Journal for Sustainable Development, Vol. 2, no. 2, 2009.

Currently, the BUS appears to be failing to deliver both the expected installation of GSHP, and ASHP (Webb 2023). However, grants for heat pumps increased in October 2023 following a consultation and review by DESNZ (DESNZ 2023).

3. Distribution of GSHC in the UK

3.1 Ground source heat pump (GSHP) surveys 1995-2023

In the decades following the first modern borehole heat exchanger in Devon in 1994 (Curtis 1995), there have been two sets of surveys of the growth of the GSHP market in the UK.

1. One set of estimates, including estimates of the cumulative numbers of GSHP installed in the UK, is largely based on GSHP sales[40]. These studies were largely coordinated by Tony Batchelor and Robin Curtis of GeoScience (Batchelor 1990, Curtis 1995, 2001, Curtis et al. 2013, 2016, 2019, Batchelor et al. 2005, 2010, 2015, 2020, Abesser et al. 2022) and were published at European Geothermal Congress (EGC) and World Geothermal Congress (WGC) meetings. A useful overview paper was also produced by Rees & Curtis (2014). The data derived from these sources are shown as the green line (with triangles) in Figure 3.
2. A second set of estimates, focussing on installed cumulative GSHP capacity (MW_{th}) has been published in regular International Energy Agency (IEA) geothermal country updates for the UK, largely coordinated by Jon Busby and Corinna Abesser of the British Geological Survey (BGS). These estimates are also largely based on GSHP sales with assumptions made about thermal capacities of installed heat pumps (Busby & Dunbabin 2013, Busby & Sutton 2014, 2015, 2016, Busby & Auld 2017, Busby & Mansor 2018, 2019, 2020, 2021, Abesser & Jans-Singh 2022). This set of estimates is shown as the red line (with open circles) in Figure 3.

[40] Abesser (pers. comm. June 2023), the author of recent UK country updates, confirms that the figures are updated annually, based on GSHP unit sales reported by BSRIA Ltd. (Building Services Research and Information Association; https://www.bsria.com/uk/), with some minor adjustment to account for understanding of market development. No correction is made for historically installed GSHP which may have been replaced or decommissioned.

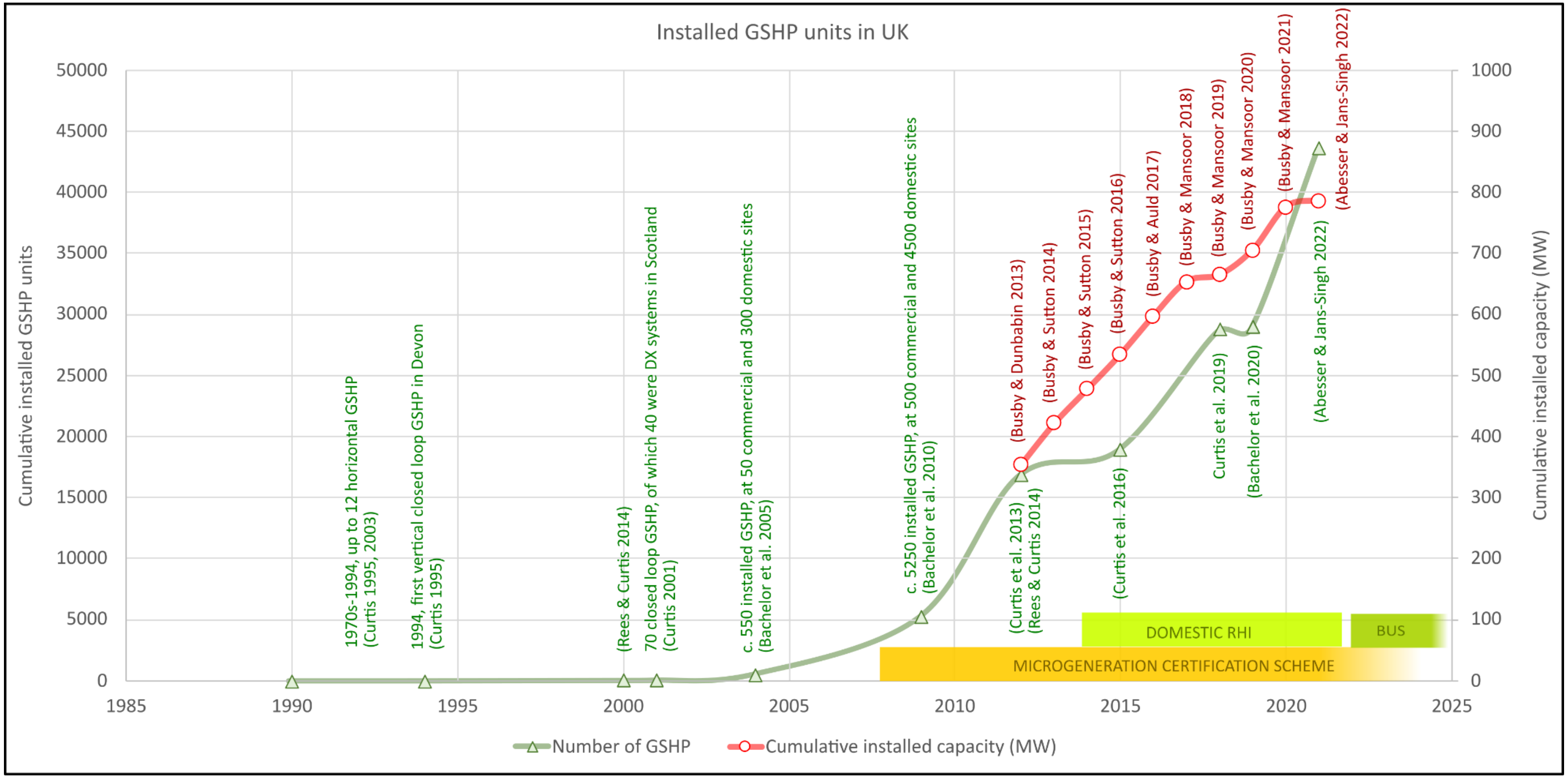

Figure 3. The evolution of the UK GSHP market since the 1990s. The green line with triangles shows the estimated cumulative numbers of GSHP installed in the UK (primarily vertical and horizontal closed-loop), while the red line with open circles shows the estimated cumulative installed GSHP capacity. Note that these figures will be larger than the numbers of GSHC systems. Coloured bars at the bottom of the graph shows the duration of operation of the MCS, Domestic RHI and BUS.

The number of operational GSHC systems will be less than the number of installed GSHP indicated in Figure 3 for two reasons:

1. While most domestic GSHP systems will use a single heat pump, many larger public sector and commercial systems will use 2 or more heat pumps. Some recent social housing schemes use many small heat pumps in individual properties that are connected to multiple boreholes by a single ground loop network (a “shared ground loop”, which can be regarded as a single GSHP system).

2. Some GSHP may have an operational life of 15-25 years, therefore it is possible that some of the earliest heat pumps have reached the end of their lives and been replaced or even decommissioned. A small fraction of recent sales (installation) figures could represent replacement units.

In 2004 the cited ratio of installed GSHP to GSHP “sites” was 550/350 = 1.57 (Batchelor et al. 2005). In 2009, the estimated ratio was much lower at 1.05 (Batchelor et al. 2010).

It is not clear whether water source heat pumps were included in the sales figures used to construct Figure 3 (i.e. units which may have been used in open-loop systems), but these represent only a small fraction of total GSHC installations, as discussed in Section 3.5.

The most recent estimate of the total number of GSHP in the UK is 43,700 for late 2021 (Abesser & Jans-Singh 2022), representing an estimated thermal capacity of 787 MW_{th} – using an average of 18 kW per heat pump (given that most domestic properties may require a peak output of 12 kW or less, this appears a little high). During 2022, a further 5584 GSHP are reported to have been sold (Aylott 2023).

3.2 Microgeneration Certification Scheme (MCS) data

The MCS collects data on smaller (<45 kW per heat pump and <70 kW per system) GSHP installations throughout the UK. Data have been collected since 2009. Most of the registered schemes are likely to be domestic / household schemes, although small commercial / public sector schemes may also be registered. The majority are likely to be retrofitted to existing properties, and the scheme does not efficiently capture data from GSHP installed at new-build properties (https://mcscertified.com/about-the-mcs-data-dashboard/, see also BEIS 2020, Aylott 2023). This may account for some of the discrepancy between MCS data and the sales-based data described in Section 3.1.

There is no formal obligation to have a GSHP system installed under the MCS but, as MCS accreditation has been a prerequisite for obtaining a range of subsidies (including Domestic RHI and BUS), it is likely that the large majority of small retrofit GSHP schemes installed during the operational period of these subsidies were installed under the MCS.

Because the MCS accredited schemes are mostly small systems, it is likely that the majority are closed-loop systems, as the expense incurred in drilling a groundwater abstraction well would likely prove off-putting to most customers. The most important GSHP systems which will not be registered under the MCS scheme are:

- Larger open- and closed-loop GSHP systems.
- Smaller GSHP systems which were not in receipt of subsidy payments because they may have been:
  - installed in new-build homes;
  - ineligible for RHI because they provide both heating and cooling, or may have failed to meet other RHI criteria;
  - installed before the Domestic RHI scheme commenced in 2014 (although there was an RHI provision for "legacy schemes" dating from 2009);
  - chosen not to pursue MCS accreditation for other reasons.

The data presented in this Section were downloaded from the MCS website (https://datadashboard.mcscertified.com/InstallationInsights) in March 2023. On that date, the total numbers of MCS-accredited GSHP (which also include a small number of water source heat pumps) were (Figure 4):

- 28,889 MCS-accredited GSHP installations in the UK
- 22,969 MCS-accredited GSHP installations in England

Of the 28,889 UK installations (Figure 5):

- 11,517 were classified as domestic (39.9%), a classification which has only been regularly used since 2015.
- 2773 were classified as "commercial" (9.6%), a classification which has only been regularly used since 2020.
- 3291 were classified as "non-domestic" (11.4%), a classification which was only regularly used between 2015 and 2020 and appears to have been largely replaced by "commercial" in 2020. This classification does, however, contain several larger social housing shared ground loop systems.
- 11,308 were classified as "unspecified" (39.1%), installed before "domestic" or "non-domestic" were used in 2015.

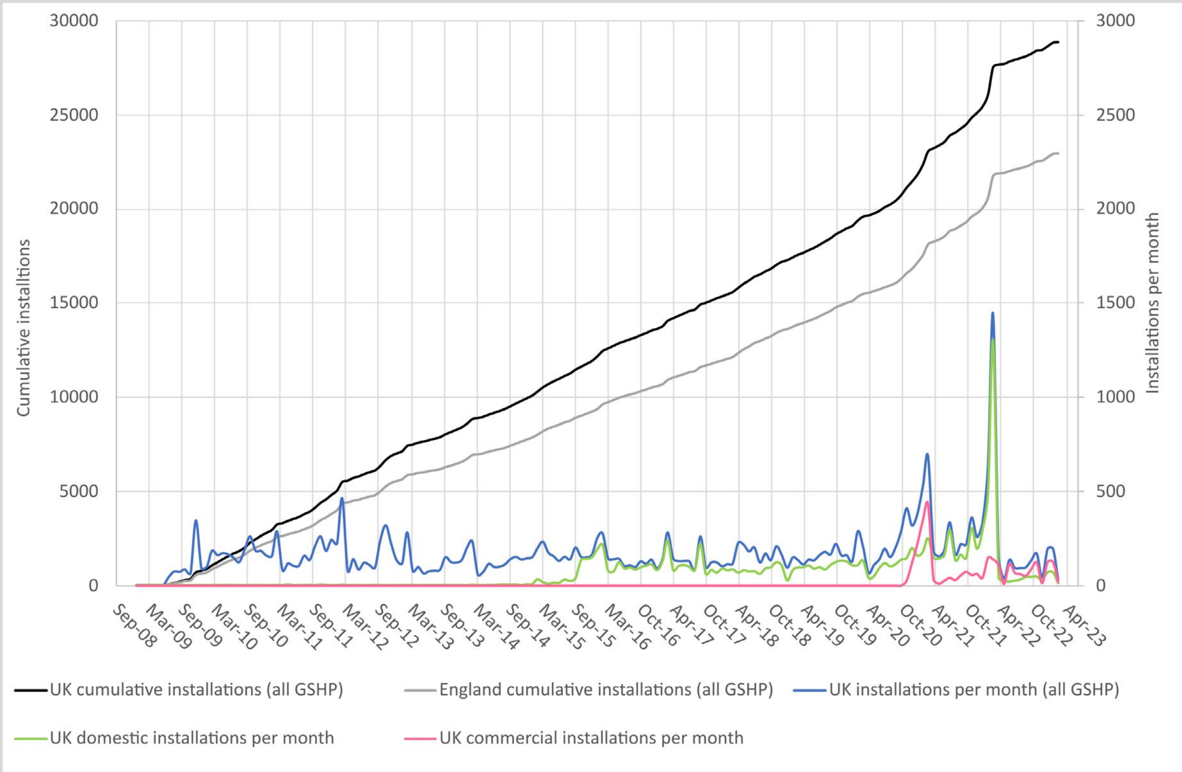

Figure 4. Cumulative MCS-accredited GSHP (including water-source heat pumps) installations and monthly installation rates, 2009 to 10th March 2023. All categories, including domestic and commercial, of GSHP in UK and England.

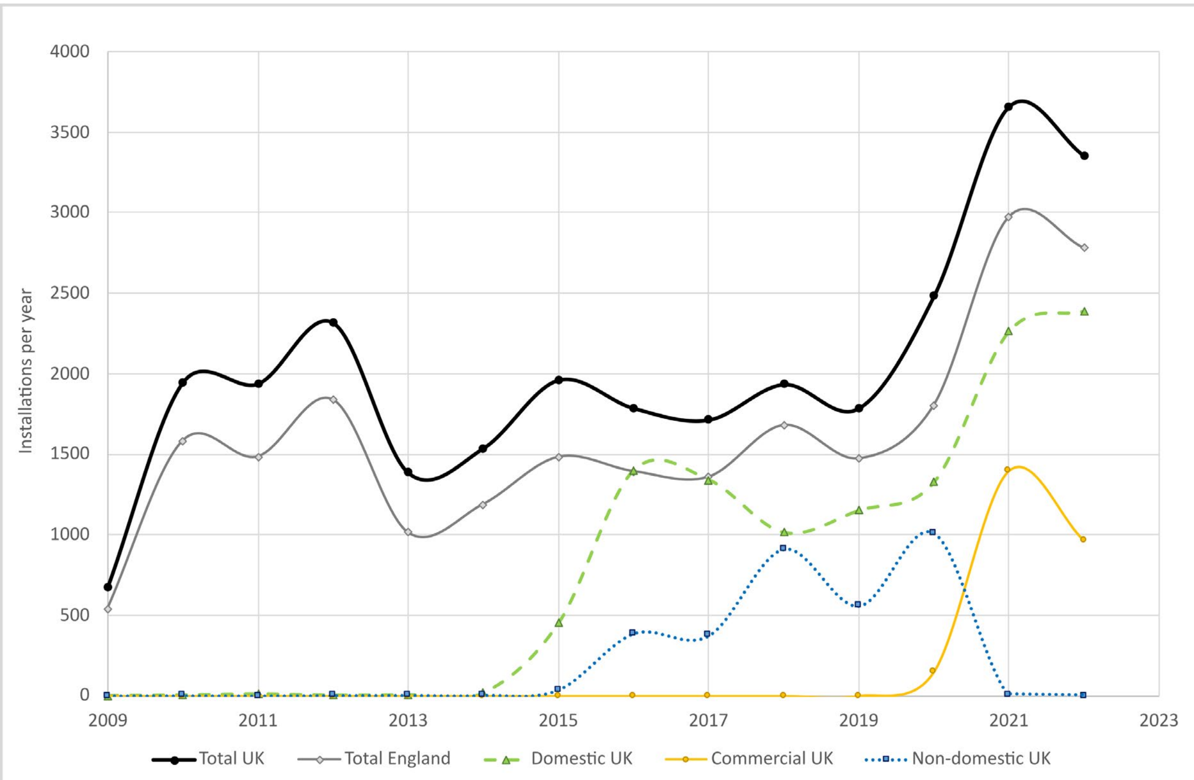

Figure 5. Annual MCS-accredited GSHP (including water-source heat pumps) installation rates, 2009-2022. In 2023, as of, and up to, 10th March, there were 413 MCS-accredited GSHP installed the UK (of which 392 were in England) - the majority were commercial and only 145 domestic (UK).

In the same period (2009-March 2023), 152,828 ASHP systems were installed in the UK under MCS-accreditation (Figure 6). The ratio of ASHP to GSHP is thus 5.29.

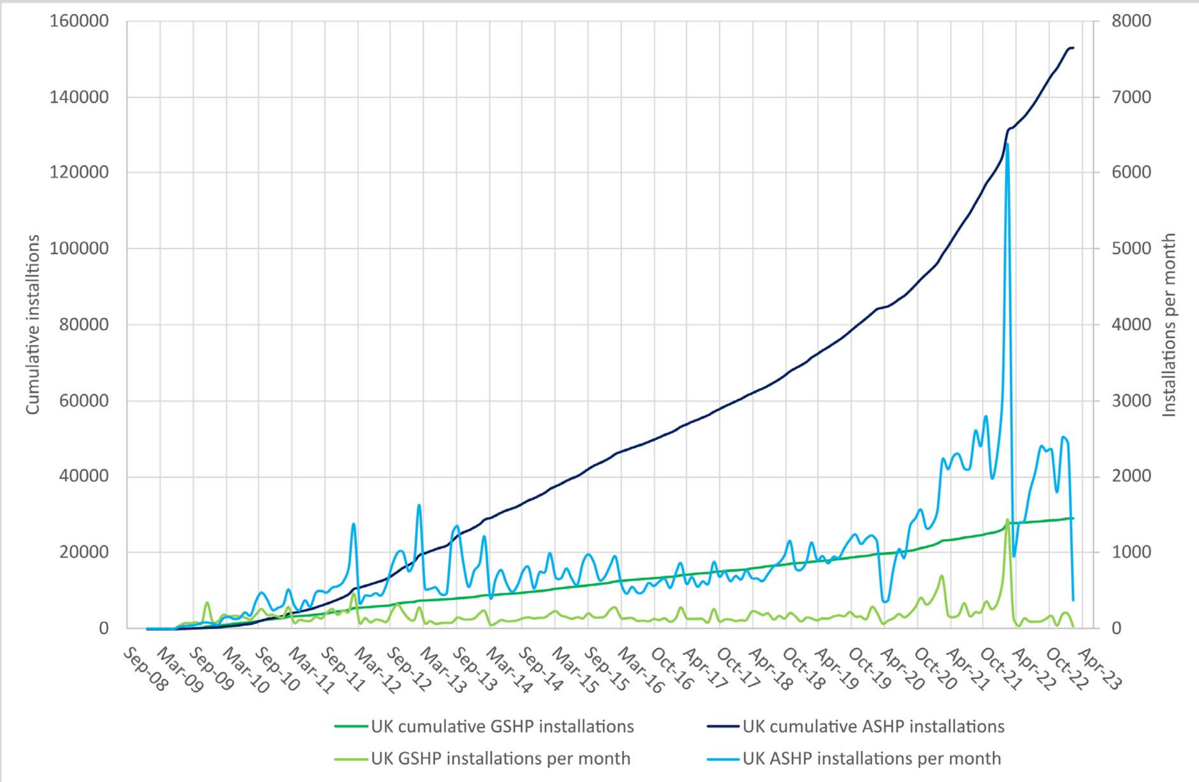

Figure 6. Cumulative MCS-accredited GSHP and ASHP installations, with monthly installation rates, 2009 to 10th March 2023. All categories of GSHP and ASHP in UK.

Figure 5 shows that the annual MCS-accredited GSHP installation rate was relatively constant at about 2000 per year in the UK and about 1500 per year in England from 2009 to 2019. There were, however, marked increases in 2020 and 2021 with peaks in spring 2021 and February to March 2022 (Figure 4).

The peak installation rate was also in February to March 2022 for ASHP (Figure 6). This peak coincides with the closure of the Domestic RHI on 31st March 2022, with customers wishing to certify MCS installations by that date.

The peak in spring 2021 could be related to the closure of the Non-domestic RHI on 31st March 2021, as the peak is predominantly seen in commercial installations (Figure 4).

In the year April 2022 to March 2023, the overall MCS-accredited UK GSHP installation rate was 153 per month (1838 in total). During this year, the commercial installation rate

(112 per month, 1345 in total) exceeded the domestic installation rate (41 per month, 493 in total)[41].

Figure 7 shows that the ratio of installed ASHP to GSHP was around 5 to 6 between 2013 and 2020. Since 2021, it has increased dramatically to over 10. Industry interviews suggest that the BUS has stimulated the growth of the domestic ASHP market at the expense of the GSHP market (see Section 2.8).

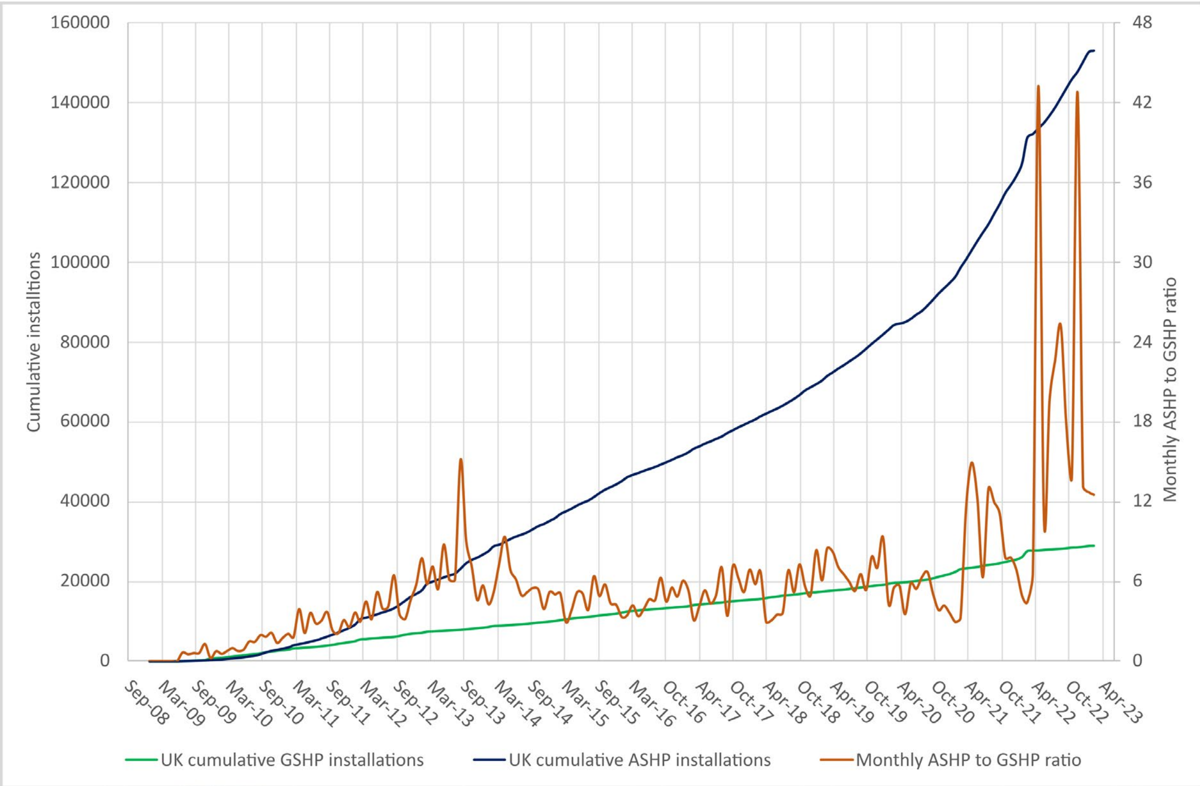

Figure 7. Cumulative MCS-accredited GSHP and ASHP installations, together with monthly ratio of ASHP/GSHP installations, 2009 to 10th March 2023. All categories of GSHP and ASHP in UK.

Figure 8 shows the MCS GSHP data for the UK, as of March 2023, as a series of “colour maps” by local authority area. The categories have been defined according to “jenks” – natural breaks in the data distribution to make it easier to see differences in GSHP installation numbers, as defined by the public domain software QGIS (https://www.qgis.org/).

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[41] The data in this paragraph were re-downloaded and analysed on 29th September 2023. These provide a more complete view of MCS certified systems for the year 1st April 2022 to 31st March 2023 to those presented in the figures which were downloaded for analysis on 10th March 2023 and may not have included the most recent installations.

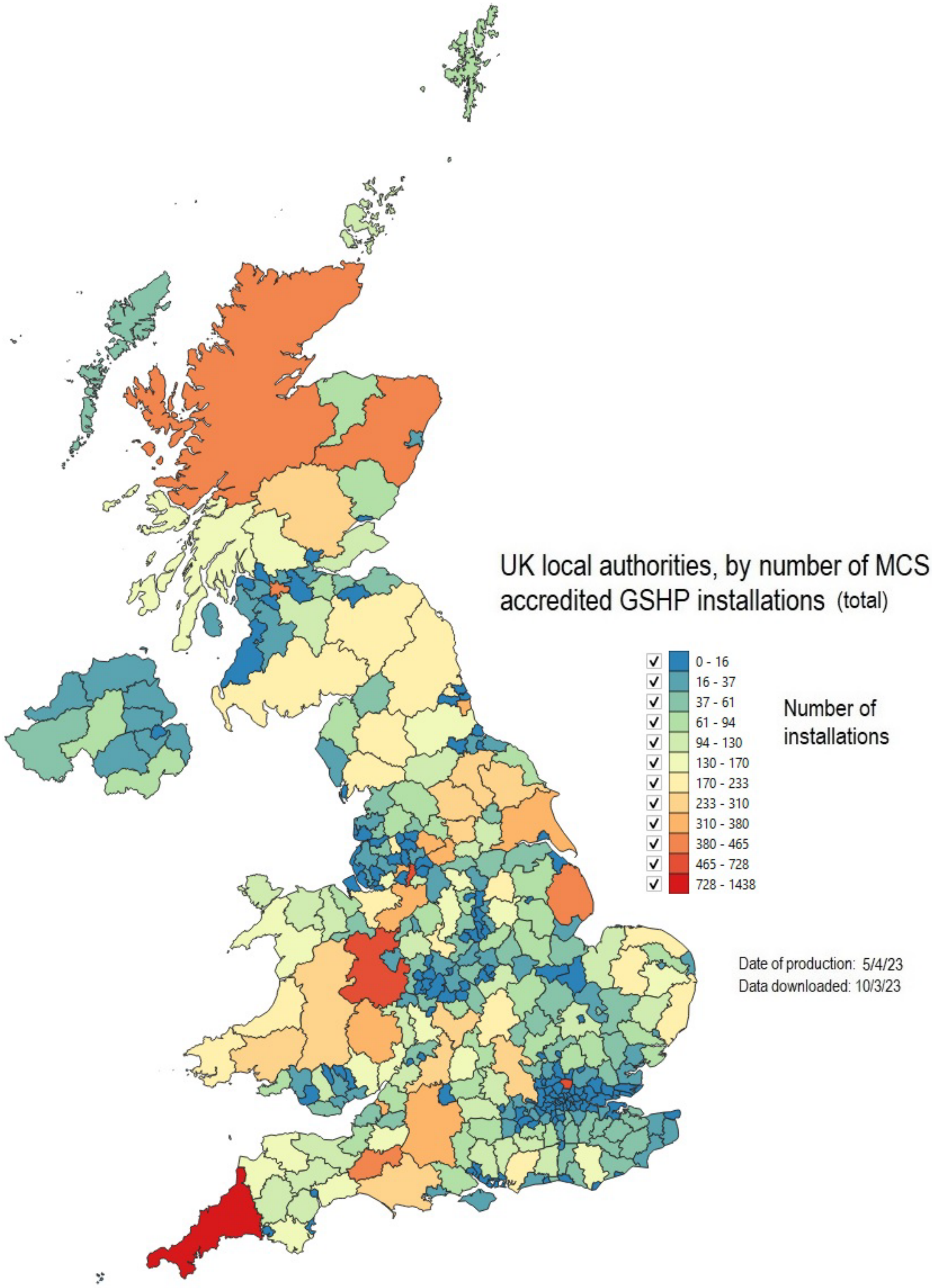

Figure 8. Number of MCS-accredited GSHP installations (2009 to 2023) by local authority in the UK. N = 28,889. As with subsequent maps, "GSHP" includes a small number of water-sourced heat pumps. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

The UK local authorities with the greatest numbers of MCS-accredited GSHP installations are:

- Cornwall with 1438 installations (0.59% of households)
- Shropshire with 728 installations (0.54% of households)
- Enfield (north London) with 594 installations (0.47% of households)

In general, rural areas have greater uptake of MCS-accredited GSHP installations than urban areas.

Text Box 3.1. The registration of social housing schemes with shared ground loops

The presence of Enfield amongst the local authorities with high numbers of GSHP demonstrates the difficulty of understanding installed heat pump numbers (Figure 8). Enfield is an outlier given the generally low uptake in small GSHPs in the urban areas of London, Birmingham, the North-West and the Midland Valley of Scotland. The high uptake in Enfield appears to reflect an ambitious joint project for installation of Kensa heat pumps in social housing (Kensa 2021a, 2023a) during 2017-18. In the Enfield case, each apartment received a small individual Kensa "shoebox" heat pump, but these were ultimately coupled to 16 large "shared" ground arrays. In total, 402 apartments were served.

This has been logged in MCS as 402 heat pump installations, rather than 16 GSHP system installations (Kensa, *pers comm.*). There are several other shared social housing ground loop schemes throughout the UK that have been similarly registered. This indicates that such shared ground loop social housing systems have been registered under the "non-domestic" category (at least, until 2020).

This example demonstrates the difficulty of distinguishing between GSHP ground loops and GSHP heat pumps within the MCS.

There is a strong similarity between Figures 8 and 9, the latter showing the number of MCS-accredited GSHP installers by local authority. Again, the largest number of installers are in Cornwall (24), followed by Shropshire (14) and Dorset (13).

While correlation does not imply causation, it is possible that rural areas that are off the mains gas grid and where land plots are large enough to permit drilling are more likely to find GSHP installation an attractive proposition, possibly also explaining the high uptake rates in Shropshire and Cornwall.

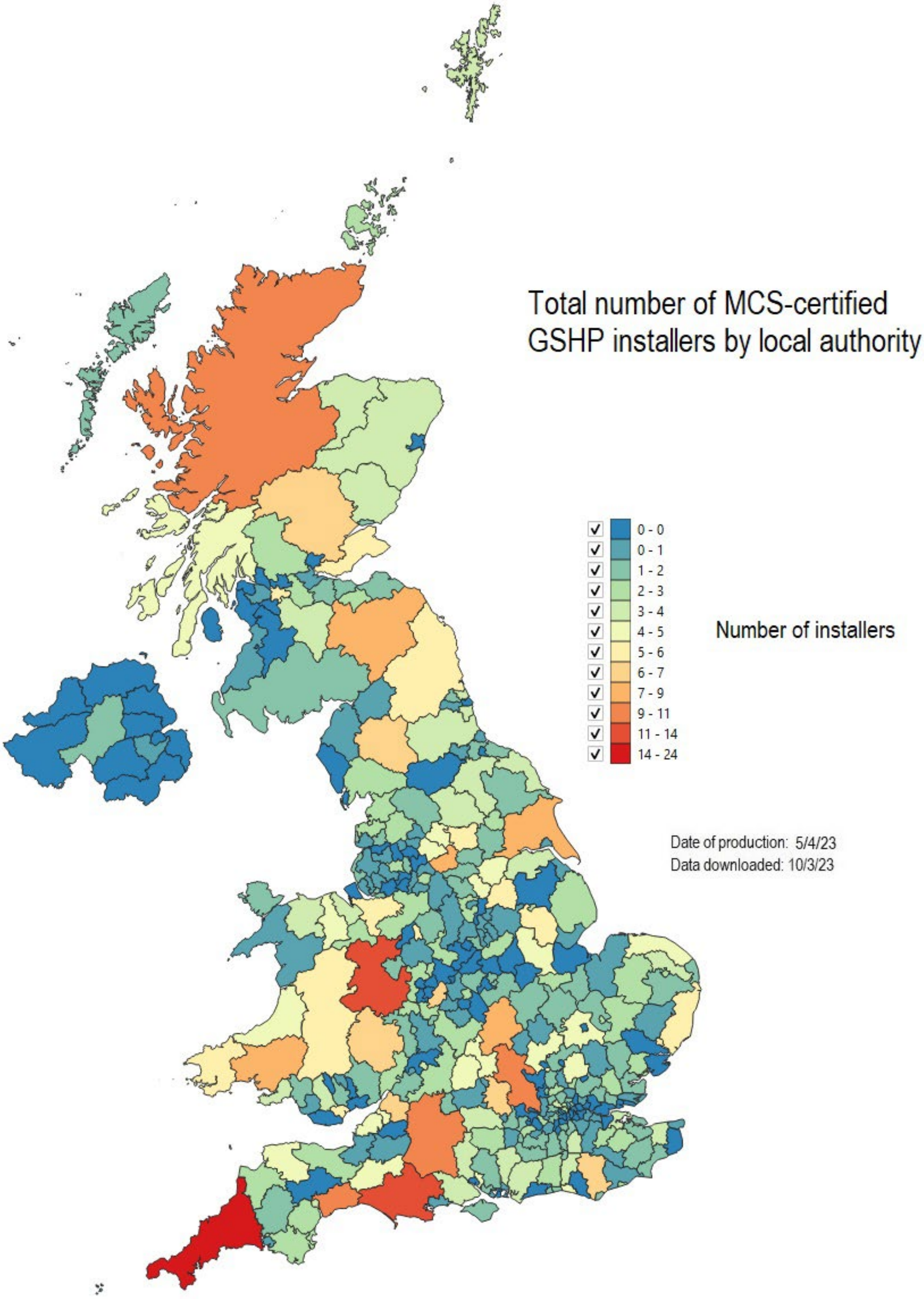

Figure 9. Number of MCS-accredited GSHP installers by local authority in the UK. N =852. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

Moreover, the high uptake rates in Cornwall could possibly reflect the attractive local geology (hard rock, which typically implies cheap drilling, due to stable downhole conditions), elevated ground temperatures (due to favourable climate and high geothermal gradient) and the presence of active local advocates for geothermal energy (Kensa Heat Pumps, GeoScience Ltd., and public awareness of geothermal heat via the Eden Project and United Downs deep geothermal ventures – BBC News 2021).

It may be that a high density of installers leads to a high uptake rate of GSHPs, although it is arguably more likely that the installer network develops to service a real demand.

Figures 10 and 11 show the numbers of “unspecified” (likely to be largely domestic installations prior to 2015) and “domestic” installations. In both cases, Cornwall, Shropshire and the Scottish Highlands have a greater number of installations, while the urban areas (London, Birmingham, the North-West and the Midland Valley of Scotland) have fewer.

Figures 12 and 13 show the numbers of “non-domestic” (2015 to 2020) and “commercial” (post 2020) installations. Again, Cornwall figures prominently.

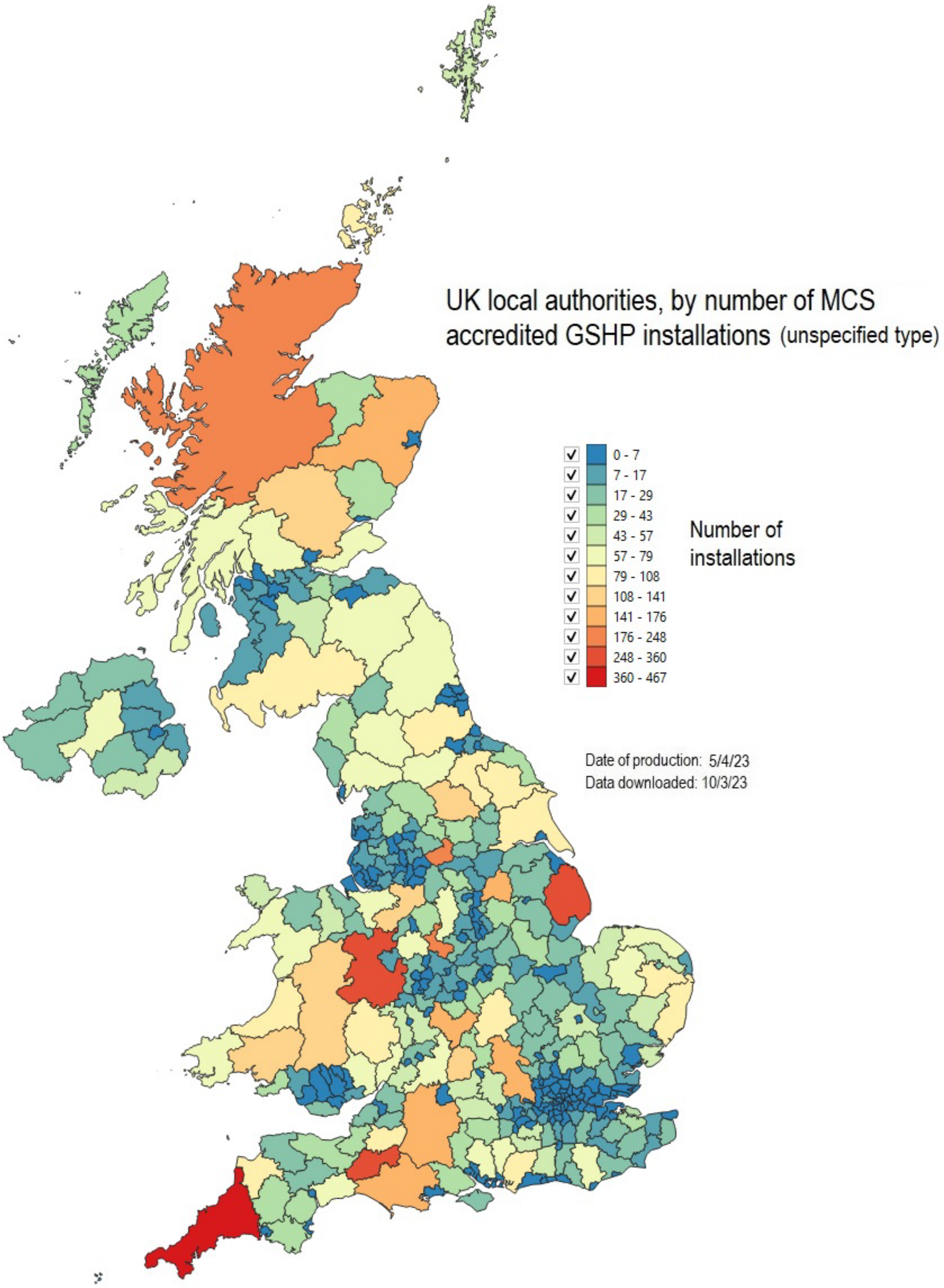

Figure 10. Number of MCS-accredited GSHP installations in the "unspecified" category (2009 to 2023) by local authority in the UK. N = 11,308. These are a mixture of domestic (predominantly) and non-domestic installations prior to 2015. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

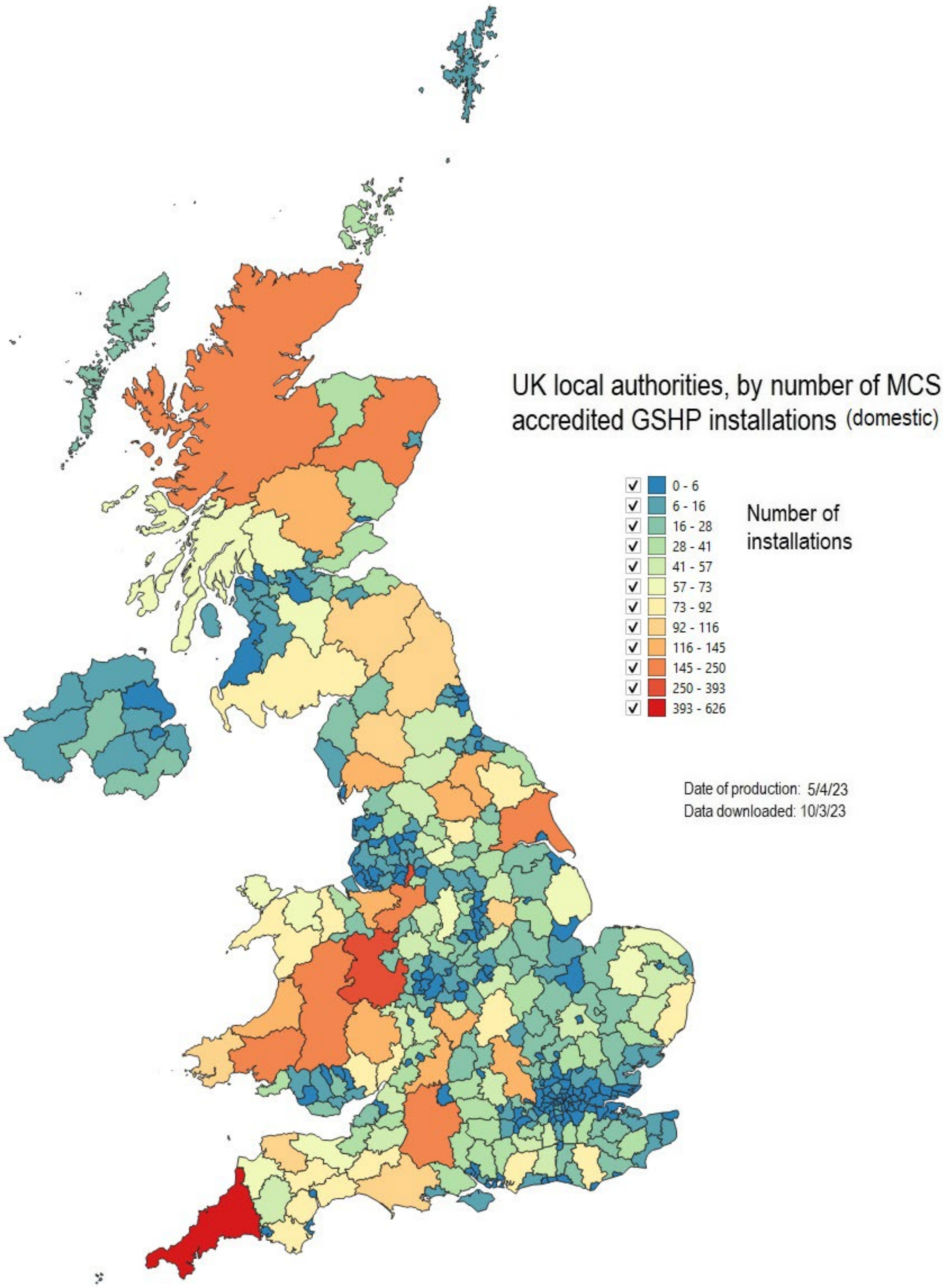

Figure 11. Number of MCS-accredited GSHP installations in the "domestic" category (2009 to 2023) by local authority in the UK. N = 11,517. These were predominantly installed after 2015. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

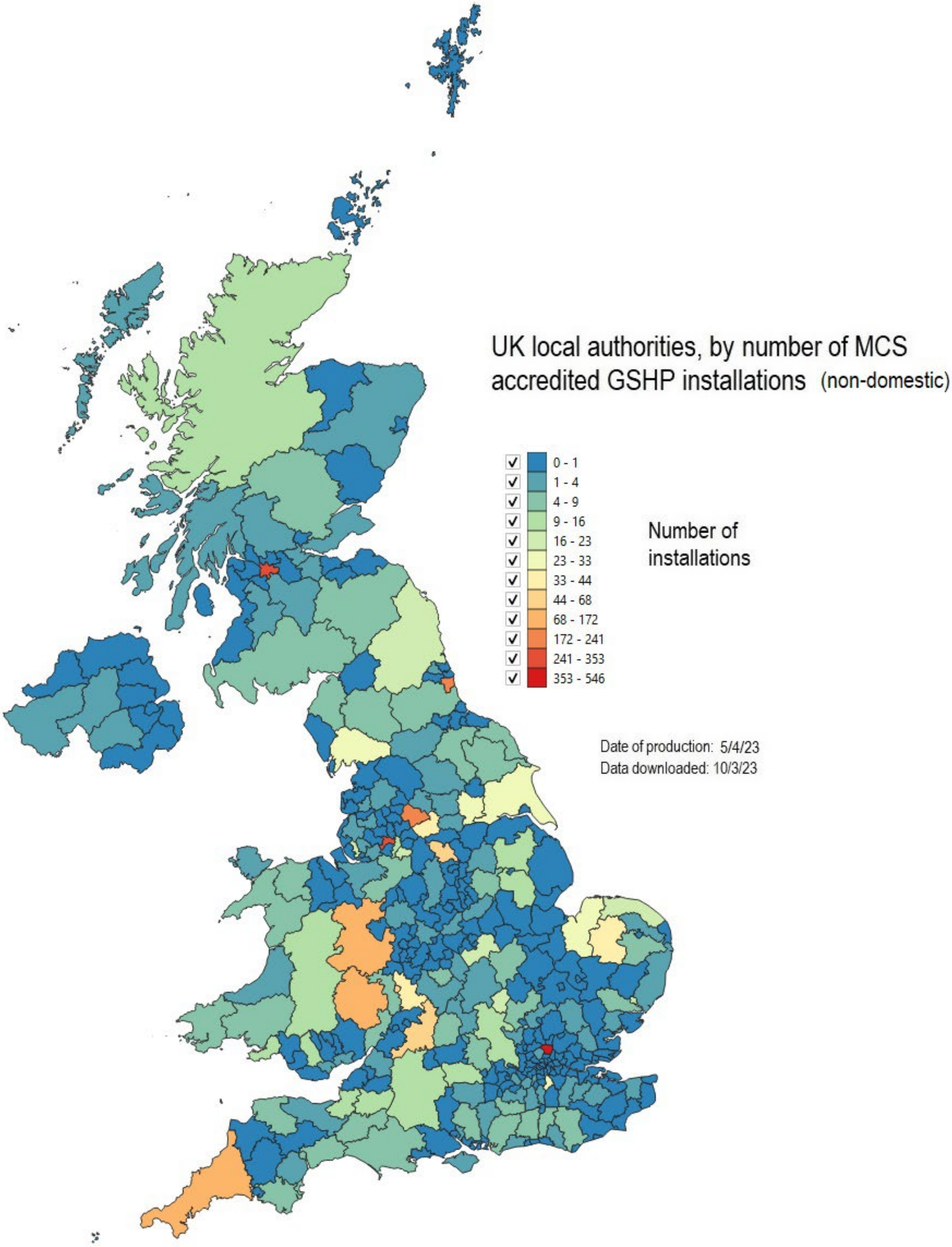

Figure 12. Number of MCS-accredited GSHP installations in the "non-domestic" category (2009 to 2023) by local authority in the UK. N = 3291. These are believed to be commercial, public sector (and shared social housing) installations installed between 2015-2020. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

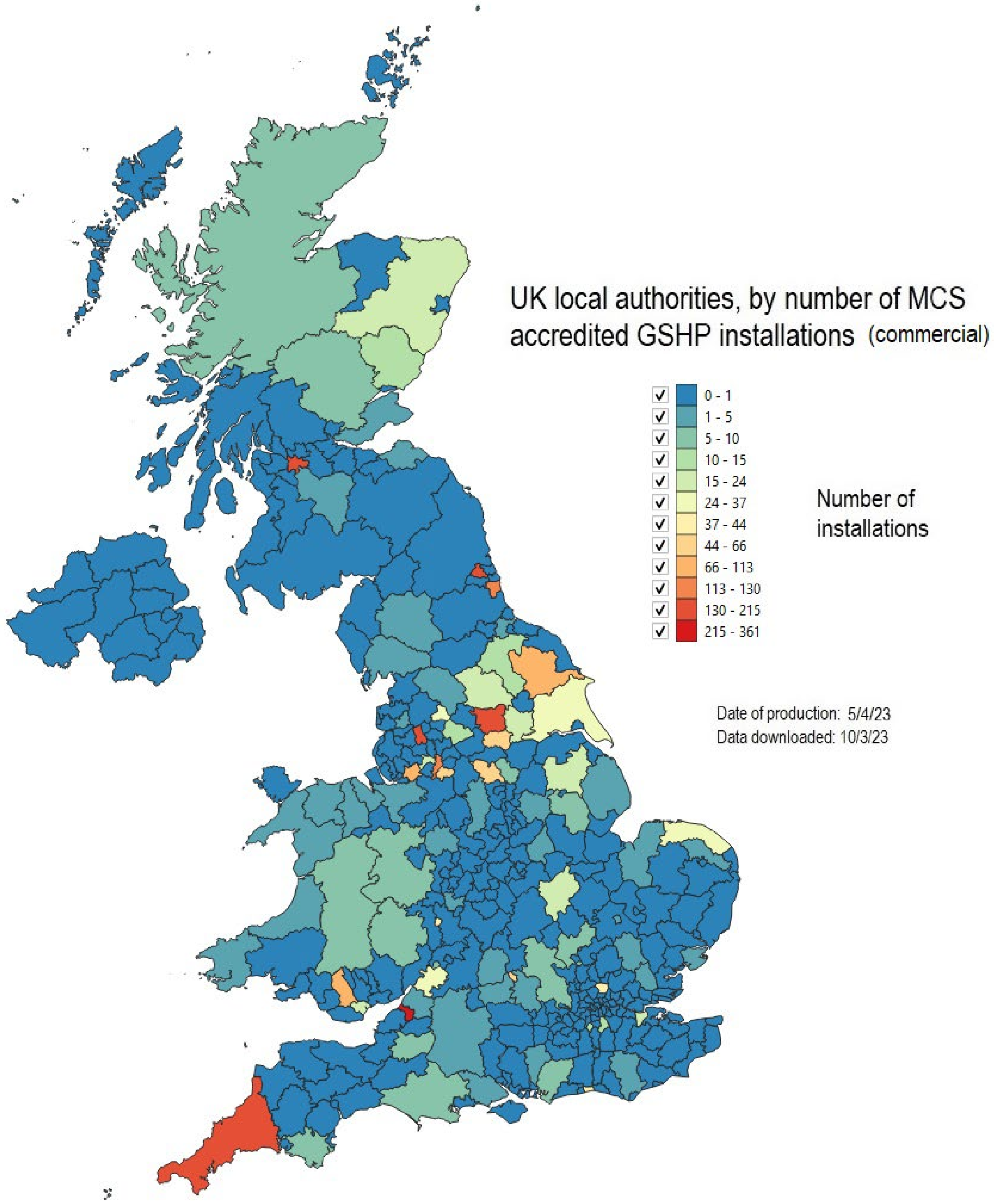

Figure 13. Number of MCS-accredited GSHP installations in the "commercial" category (2009 to 2023) by local authority in the UK. N = 2773. These are believed to have been installed predominantly post-2020. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

The highest numbers of “non-domestic” installations are in a few urban local authorities:

- Enfield (546 installations – see Text Box 3.1)
- Salford (353)
- Glasgow City (274)
- Calderdale (241)
- Sunderland (234)

It is likely that several of these represent social housing projects where multiple small domestic heat pumps (See Text Box 3.1) have been installed on shared ground-coupled loops, for example by Kensa in Enfield, Sunderland (Kensa 2019, 2021b), Halifax (Calderdale, Kensa 2023b) and by other actors in Salford (DECC 2014b, Mwamba 2021).

This implies that the practice of registering households rather than “systems” in the MCS database, (for example, in the case of large, shared-loop schemes for social housing, especially in the “non-domestic” category), may tend to overestimate the number of GSHP systems installed. Kensa have made an estimate of the proportion of MCS data entries such systems might represent[42]. If taken at face value, the total number of 28,889 MCS-accredited GSHP installations in the UK may represent no more than 22,000 GSHP systems (and probably fewer, as some of the other non-domestic and commercial systems will also be multiple heat pump systems).

The following local authorities have the greatest number of “commercial” installations (Figure 13), (note, urban areas are far better represented):

- Bristol (361)
- Blackburn with Darwen (215)
- Cornwall (173)
- Leeds (169)
- Glasgow City (166)
- followed by Newcastle-upon-Tyne, Sunderland and Manchester.

[42] Kensa (D. Roberts, pers. comm. May 2023) estimate that around 40-50% of all GSHP entries in the MCS database are Kensa installations. Of these 40-50%, Kensa estimate that 75% are installations on a shared ground loop (often social housing) and 25% are small “standalone” domestic heat pumps. Each individual household on a shared array is registered as a separate installation. A shared array will typically service between 2 to more than 12 apartments with a very rough estimate, of an average of around 5 per ground loop. This implies that 1000 MCS GSHP registrations may represent around 760 systems

$$(1000 * 0.6) + (1000 * 0.4 * 0.25) + (1000 * 0.4 * 0.75 / 5) = 760$$

It is possible that the “commercial” classification, which replaced “non-domestic” after 2020 may also contain housing GSHP systems using shared ground-coupled loops (Text Box 3.1, Kensa 2023c).

Figure 14 shows the percentage of households with MCS-accredited domestic GSHP (a category which predominantly applies to data after 2015). The local authorities with the highest percentage uptake rates are:

- Eden, Cumbria (0.41% of households)
- Ceredigion, Mid Wales (0.39%)
- Cotswold and Orkney (0.34% each)

For comparison, Figure 15 shows total ASHP (irrespective of category). The distribution is not dissimilar to that for GSHP. The highest numbers are installed in:

- Cornwall (5458)
- Highland (4751)
- Argyll & Bute (2764)

with relatively high numbers in Shropshire, Wiltshire and East Anglia, and relatively low numbers in the main urban areas. Relative to population, the highest densities are in the remoter areas of Scotland. In some areas (Na h-Eileanan Siar – Outer Hebrides) there is one MCS-certified ASHP installation for every 6 households (Figure 16).

In summary, the data presented in Section 3.1 are best understood as installed numbers of GSHP units. The data presented in Section 3.2 are best understood as numbers of households or commercial entities with installed MCS-accredited GSHPs*.* It can also be noted that:

- Between 2009 and the end of 2021, 25,124 MCS-accredited installations of GSHP were made in the UK (from Section 3.2).

- Between 2009 and the end of 2021, 38,450 GSHP units are estimated to have been sold and installed in the UK (from Section 3.1).

The estimated number of GSHP units sold and installed thus exceeds the number of MCS accredited installations by a factor of 1.53.

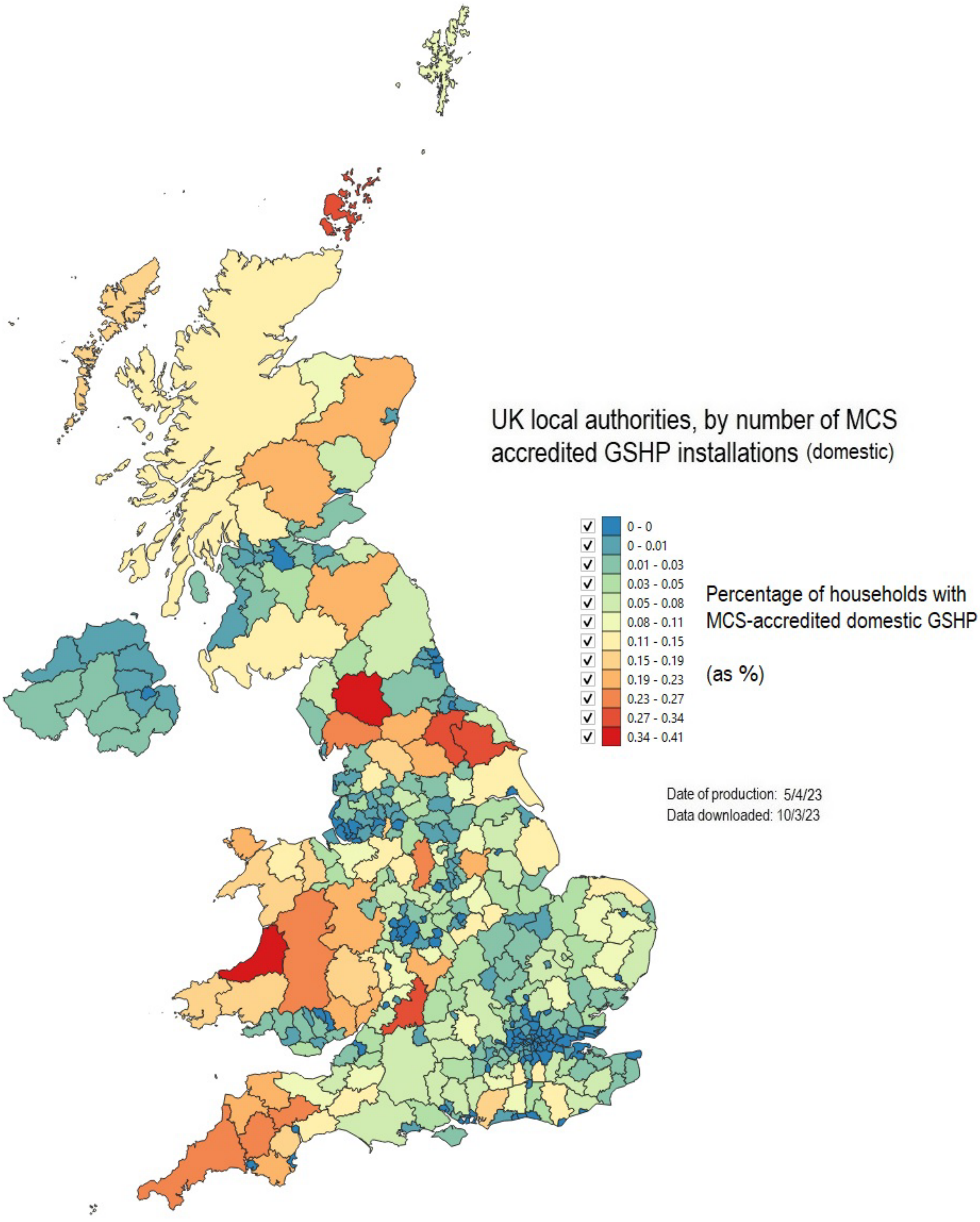

Figure 14. Percentage of households with MCS-accredited GSHP in "domestic" category. N = 11,517. These were predominantly installed after 2015. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

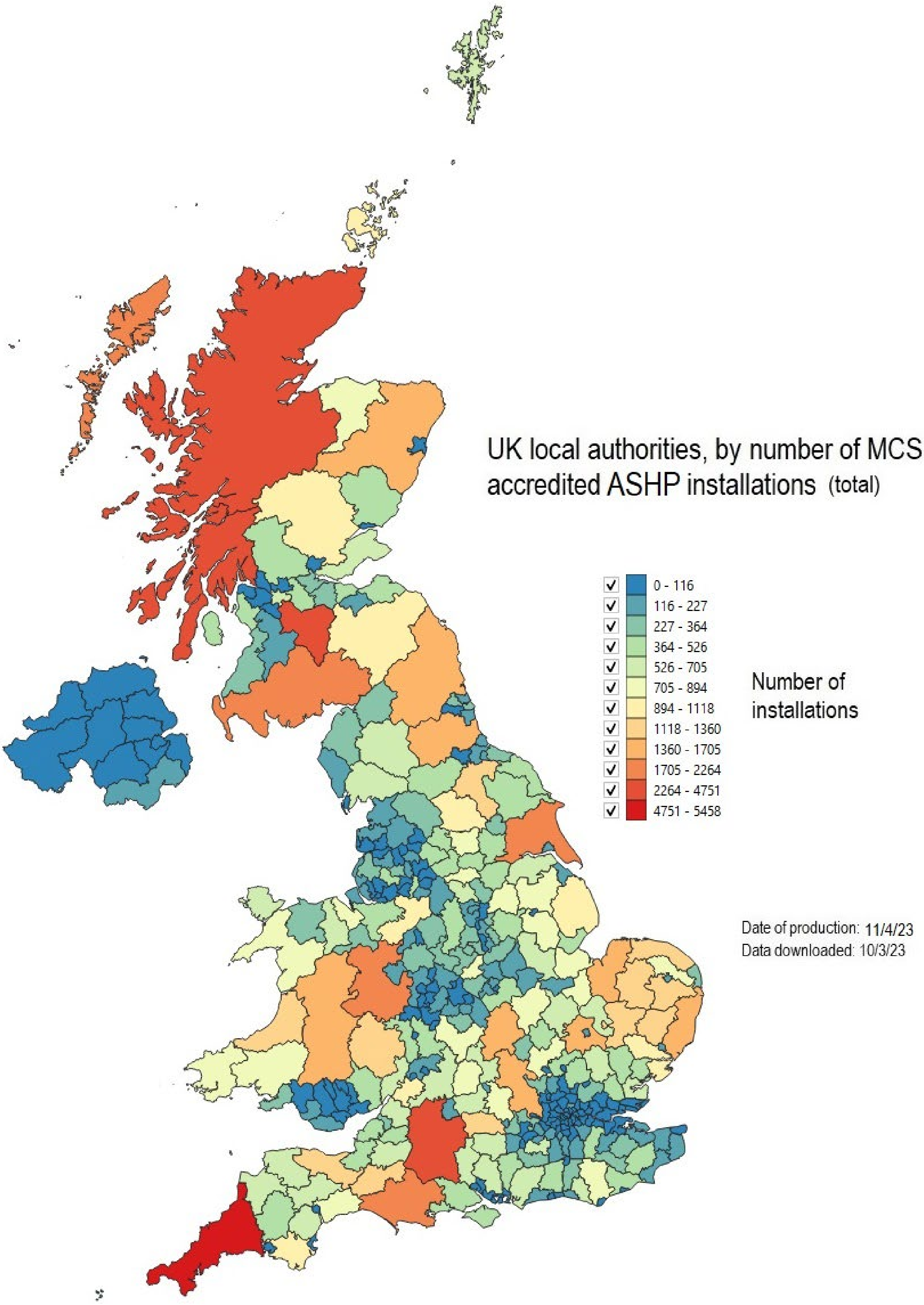

Figure 15. Number of MCS-accredited ASHP installations (2009 to 2023) by local authority in the UK. N = 152,828. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

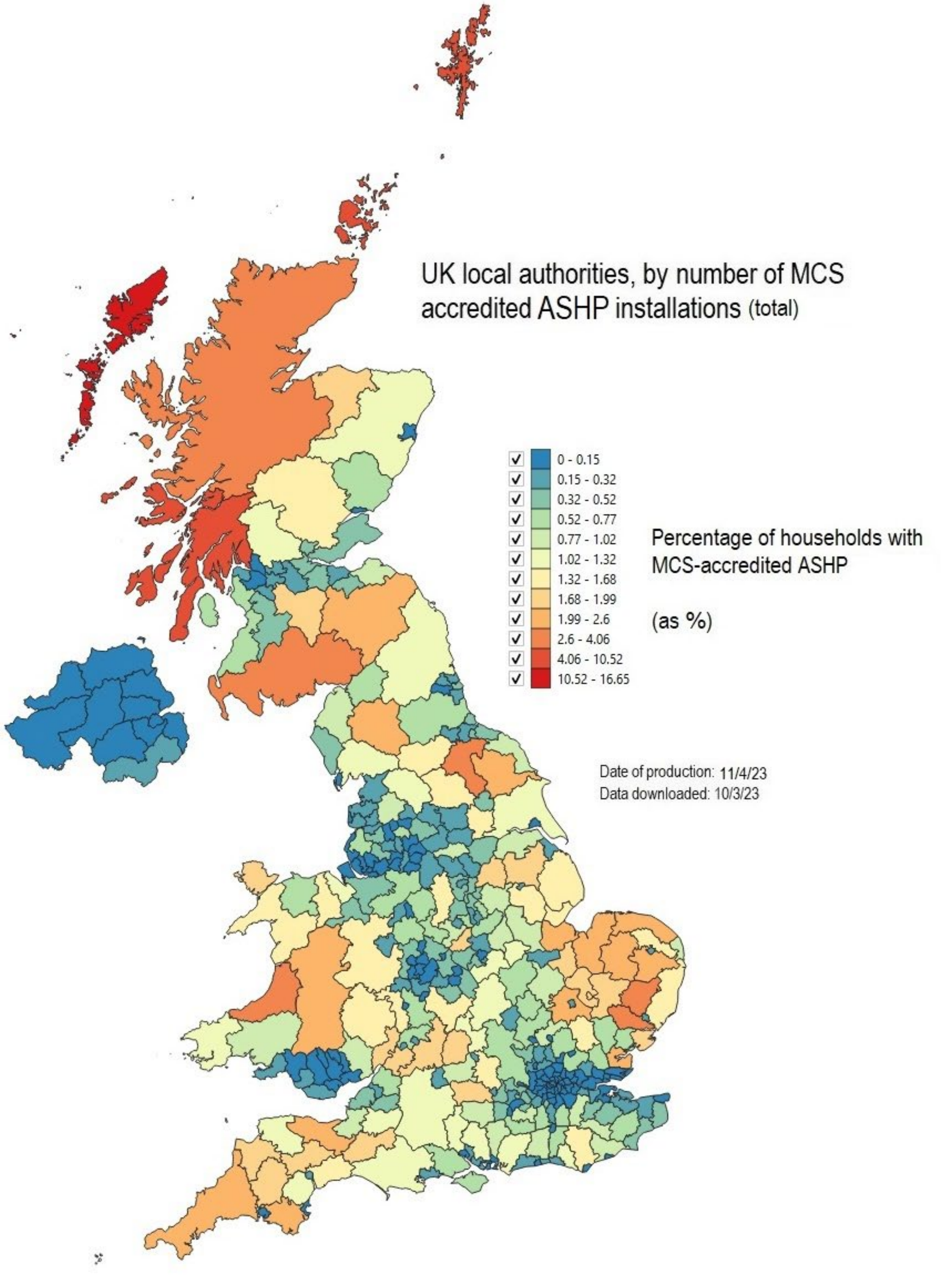

Figure 16. Number of MCS-accredited ASHP installations (all categories; 2009 to 2023) by local authority in the UK. Expressed as a percentage calculated by dividing number of ASHP installations by number of households. Derived from data downloaded from MCS dashboard at https://datadashboard.mcscertified.com/

3.3 Renewable Heat Incentive (RHI) data

Note that the RHI covers Scotland, Wales and England. A separate version of the scheme has been running in Northern Ireland.

3.3.1 Domestic RHI

As of May 2023, 114,634 renewable heat installations had been approved under the Domestic RHI. Of these, 77,826 were ASHP and 15,290 were GSHP, according to online graphs published by OFGEM and accessed June 2023[43]. Annual Domestic RHI accreditations for ASHP had been around 9000-10,000 per year in around 2020 (rising to over 21,000 in 2021-22), with around 1000 per year for GSHP between 2016-2021 (OFGEM 2022a). Cumulative tariff payments under the domestic RHI to GSHP have totalled £276 million (OFGEM 2023b).

GSHP have accounted for 12.9% of schemes since the launch, compared with 67.5% for ASHP. Of the accredited GSHP, 78% have been in England, 10% in Wales and 12% in Scotland (OFGEM 2022a)[44]. The regional distribution in shown in Figure 17. SW England has the highest numbers of Domestic RHI GSHP schemes.

Because the Domestic RHI requires MCS accreditation, these data are presumed to form a large subset of the data discussed in Section 3.2.

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[43] https://www.ofgem.gov.uk/environmental-and-social-schemes/domestic-renewable-heat-incentive-domestic-rhi/contacts-guidance-and-resources, online graph of approved renewable heating systems by technology type, accessed 16/6/23.

[44] The figures cited in this paragraph differ very slightly from those in the published quarterly report for May 2023 (OFGEM 2023b)

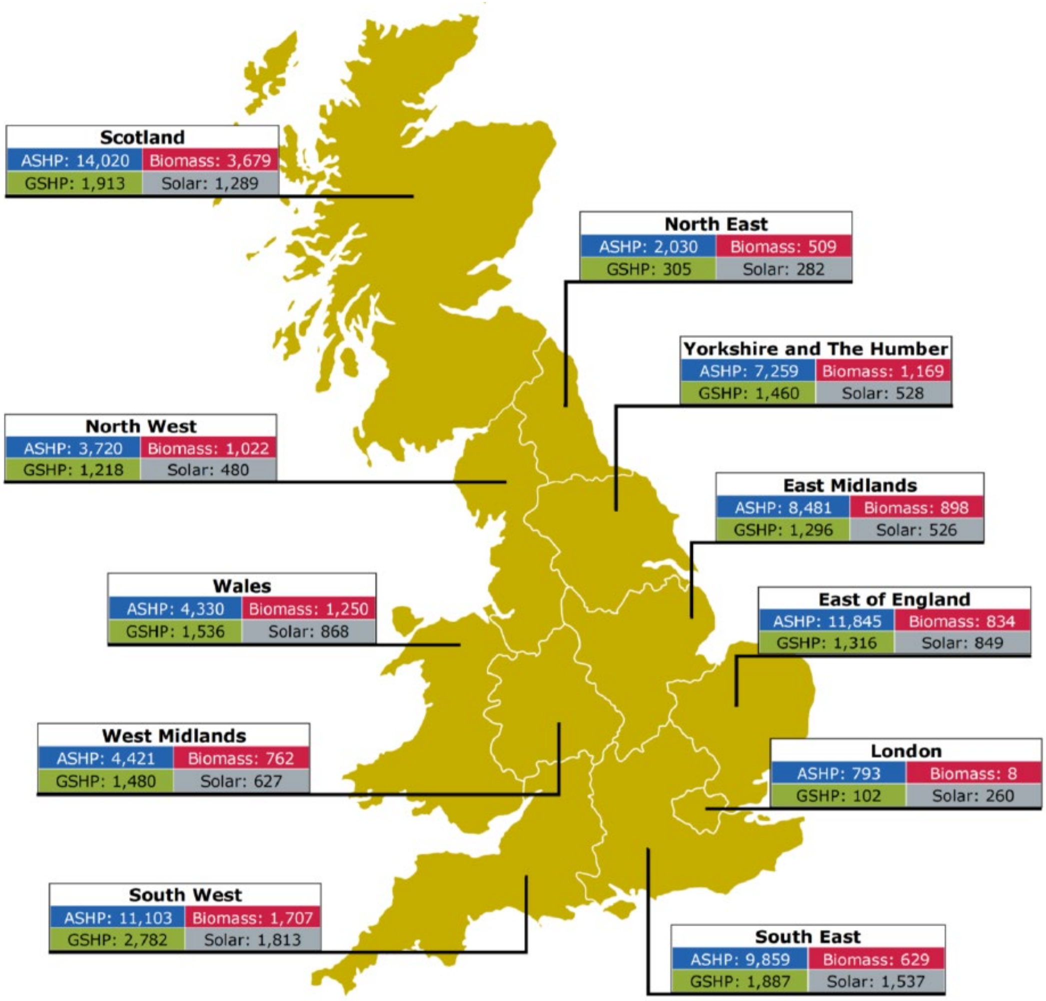

Figure 17. Total numbers of installations made under the Domestic RHI, according to technology type, after OFGEM (2023b). Crown Copyright reproduced under terms of Open Government Licence, https://www.ofgem.gov.uk/ofgem-privacy-policy

3.3.2 Non-Domestic RHI

The final report on the Non-domestic RHI scheme (OFGEM 2022b) states that 21,982 accredited renewable heating systems have been supported in total (15,813 in England, or 71.9%), representing almost 5.5 GW_{th} of installed capacity and £4.1 billion in payments.

Of these 21,982 total accredited installations, almost 79% of the were solid biomass boilers, with GSHP the next highest, representing 10.6% (2322 installations and 245 MW_{th} installed capacity) and water-source heat pumps 0.6% (137 and 36 MW_{th}).

The average nominal thermal capacity of each accredited GSHP system is thus 106 kW.

BEIS (2022) subdivides the RHI-accredited heat pump systems by size. Between November 2011 and May 2022 there were:

- 2098 accredited full applications for small (<100 kW) ground or water source heat pumps;
- 456 accredited full applications for large (>100 kW) ground or water source heat pumps;

	ASHP		GSHP		WSHP	
Region	**No.**	**Installed capacity (MW_{th})**	**No.**	**Installed capacity (MW_{th})**	**No.**	**Installed capacity (MW_{th})**
West Midlands	42	2.26	365	46.4	12	1.59
South-West	140	5.4	320	16.39	12	0.77
South-East	74	5.67	292	34.57	29	2.41
Yorkshire and The Humber	106	2.39	277	15.58	15	2.13
East of England	110	3.3	217	16.56	11	1.47
North-West	87	3.59	189	17.81	12	1.83
East Midlands	77	2.47	160	15.86	8	9.66
Wales	52	2.24	123	5.79	9	1.1
West Central Scotland	18	3.15	81	4.56	1	0.06
North-East	39	0.93	79	17.72	1	0.02
Southern Scotland	13	0.56	59	19.52	8	6.75
East Scotland	36	0.56	54	13	8	2.51
London	19	3.51	52	10.46	7	3.3
Highlands and Islands	49	1.49	35	2.85	3	2.35
North-East Scotland	6	0.09	19	7.71	1	0.06
Total	**868**	**37.62**	**2322**	**244.76**	**137**	**35.99**

Table 1. Number and installed thermal capacity, of heat pump installations supported by the Non-domestic RHI (commercial, public-sector, not for profit), by region and in total. WSHP = water sourced heat pump. Of the 2322 GSHP, 1951 were in England (84%). After OFGEM (2022b).

3.4 European Heat Pump Association (EHPA) data

The EHPA (EHPA 2022) released a survey suggesting that 59,862 heat pump units were sold in the UK in 2022, an increase of 17,103 on 2021, representing a growth of 40%. It should be emphasised that these figures are dominated by ASHP: the figures include both air-to-water heat pumps and air-to-air heat pumps, but are not believed to include air conditioning units sold solely for chilling.

For comparison, MCS accredited (ASHP + GSHP) installations in 2022 were (28,321 + 3352) = 31,673 – approximately half of the EHPA figure. The discrepancy could be due to:

- A large number of air-to-air units appearing in the EHPA figures, but which are potentially under-represented in MCS-accreditations.
- A significant number of non-MCS accredited new-build installations or large / commercial installations, many of which include multiple heat pumps.
- The MCS figures largely representing installed systems (a few of which may be multi-heat pump installations), with the EHPA figures representing heat pump units sold.

The EHPA press release does not separate GSHP, but it is unlikely that the MCS figures will underestimate the total number of GSHP installations by more than 50%.

3.5 Environment Agency abstraction licence data: groundwater-sourced heat pumps

All open-loop groundwater-sourced heating and cooling schemes in England should be licensed if they abstract more than 20 m^3/day.

Environment Agency data, for all groundwater abstraction licences where "heat pump" is listed as a licensed use as of March 2023, have been examined. The licence data do not record whether the heat pump is used for heating, for cooling or for both. The licence data do not record whether the thermally-spent water is returned to the aquifer (via reinjection boreholes or soakaways) or whether it is discharged elsewhere (sewer, surface water or sea). The Environment Agency have a strong preference for non-consumptive abstraction in the case of groundwater heat pump systems, so it is likely that, in most cases, the thermally spent water is returned to the aquifer. In the case of very small schemes (<20 m^3/day abstraction), or where the abstracted water has relatively little water resources value (for example, saline water), other forms of discharge may be permitted, where appropriate for the receiving environment.

In the context of this project, abstraction licence data have not been correlated with discharge consent data in order to ascertain which systems are reinjecting thermally spent groundwater to the aquifer. We note, however, that some progress has been made in this respect, in the context of the joint Imperial College London / British Geological Survey /

University of Manchester ATESHAC project (*Aquifer thermal energy storage for decarbonisation of heating and cooling: Overcoming technical, economic and societal barriers to UK deployment* - https://www.imperial.ac.uk/earth-science/research/research-groups/ateshac/).

The data provided here only apply to England. Figures 18 and 19 show the locations of all 149 "heat pump"-related groundwater abstraction licences in England as of March 2023. In some cases, abstracted water is also used for other purposes than heat pumps.

The Thames region has the greatest number of such licences, where licences are concentrated in Greater London and the Thames Valley, with some licences around the West Midlands and the Liverpool / Manchester area (Figures 18 and 19). Open-loop heat pump licences are also distributed throughout rural England. One can tentatively see from Figure 18 that licences coincide with the unconfined and concealed major aquifers of England (the Chalk and the Sherwood [Triassic] Sandstone[45]).

In order to give some impression of the magnitude of heat extraction or rejection that each licence represents, a number of generic assumptions have been made to convert the licensed water quantities to a maximum heat extraction or rejection capacity in kW[46].

Approximately 70% of the licences (Figure 20) have a likely maximum heat exchange with groundwater of more than 100 kW (representing around 6 L/s abstraction rate), confirming the notion that groundwater-sourced heat pump systems are most likely to be attractive to

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45 https://www2.bgs.ac.uk/groundwater/shaleGas/aquifersAndShales/maps/aquifers/home.html

46 If 1°C of heat is extracted from 1 L of water, the amount of heat extracted is 4.19 kJ. This figure (4.19 kJ/L/K) is the *volumetric heat capacity* of water.

For the licence data, the maximum ("peak") thermal exchange has thus been estimated from the maximum instantaneous or hourly licensed abstraction rate for use with the heat pump, multiplied by 4.19 kJ/L/K, multiplied by a nominal temperature change of 4°C. Where no instantaneous or hourly licensed rate is cited, the annual licensed quantity has been used to estimate peak discharge rate, by assuming a Full Load Equivalent Hours (FLEQ) figure of 4056 hr/yr.

This FLEQ was estimated by dividing the annual licence quantity by the hourly licence quantity. For all heat pump licences where these data are available, the average FLEQ was 4056 hr/yr.

larger thermal loads (where the capital expenditure in water well construction and engaging in the regulatory process can be justified).

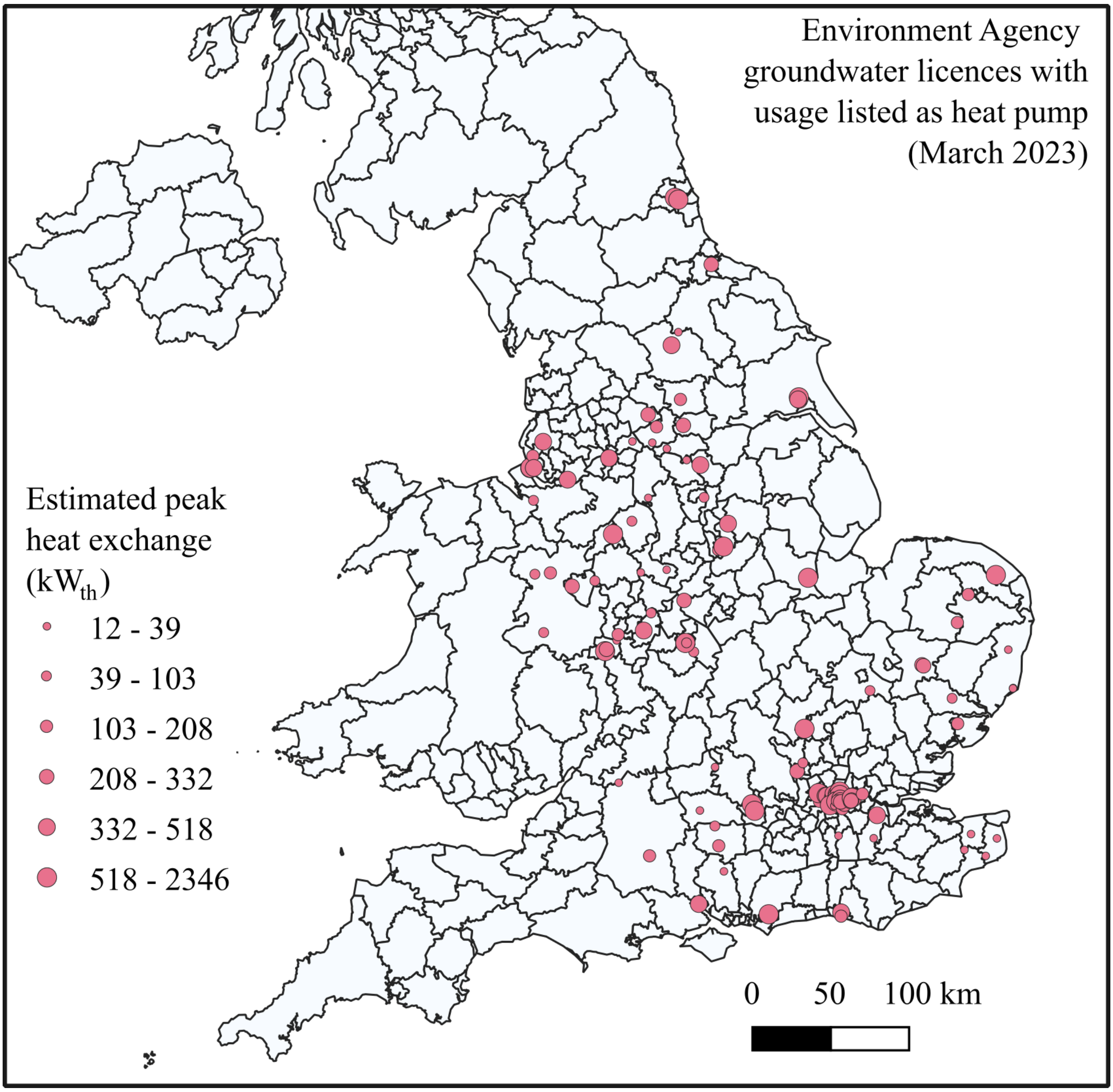

Figure 18. Map of all Environment Agency groundwater abstraction licences where “heat pump” is listed as a usage, as of March 2023 (N = 149). Of these, 3 licences also list non-evaporative cooling as a usage.

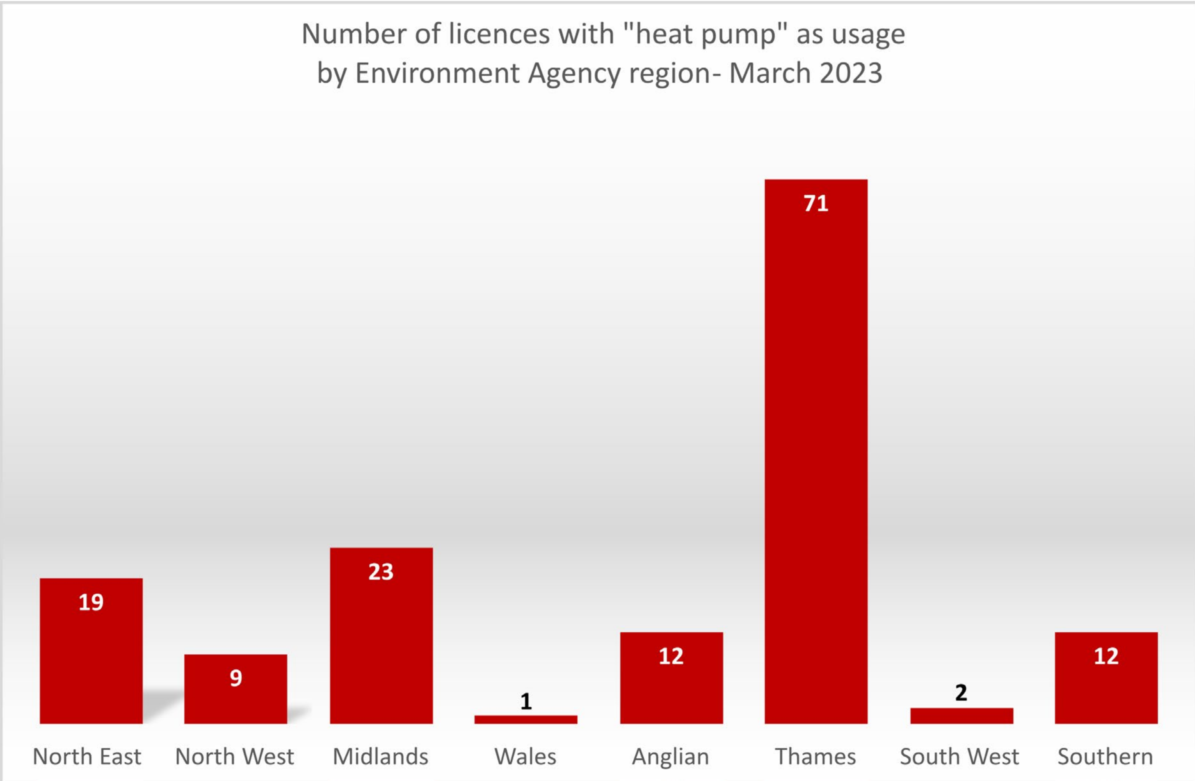

Figure 19. Environment Agency groundwater abstraction licences where "heat pump" is listed as a usage, as of March 2023 (N = 149), according to Environment Agency region. Of these, 3 licences also list non-evaporative cooling as a usage.

Since 2013, the number of new "heat pump" licences has been increasing at a fairly steady rate of 13 per year (Figure 21).

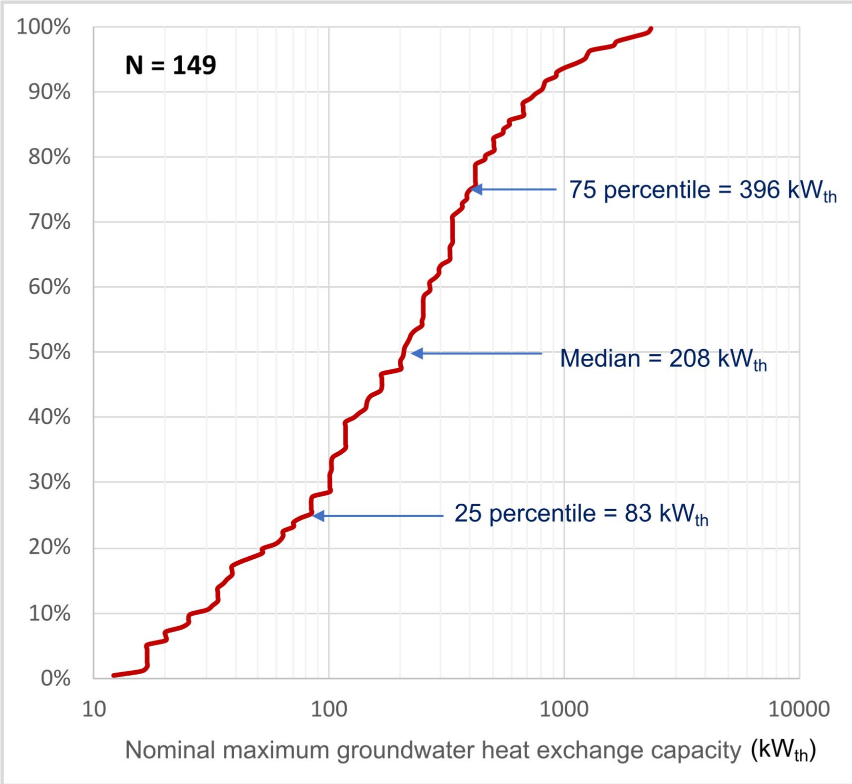

Figure 20. Cumulative frequency distribution of nominal maximum ("peak") heat extraction/rejection capacity in kW of all Environment Agency groundwater abstraction licences where "heat pump" is listed as a usage, as of March 2023 (N = 149).

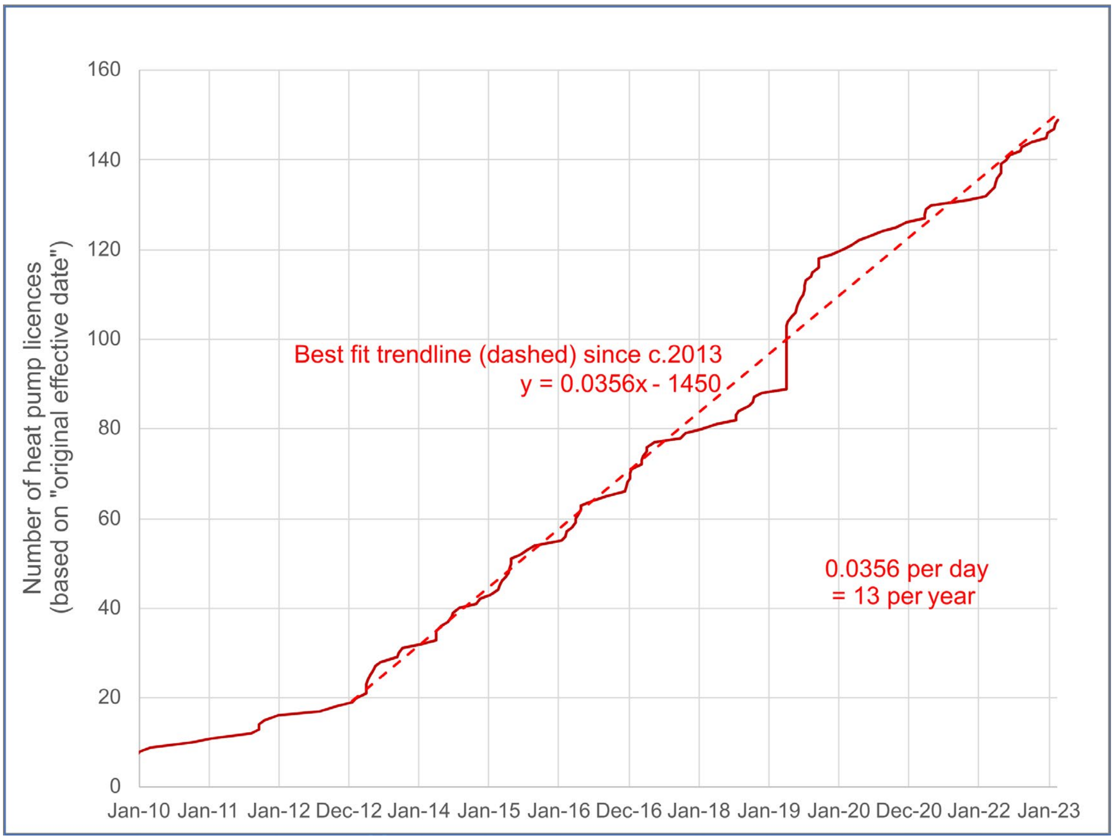

Figure 21. Original date of commencement of all Environment Agency abstraction licences where "heat pump" is listed as a usage, as of March 2023 (N = 149). Of these, 3 licences also list non-evaporative cooling as a usage. Note: it is conceivable that a licence was initially issued for another use, and then modified to include "heat pump" at a later date.

3.6 Environment Agency licence data: passive groundwater cooling

Groundwater can also be used for passive cooling of industrial processes or air conditioning / dehumidification systems. In such cases a heat pump is not used, but heat exchange is taking place with cooler groundwater under natural temperature gradients.

Environment Agency groundwater abstraction licences where "non-evaporative cooling" or "general cooling (low loss)" are listed as a licensed use, have been examined. These 2 uses are selected as these are most likely to result in warmed groundwater (following heat exchange) being returned to the ground (or to surface water). However, the licence data do not record whether the thermally-spent water is returned to the aquifer (via reinjection boreholes or soakaways) or whether it is discharged elsewhere (sewer, surface water or sea).

The data provided only apply to England (with a small overlap in Wales, when under the administration of the Environment Agency).

Other licensed cooling uses are recorded, including evaporative cooling and general cooling (high loss), but in such cases, thermally spent groundwater is less likely to be returned to the ground, (i.e. potentially resulting in a rise in ground / groundwater temperature). These usages have thus been omitted from this search, although they can still arguably be classed as groundwater-sourced cooling.

Figures 22 and 23 show the locations of all 174 "non-evaporative" or "low loss" groundwater cooling-related abstraction licences in England as of May 2023. In many cases, abstracted water is also used for other purposes than low loss cooling.

The North-West has the greatest number of licences, followed by North-East and the Midlands (Figures 22 and 23). A far greater number of groundwater cooling licences appear to be used for industrial purposes in the north of England, in comparison to heat pump licences. The main purposes of cooling in these regions are in the metals / machinery / electronics and chemicals industries. Other large users include the food / drink / brewing, dairy, extractive and water bottling industries.

Similar to the groundwater-sourced heat pumps, in order to give some impression of the magnitude of heat rejection to groundwater that each passive groundwater cooling licence represents, a number of generic assumptions have been made to convert the licensed water quantities to a nominal maximum heat rejection capacity in kW[47].

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[47] For the licence data, the maximum ("peak") heat rejection to groundwater has been estimated from the maximum instantaneous or hourly licensed abstraction rate for use in cooling, multiplied by 4.19 kJ/L/K, multiplied by a nominal temperature change of 4°C. Where no instantaneous or hourly licensed rate is cited, the annual licensed quantity has been used to estimate peak discharge rate, by assuming a Full Load Equivalent Hours (FLEQ) figure of either 3855 or 5644 hr/yr.

The FLEQ used for these calculations was obtained by dividing the annual licence quantity by the hourly licence quantity. For all "non-evaporative cooling" licences where these data are available, the average FLEQ was 3855 hr/yr. For all "general low-loss" cooling licences where these data are available, the average FLEQ was 5644 hr/yr.

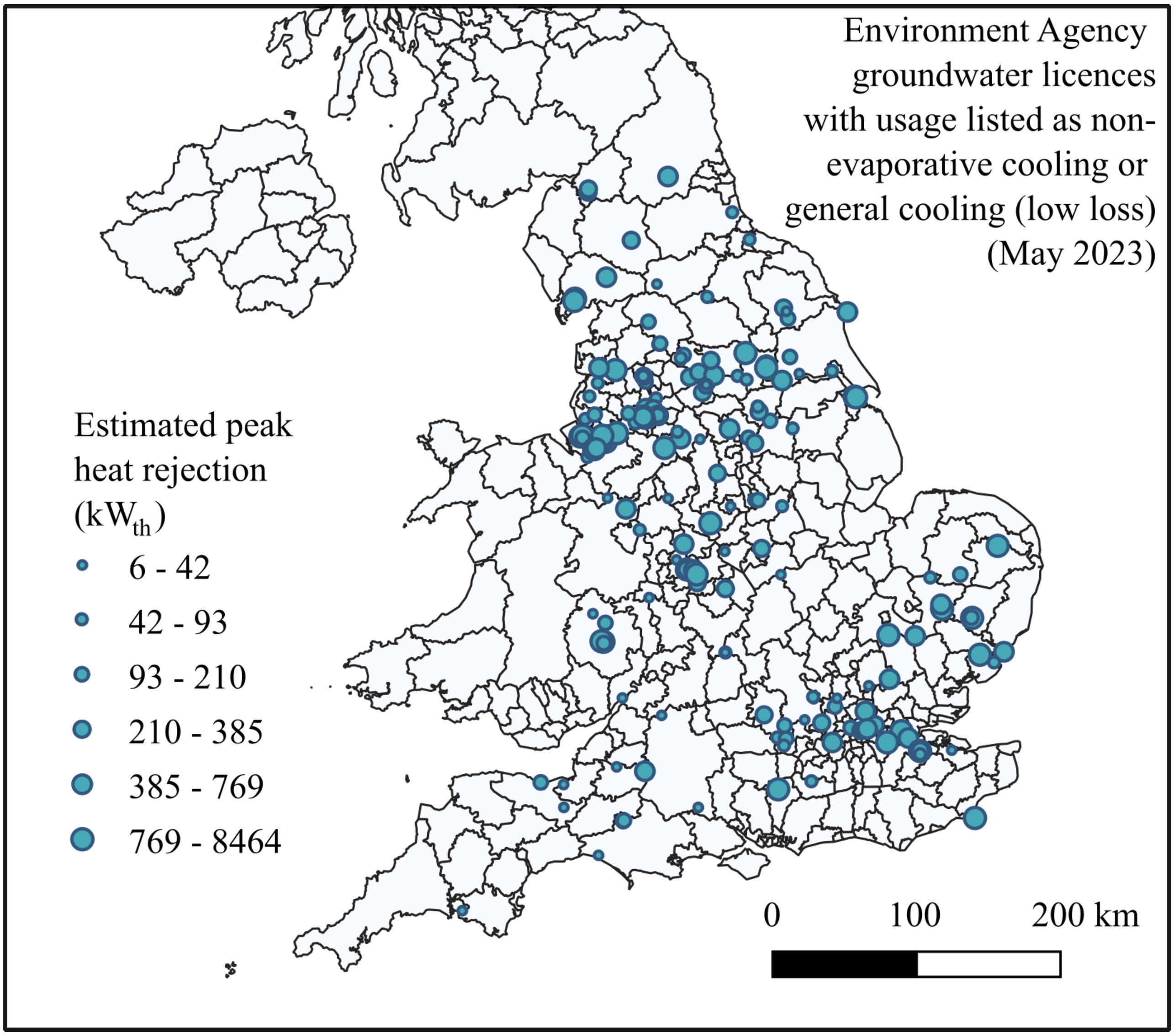


Figure 22. Locations of all Environment Agency groundwater abstraction licences where "non-evaporative" or "general low loss" cooling is listed as a usage, as of May 2023 (N = 174). Of these, 3 licences also list heat pump as a usage.

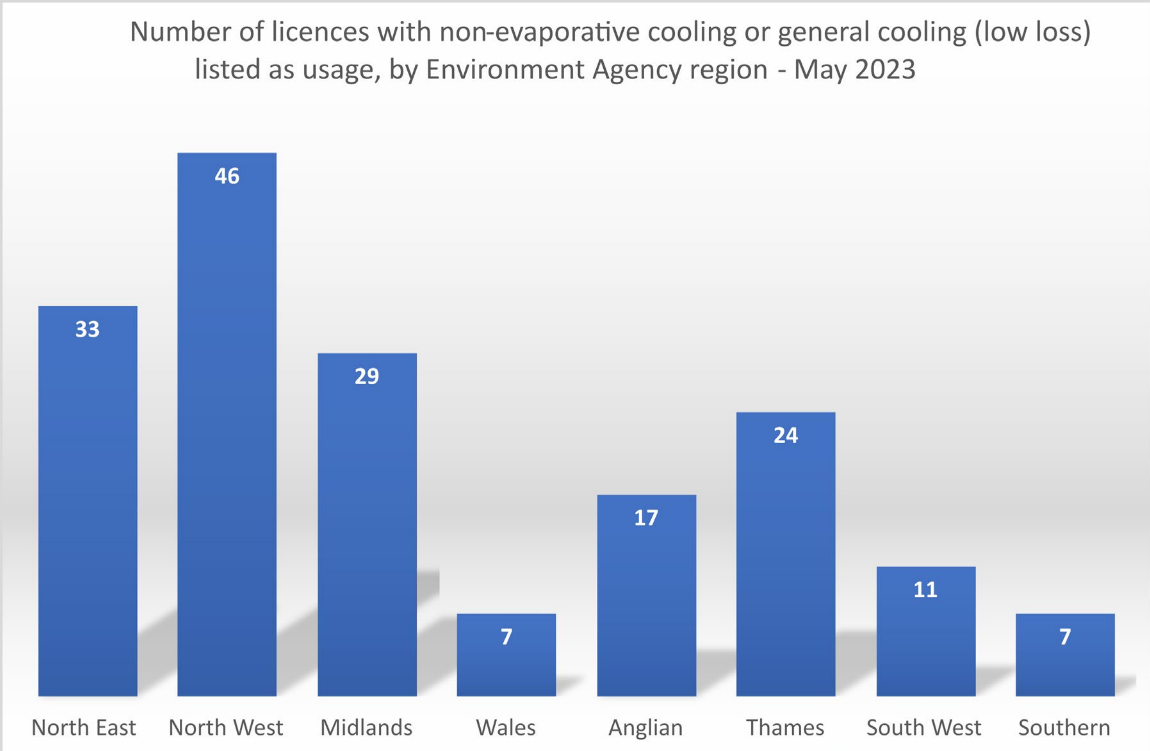


Figure 23. Environment Agency groundwater abstraction licences where "non-evaporative" (N=122) or "general low loss" (N=54) cooling is listed as a usage, as of May 2023 (N = 174 in total) according to Environment Agency region. Of these, 3 licences also list heat pump as a usage.

Approximately 66% of the 174 licenses (Figure 24) have a likely peak heat rejection to groundwater of more than 100 kW (representing around 6 L/s abstraction rate), confirming the notion that groundwater-sourced heat exchange systems are most likely to be attractive to larger thermal loads (where the capital expenditure in water well construction and engaging in the regulatory process can be justified).

Around 50% of these 174 "cooling" licences are relatively old, many of them dating back to the 1960s. As such, many of them may not be "modern" abstraction-heat exchange-well doublets of the type described by Todd & Banks (2009).

Since around 2013, the numbers have been increasing at around 3 per year.

Thus, taking the heat pump and cooling abstraction licences together, total number of licensed open-loop groundwater heating and cooling schemes in England is estimated as 320 (allowing for 3 licences citing both "heat pump" and "low loss cooling" as uses). These figures may exclude a modest number of very small (unlicensed) schemes.

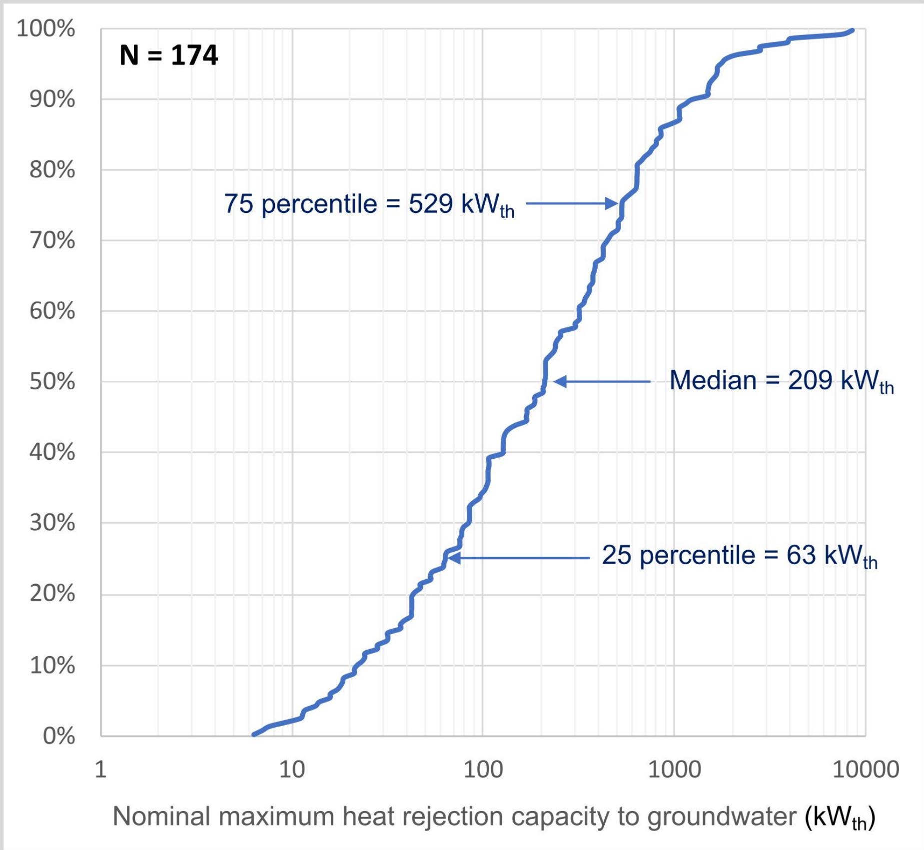


Figure 24. Cumulative frequency distribution of nominal maximum ("peak") heat rejection capacity in kW of all Environment Agency groundwater abstraction licences where "non-evaporative" or "general low loss" cooling is listed as a usage, as of May 2023 (N = 174). Of these, 3 licences also list heat pump as a usage.

3.7 Commercial closed-loop schemes: UK industry data

Several industry consultees have offered data to this project regarding the sizes and locations of recent ground source heat schemes they have designed and/or installed. These schemes are closed-loop and so have not required abstraction licences or discharge permits from the Environment Agency.

Genius Energy Lab, who currently represent a significant fraction of the large-scale closed-loop design market in the UK, have provided details of 483 vertical (borehole) closed-loop schemes designed since 2017, and 43 horizontal closed-loop schemes designed since 2018 (to mid-2023 in both cases). These schemes are believed to have been installed or be in the process of installation.

Of the horizontal closed-loop schemes (dated 2018 to mid-2023)

- 17 of the 43 schemes were rated at ≥45 to <100 kW;
- only 4 were rated at ≥100 kW;
- 39 of the schemes provided heat only;

- 4 of the schemes were heating-dominated, but provided a component of cooling (of these, 2 were rated with a peak heating load of ≥100 kW).

The geographical distribution of the larger (>45 kW) horizontal schemes is shown in Figure 25.

The 483 vertical (borehole) closed-loop schemes are shown according to size and purpose in Tables 2 and 3. Most schemes are “heating only” or heating dominated schemes.

The geographical distribution of the larger (≥45 kW) vertical schemes is shown in Figure 26. Of the 482 vertical closed-loop schemes where average borehole depth is specified, the median depth is 140 m (Table 4).

As Genius Energy Lab are currently designing at least 30-40 larger (>100 kW) closed-loop GSHP schemes per year, and represent a significant market share, it is estimated that the current total installation rate of large (>100 kW) closed-loop systems in the UK could be around 60-80 per year.

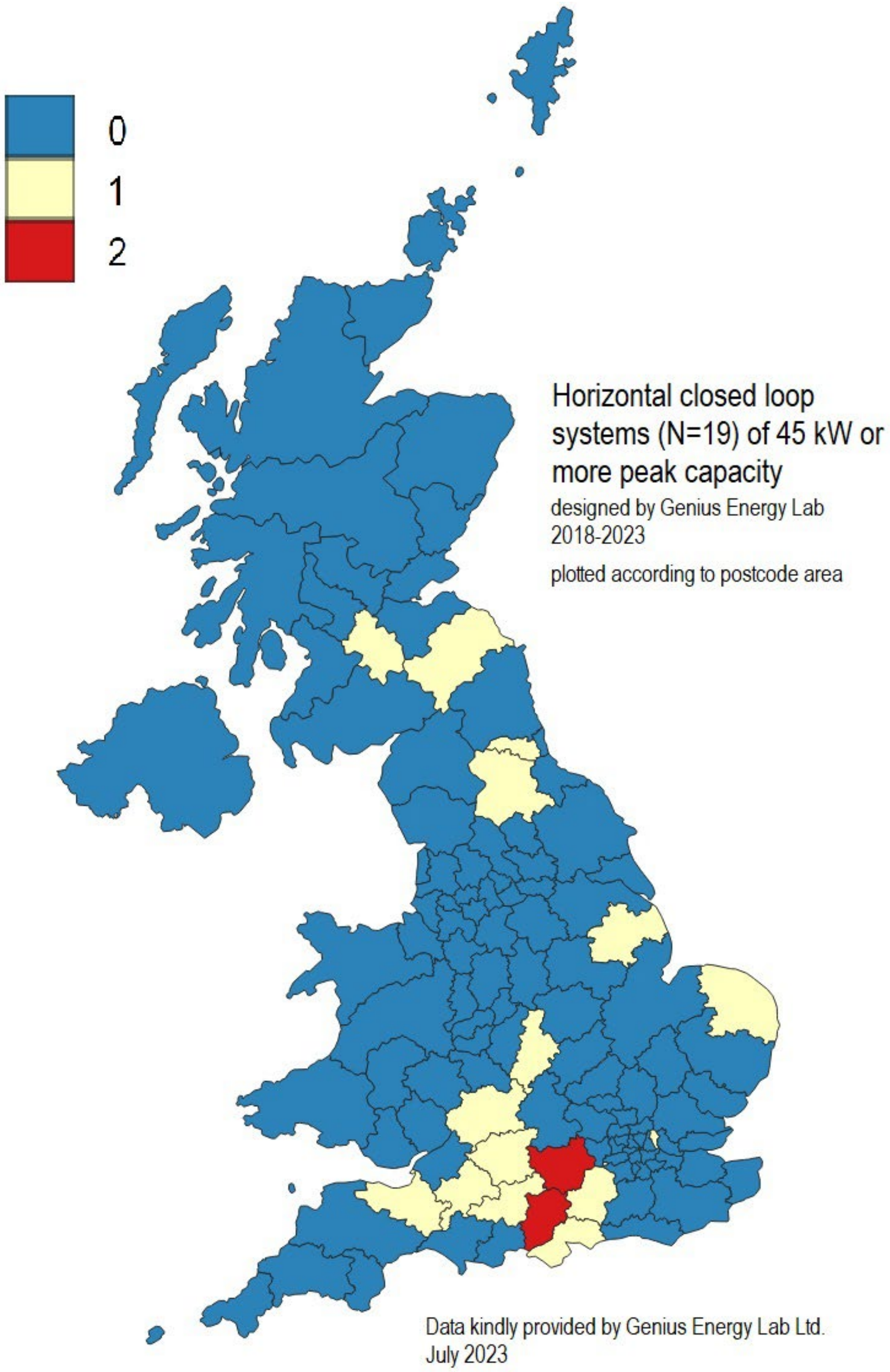


Figure 25. Geographical distribution of horizontal closed-loop schemes ≥ 45 kW peak capacity, designed by Genius Energy Lab (2018-mid 2023). N= 19 with location information defined by postcode area. Data kindly provided by Genius Energy Lab Ltd.

	All	<45 kW	≥45 to <100 kW	≥ 100 kW
2017	21	12	4	5
2018	35	19	8	8
2019	40	24	9	7
2020	59	32	17	10
2021	88	49	17	22
2022	114	65	17	32
2023	126	45	40	41
Total	**483**	**246**	**112**	**125**

Table 2. Closed-loop borehole-based schemes (N=483) designed by Genius Energy Lab. by year from 2017 to mid-2023, by peak thermal output in kW (heating or cooling, whichever is greater).

	<45 kW	≥45 to <100 kW	≥ 100 kW	Total
Heating only	236	107	109	452
Heating dominated	7	5	9	21
Cooling only	0	0	0	0
Cooling dominated	3	0	4	7
Not clarified	0	0	3	3
Total	**246**	**112**	**125**	**483**

Table 3. Closed-loop borehole-based schemes (N=483) designed by Genius Energy Lab. (and believed to have subsequently been installed) from 2017 to mid-2023 by use (heating or cooling only, or providing both but heating- or cooling-dominated in terms of MWh_{th}/a thermal load).

Statistic (N = 482)	Borehole depth (m)
Minimum	24
25%-ile	117
50%-ile	140
Mean	144
75%-ile	171
Maximum	291

Table 4. Closed-loop borehole-based schemes designed by Genius Energy Lab. (and believed to have subsequently been installed) from 2017 to mid-2023, where average depth of boreholes is specified (N=482).

Both Kensa and Carbon Zero Consulting have also provided data for the larger closed-loop schemes with which they have been involved and which are believed to have been carried forward to completion (Figure 27). There may be some overlap between Genius Energy Lab and Kensa installations, as both organisations may have been involved in the same design chains.

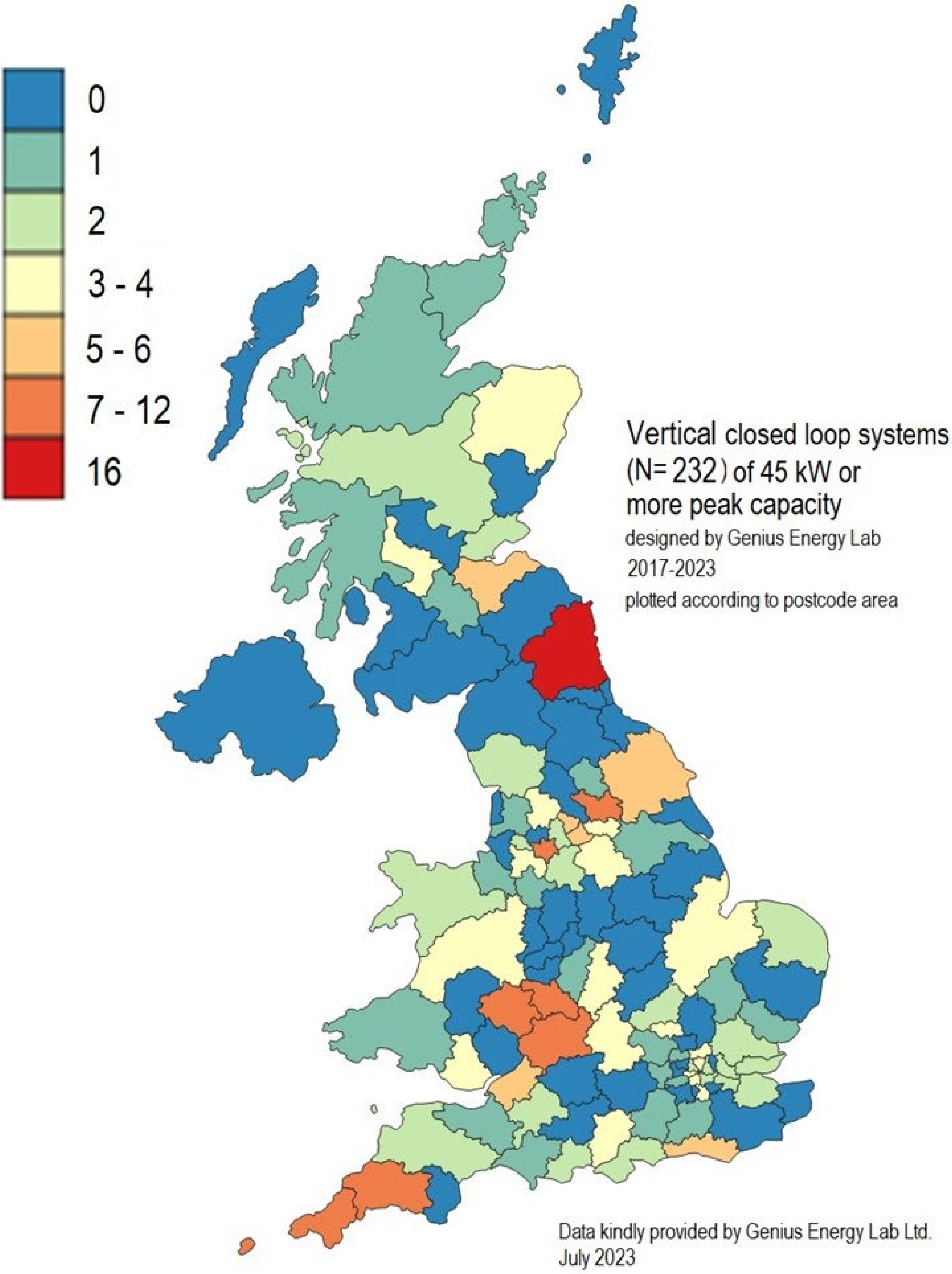


Figure 26. Geographical distribution of vertical closed-loop schemes ≥ 45 kW peak capacity, designed by Genius Energy Lab (2017-mid 2023). N= 232 with location information defined by postcode area. Data kindly provided by Genius Energy Lab Ltd.

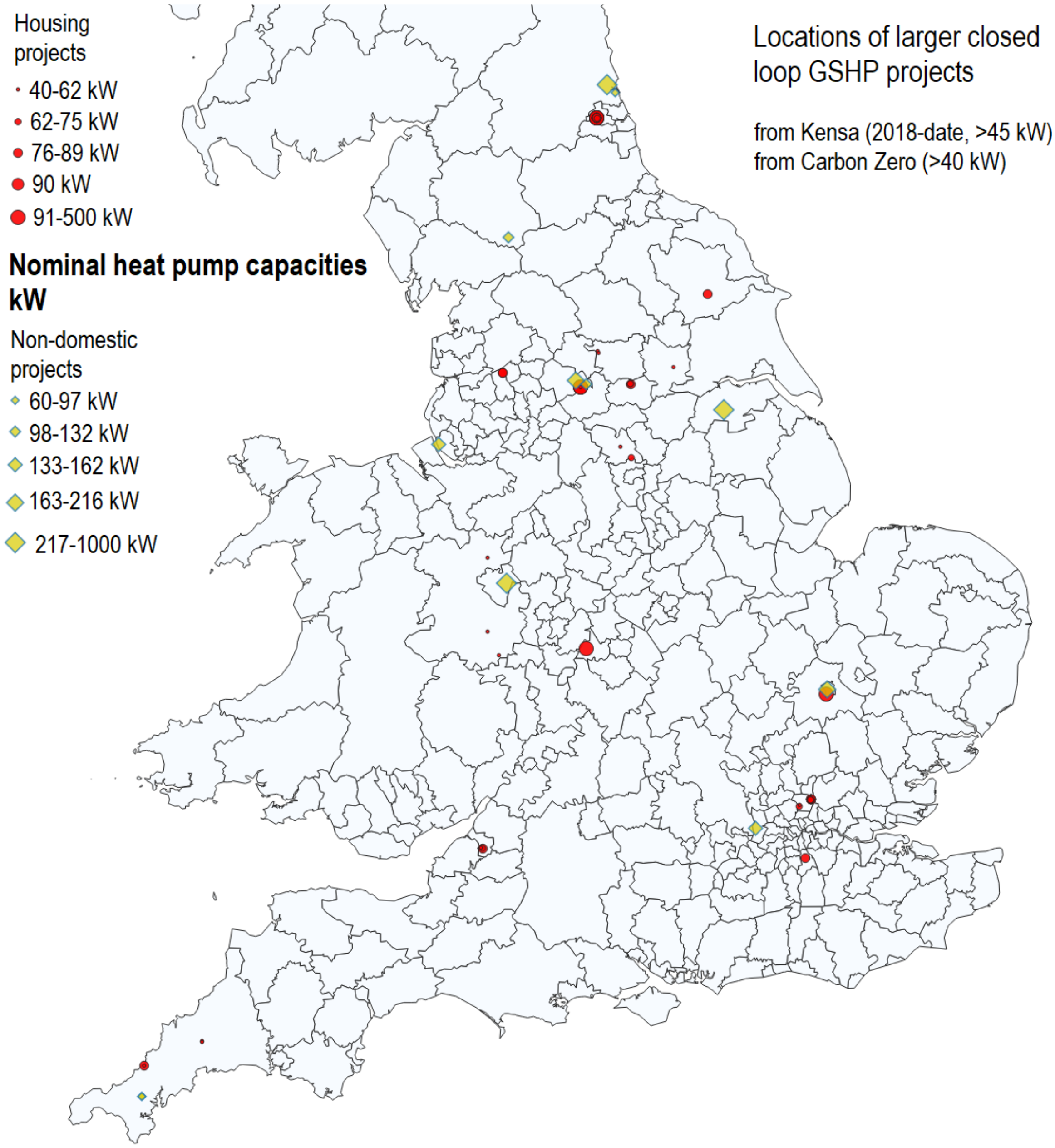


Figure 27. Locations of larger recent closed-loop GSHP projects, in England, using data kindly provided in 2023 by 2 industry consultees: Carbon Zero Consulting (minimum project size 40 kW) and by Kensa Contracting Ltd. (minimum project size 45 kW, data from 2018). Projects may be commercial, public sector or (social) housing clients. Locations are not precise: locations are estimated from the first half of postcode only.

3.8 GSHC industry in other European countries

The first modern borehole heat exchanger GSHP in the UK was installed in Devon in around 1994 (Section 1.4; Figure 3). By 2009, the number of installed GSHPs was around 5250 at around 5000 sites (Batchelor et al. 2010). By late 2021, the number of GSHP had grown to around 43,700 units, representing some 787 MW_{th} installed capacity (Abesser & Jans-Singh 2022). These figures represent:

- 0.65 GSHP per 1000 population by 2021 (in 2020 the UK's population was 67.1 million);
- an average increase of about 3200 GSHP per year between 2009 and 2021, or an average cumulative growth in GSHP numbers of 19% per year.

The scope of this report does not allow an extensive comparison of the UK's GSHC industry with that internationally but a brief comparison with the GSHC industry in selected other European countries is made. More detailed European comparisons are published by EUROBSERV'ER (2020) and Menegazzo et al. (2022).

- From 2017 to 2018 the sales of GSHP in the EU28 countries grew by 4.5%. Between 2018 and 2019 sales grew by 7.9%, reaching an annual sales figure of 93,673 by 2019 (EUROBSERV'ER 2020).

Table 5 presents data from the UK and the following countries:

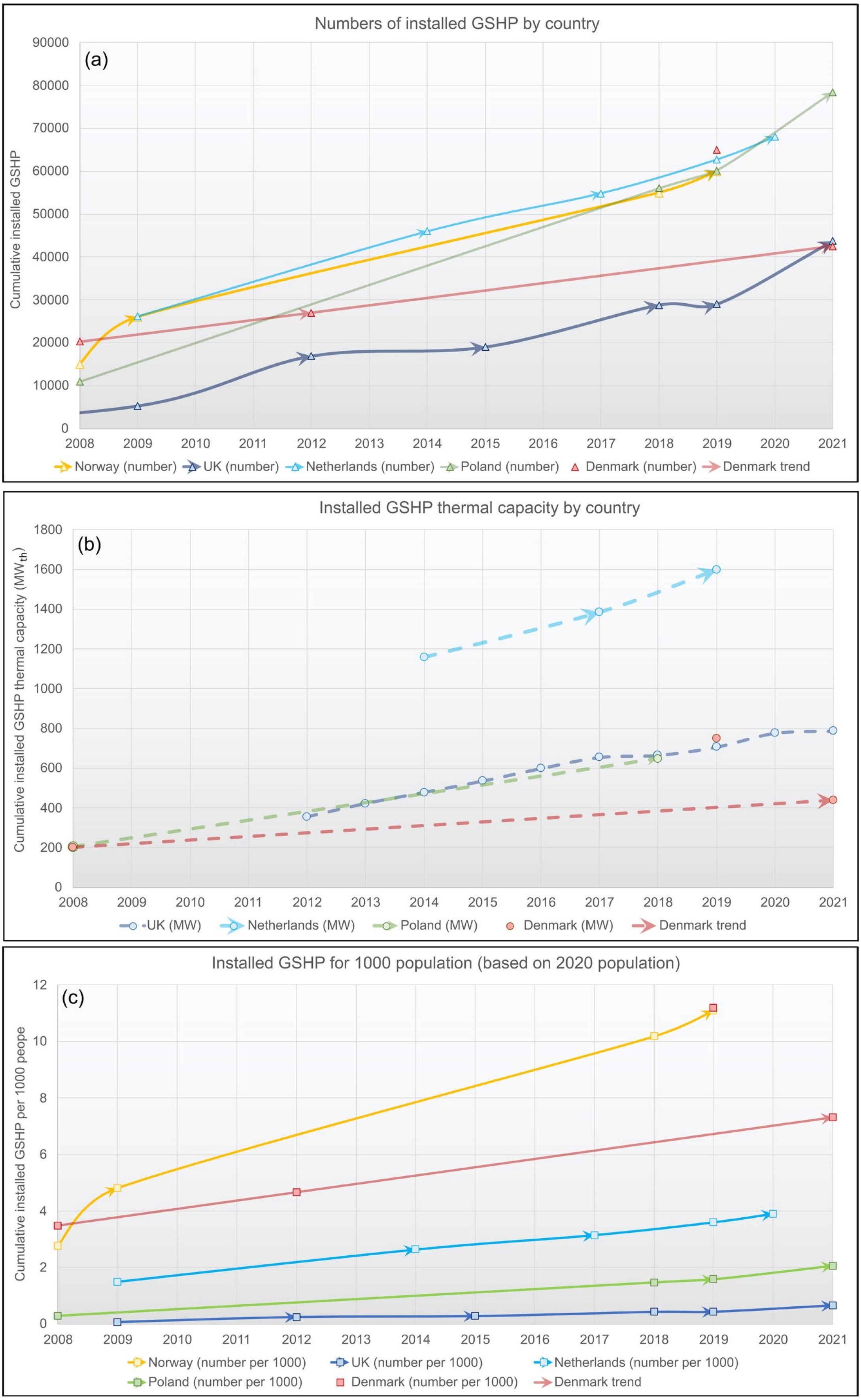
- Norway, whose GSHP industry started expanding a few years earlier than the UK, but which has a markedly different energy mix and geology to the UK (Midttømme et al. (2008), Midttømme & Mus (2010), Midttømme et al. (2015), Kvalsvik et al. (2019), Gehlin (2019) and Midttømme et al. (2020)).
- The Netherlands, Denmark and Poland, whose culture, energy mix and geology have many similarities with the UK.
  - Denmark (Mahler & Magtengaard (2010), Mahler et al. (2013), Poulsen et al. (2019), Mathiesen et al. (2020) and Mathiesen et al. (2022)).
  - Poland (Kępińska (2010, 2019 and 2020), Chomać-Pierzecka et al. (2022) and Kępińska & Hajto (2022)).
  - Netherlands (van Heekeren & Koenders (2010), van Heekeren & Bakema (2015), Bakema & Schoof (2016), Provoost et al. (2019) and Provoost & Agterberg (2022)).

	UK		Netherlands		Poland		Denmark		Norway	
	No	GSHP per thousand	No	Per thou’	No	Per thou’	No	Per thou’	No	Per thou’
2008					>11000	0.29	20250	3.49	15000	2.78
2009	5250	0.08	26212	1.51					26000	4.81
2010										
2011										
2012	16880	0.25					27000	4.66		
2013										
2014			45986	2.64						
2015	19000	0.28								
2016										
2017			54846	3.15						
2018	28800	0.43			56000	1.48			55000	10.2
2019	29000	0.43	60354	3.47	60196	1.59	65007*	11.21*	60000	11.1
2020			68000	3.91						
2021	43700	0.65			78400	2.07	42500	7.33		
Population (millions, as of 2020)										
2020	67.1		17.4		37.9		5.8		5.4	
Average growth rate of cumulative GSHP numbers										
Linear average p.a.	3204		3799		5185		1712		4091	
Cumulative average % p.a.	19%		9%		16%		6%		13%	

Table 5. Total number of GSHP and number of GSHP per thousand (Per thou’) population for the UK, the Netherlands, Denmark, Poland and Norway, from 2008 to 2021. Note that different countries may record numbers in different ways (UK as GSHP sales, the Netherlands possibly as systems installed). * = possibly erroneous. p.a. per annum.

3.8.1 Norway

Norway covers a large area and has a very small population (Table 5). Its geology dominated by hard Precambrian and Palaeozoic igneous, metamorphic and metasedimentary rocks with a discontinuous cover of Quaternary superficial sediment. The hard rock lithologies mean that drilling costs (down-the-hole hammer) are relatively low and borehole heat exchanger (BHE) installation is simple (not requiring grouting). Household incomes are high, low-carbon hydroelectric electricity has historically been plentiful and relatively inexpensive and there has not been widespread access to mains gas for heating due to the geography of the country. In recent decades, space heating was typically via heating oil or electrical resistance heating. Heat pumps thus result in genuine cost savings, without having to compete with cheap North Sea mains gas. This combination of factors, together with the highly seasonal climate and low winter air temperatures, strongly favours GSHP. The first domestic horizontal closed-loop heat pump systems were installed in 1978. By 2008, Norway reported around 15,000 GSHP systems, mostly domestic (Figure 28, Table 5). About 280 of these 15,000 systems were medium-to large-scale systems (> 50 kW) for commercial/ public buildings and for multi-family dwellings (Midttømme et al. 2008). Stene et al. (2008) describe several case studies of large-scale innovative systems. The majority of GSHP systems in Norway are now drilled closed-loop BHE and <20 kW (Kvalsvik et al. 2019). As of 2019, there were over 11 GSHP per 1000 population, with significantly higher GSHP totals than in the UK (despite one tenth the population). Despite the high market penetration, the cumulative number of GSHP still appears to have grown healthily at an average of 13% per year from 2008 – 2019.



Numbers of installed GSHP by country
(a)
Cumulative installed GSHP
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Norway (number)
UK (number)
Netherlands (number)
Poland (number)
Denmark (number)
Denmark trend
Installed GSHP thermal capacity by country
(b)
Cumulative installed GSHP thermal capacity (MW_{th})
0
200
400
600
800
1000
1200
1400
1600
1800
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
UK (MW)
Netherlands (MW)
Poland (MW)
Denmark (MW)
Denmark trend
Installed GSHP for 1000 population (based on 2020 population)
(c)
Cumulative installed GSHP per 1000 peope
0
2
4
6
8
10
12
2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Norway (number per 1000)
UK (number per 1000)
Netherlands (number per 1000)
Poland (number per 1000)
Denmark (number per 1000)
Denmark trend

Figure 28. GSHP installations in the UK, Norway, Denmark, Poland and the Netherlands from 2008 to 2021: (a) number of installations, (b) installed thermal capacity and (c) installed number per 1000 population (using 2020 population figures).

3.8.2 Denmark

Denmark also has a small population, but a much smaller land area than Norway. Its geology is more similar to the UK, being dominated by Mesozoic, Cenozoic and Quaternary sediments and sedimentary rocks. The number of GSHP installed is similar to the UK, despite the much smaller population, but the growth in numbers has been slower, at around 6% per year between 2008 and 2021 (Figure 28, Table 5). Shallow geothermal heat pump systems have been used in Denmark since the oil crisis in the 1970s, with a relatively high number (20,000) of closed-loop GSHP operating in 2008 (with an additional 250 groundwater sourced heat pumps). In 2008, GSHP represented around 200 MW_{th} capacity, of which 44 MW_{th} was for district heating. However, most of the domestic GSHP systems are horizontal, probably reflecting the difficulty and cost of borehole drilling and the requirement for an environmental permit for borehole systems (Mahler et al. 2013, Gehlin 2019). Denmark has a far higher market share of district heating than the UK. The *Termonet* concept of ambient BHE-coupled shared thermal loops[48] emerged in 2017-2018 (Mathiesen et al. 2020).

3.8.3 Poland

Poland also has a geology dominated by Mesozoic, Cenozoic and Quaternary sediments. Historically, it has had reserves of cheap coal and has been reliant on coal combustion for space heating, through either centrally fired district heating systems or individual fires/stoves (Chomać-Pierzecka et al. 2022, Forum Energii 2019). To some extent, Poland has avoided low-cost mains natural gas and the domestic heat pump market (aided by subsidy frameworks, such as the recent "Clean Air" programme) has grown rapidly. The cumulative number of GSHP has grown from at least 11,000 GSHP in 2008 at an average rate of 16% per year (Figure 28, Table 5), behind only Sweden, Germany and Finland (Kępińska 2019). At present, there are believed to be at least 78,400 GSHP in Poland, representing an installed capacity of between 900 and 2000 MW_{th}. As in the UK, however,

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[48] An ambient shared loop is typically a cluster of homes or commercial buildings connected to a single closed-loop of heat transfer fluid and an array of borehole heat exchangers. The buildings each have their own heat pumps which extract heat from the loop when required, or reject heat to the loop to provide cooling. The excess or deficit of heat within the shared loop is then exchanged with the ground.

ASHP are outperforming GSHP in terms of sales, with a current annual growth rate of 88% (Kępińska & Hajto 2022).

3.8.4 The Netherlands

The geology of the Netherlands is also broadly similar to much of southern England, dominated by Cenozoic and Quaternary sediments at outcrop, overlying Mesozoic sedimentary rocks. At depth, Permo-Triassic and Carboniferous aquifers form the geothermal reservoir for a number of hydrothermal well doublets. As in the UK, domestic GSHP have been relatively slow to gain traction due to the discovery of Dutch natural gas in the mid-20th century and subsequent cheap availability of mains gas (van Heekeren & Koenders 2010, van Heekeren & Bakema 2015). The Netherlands is, however, widely held to be an example of the successful mapping and development of sustainable groundwater-based open-loop GSHP and geothermal well doublet systems (Drijver et al. 2019, Vrijlandt et al. 2020). In particular, the Netherlands has a reputation for being forward-thinking in the fields of underground thermal energy storage and open-loop doublet systems for use in horticulture.

The earliest shallow geothermal installations in the Netherlands commenced in the 1980s. In 2009, the Netherlands reported just over 26,000 GSHP (van Heekeren & Koenders 2010), including around 10,000 vertical closed-loop BHE projects and around 1200 groundwater-sourced heat exchange/heat pump systems (Figure 28, Table 5). By 2015, cited figures include: over 50,000 GSHP systems, of which 1976 were open-loop systems (referred to as ATES systems - Bakema & Schoof 2016) and around 50,000 vertical closed-loop BHE boreholes (van Heekeren & Bakema 2015). By 2018, there were 2368 open-loop ATES systems and 54,846 GSHP systems (Provoost et al 2019). At around this time, a series of earthquakes in the Groningen natural gas field shifted public opinion away from gas and towards low carbon energy (Van der Graaf et al 2018). The introduction of a household energy efficiency subsidy scheme in 2016 also stimulated the GSHP market (Provoost & Agterberg 2022). By about 2020, there were a total of 3000 open-loop (ATES) systems and around 65,000 GSHP (mostly BHE-based) systems, representing over 1.6 GW_{th} installed capacity (Provoost & Agterberg 2022). The higher installed thermal capacity for the Netherlands, despite similar numbers of GSHC systems or units to the other countries considered here, could reflect that the Netherlands country reports may tend to report GSHP *systems*, rather than simply heat pump *units*, or possibly that a greater proportion of GSHP serve larger commercial, agricultural or public sector clients than elsewhere.

3.8.5 Summary

By 2020 all 5 of the countries considered above (UK, Poland, Netherlands, Norway and Denmark) had between 40,000 and 80,000 GSHP, despite radically different populations (Figure 28). In all cases (except possibly Denmark), an average of between about 3000 to 5000 GSHP are installed each year. The trajectories of Poland, Norway and Netherlands are similar in terms of gross cumulative GSHP numbers (Figure 28a). The UK market is growing slightly slower than in these countries, and the market is growing slightly slower in Denmark than the UK (if one disregards the anomalously high figures cited by Mathiesen et al. (2020)). Mahler et al. (2013) suggest that this may be partially related to a relatively strict regulatory environment regarding installation of borehole heat exchangers in Denmark. Similar trends can be seen for overall installed GSHP capacity (Figure 28b), with the exception that installed capacity in the Netherlands is significantly greater than in the other countries, possibly reflecting a greater percentage of larger GSHP systems.

As regards market penetration (number of GSHP per 1000 population) (Figure 28c), however, there are big differences for the countries considered, with around 11 GSHP per 1000 inhabitants in Norway, over 7 in Denmark and over 2 per 1000 in Poland. The UK demonstrates a very low market penetration rate of 0.65 GSHP per 1000.

The figures presented in this section are heavily caveated by the fact that country reports do not always distinguish between numbers of heat pumps, numbers of BHE and numbers of GSHP systems.

4. The future: industry views and prognoses

"Det er vanskeligt at spaa, især naar det gælder Fremtiden"

("It's tricky to make predictions, especially concerning the future" – in Danish).

Unattributed Danish Parliamentarian (1938) via Karl Kristian Steincke (1948)

4.1 Past prognoses

It is instructive to examine a couple of past predictions about the future of the GSHC industry.

Curtis et al. (2013) cite the 2012 targets made under the "Medium Abatement" scenario of the 4th Carbon Budget, predicting the deployment of:

- 600,000 domestic heat pumps by 2020
- 2,600,000 domestic heat pumps by 2025

From Figure 7, we can see that the total numbers of MCS accredited heat pump installations in 2020 were actually 90,000 ASHP and 20,000 GSHP, a total of 110,000.

Even allowing for the fact that the World / European Geothermal Congress estimate of GSHP installed for 2020 is around 35,000 (Figure 3), around 75% higher than the MCS figure, the total number of heat pumps installed in the UK in 2020 was unlikely to have been more than 110,000 * 1.75 = 190,000. The 2012 target thus likely overestimated the true number of heat pump installations by around 200%.

In 2009 an Environment Agency (2009) review of the GSHC market estimated that the number of total installed GSHP in the UK at that time was around 8000 (which coincides relatively well with Figure 3) of which about 90% were domestic, 9.5% were commercial scale (about 100 kW) and 0.5% were very large "industrial scale" installations. The review made the following projections based on what were thought at that time to be plausible trends:

- A reasonable growth scenario projected 320,000 GSHP by 2020;
- A high growth scenario projected 1,200,000 GSHP by 2020;

Figure 3 suggests that the total number of installed GSHP in the UK in 2020 was around 35,000. The report's projections overestimated the 2020 numbers of GSHP by orders of magnitude.

In 2009, the Environment Agency identified 300 open-loop systems. It is unclear whether this number represents just heat pump systems (the context of the Environment Agency

(2009) report suggests this may be the case) or also passive cooling systems[49]. It seems that this term covers both surface- and groundwater-based systems; thus the numbers of groundwater-based systems may thus have been lower than 300 in 2009.

Nevertheless, it appears that the numbers of open-loop systems have experienced low growth since 2009, with the analysis of the Environment Agency licence database here (2023; Sections 3.5 and 3.6) identifying only 149 open-loop groundwater heat pump schemes and a further 174 groundwater low-loss passive cooling schemes. The total number of licensed groundwater heating and cooling schemes in England is thus estimated as 320 (allowing for 3 licences citing both “heat pump” and low loss cooling). These figures might exclude a small number of very small (unlicensed) schemes. The Environment Agency (2009) report predicted a total of 7800 open-loop GSHC systems by the year 2020, which appears to be a considerable overestimate.

The Environment Agency (2009) report noted that “the ground source pump market is expected to grow until 2020 and no periods of stagnation are anticipated”. However, this report immediately preceded the cessation of the LCBP and a 4-year industry hiatus while the details of the domestic RHI scheme were agreed (Section 2.7). A further period of stagnation in domestic GSHP growth followed the recent (2022) announcement of the BUS.

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[49] Environment Agency (2009) also identifies 500 “cooling or heat and cool” systems. It is unclear whether this figure represents both open-loop and closed-loop systems.

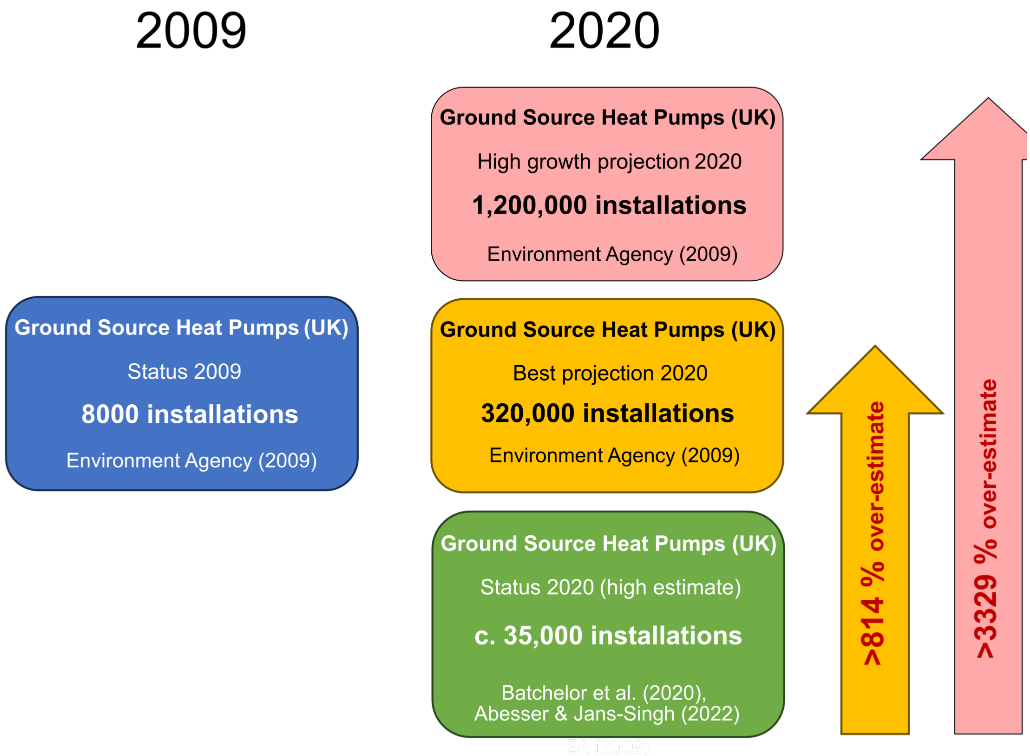

Figure 29. The Environment Agency's (2009) projections (yellow and red boxes) of the state of the UK GSHP numbers by 2020 and actual numbers (blue and green boxes). The Environment Agency projections are assumed to include open- and closed-loop GSHP, used for heating, cooling or both.

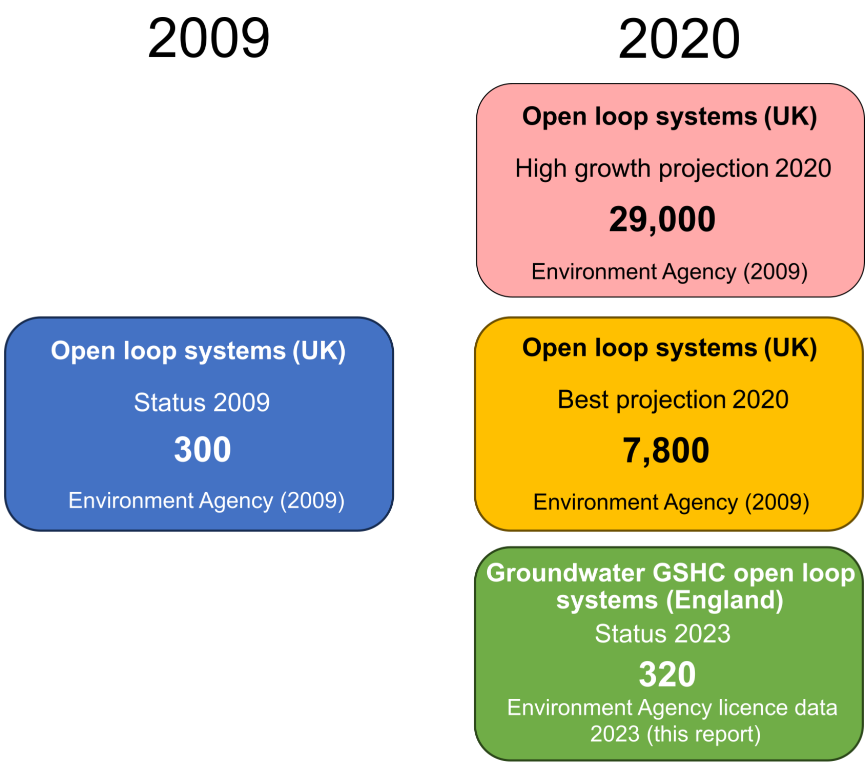

Figure 30. The Environment Agency's (2009) projections of the state of the UK open-loop GSHC numbers by 2020. See text for discussion of whether these figures include passive cooling systems.

4.2 Industry views

To gain a perspective on the likely development of the GSHC industry in the next 5-10 years, the views of 6 commercial GSHC designers, consultants and installers were canvassed[50]. The businesses vary in size from small consultants to some of the largest designers / installers operating in the UK market. Five of the industry representatives were asked to respond to a structured interview, while the sixth responded as a "reality check" on the findings and implications. During the interviews, the following questions were posed:

1. MCS data tend to suggest a fairly flat rate of installation of smaller MCS-accredited systems over the past decade or so. Can you comment on the rate of growth of the "larger" capacity end of the sector?
2. In terms of major public sector procurement projects in low carbon heating and cooling – for example, in the Defence, Education and Health sectors – do you see any preference for ASHP or GSHP systems being selected? Are larger public sector clients choosing ASHP due to perceived issues of risk/geological uncertainty or capital cost?
3. Bearing in mind the Government's target of the installation of 600,000 heat pump installations per year by 2028, what are the main factors that would "change the market" and stimulate a sustainable growth rate in:
    a. heat pump systems in England
    b. ground source heating and cooling (GSHC) systems in England

The responses from the industry representatives have been collated and anonymised in the following section. The responses from the interviewees were, however, generally consistent.

1. The representatives confirmed that the "smaller" (domestic) end of the GSHP market was currently rather stagnant. The cause of this was consistently held to be the BUS which, by essentially offering a similar level of subsidy to ASHP and GSHP, despite the much larger capital cost of GSHP, had effectively disincentivised the installation of GSHP and favoured the installation of ASHP (this can be clearly seen in the MCS data

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[50] The Ground Source Heat Pump Association (GSHPA) advised contacting member industry representatives directly for opinion. The responses from the interviewees are on behalf of their own businesses, however, and do not necessarily represent the opinions of the GSHPA.

in Figure 6). One representative commented that the BUS scheme had been particularly unhelpful to the GSHP industry as it had replaced the RHI just when the latter had begun to show some traction in the GSHP market.

As regards the larger (commercial / public sector) end of the GSHP market, the interviewees tended to report modest to relatively strong growth.

- One respondent suggested that, within one decade, there might be an increase in growth rate by a factor of 5-10 at the larger end of the GSHC sector. This was likely to be driven by demand for GSHC, with a component of ATES / BTES, at large "campus" type localities, such as universities, hospitals or even commercial / industrial sites with both heating and cooling demands.
- Other respondents tended to report recent relatively high growth at the larger closed-loop / commercial end of the market, at rates of 30 to 100% per year.
- One interviewee predicted higher growth in about 2 years when major feasibility studies in the public sector might come to fruition.

2. Most responders identified a challenge at the larger (commercial, public sector) end of the GSHP market, where ASHP were perceived as being a lower capital and lower risk alternative to GSHP. They expressed a concern that poorly-informed and short-sighted feasibility studies could lead public sector customers to favour ASHP. One responder stated that overly conservative feasibility studies at an early stage (conservative assumptions about thermogeological properties of the ground and building loads) can lead to overestimates of numbers of drilled boreholes necessary, which can be off-putting to clients at an early stage of assessment. Conversely, another responder stated that where a "geologically informed" feasibility study is undertaken for these sectors, approximately 50% of clients select GSHC as the ultimate solution, and 50% ASHP.

   One responder also noted that, in the collective social housing market, the SHDF is delivering far fewer GSHP projects than the Non-domestic RHI, although there could be significant growth in this market in 2-3 years.

3. Regarding factors that would favour the installation of heat pumps (ASHP and GSHP) in the UK above other heating technologies, there was near unanimity in the following responses:

   - A reduction in electricity versus gas prices.
   - A clear and consistent policy and path towards net zero in 2050, including clarity as to the exact date when new gas boilers will be phased out (see Bielby 2023).
   - Unambiguous legislation and building regulations to force the decarbonisation of buildings.

Regarding factors that would favour the installation of GSHP over ASHP, the following were mentioned:

- The need to reduce drilling costs.
- Review of the BUS, to present equally favourable grants towards GSHP and ASHP.
- A review of policies / methodologies within the Standard Assessment Protocol[51] and Energy Related Products[52] directive which are perceived as unfavourable towards GSHP.
- Recognition by Government and developers that ground loops (as opposed to heat pumps) represent infrastructural investment in their own right – both individual ground loops and (especially) shared ground loops[53].
- Recognition of the benefits of networked GSHC in local authority heat zoning plans – for example, heat networks in urban cores, ambient shared loop GSHP networks in suburban settings and standalone GSHP in rural settings (Foster et al. 2022).
- Greater recognition of the value of subsurface thermal energy storage i.e. using the subsurface for thermal buffering / storage / load shifting, and the flexibility in energy usage that this allows that would favour GSHP (Peplinski et al. 2023). This would include the potential for coupling with solar PVT (photovoltaic thermal) cells.
- One respondent pointed out that GSHC would tend to be favoured over ASHP in situations where:
  - aesthetic factors (for example, valued architecture) are prioritised, with the need to provide heating / cooling without big fan units being visible.
  - space factors (i.e. insufficient space for coolers) or value of penthouse space or facades (which might otherwise be occupied by coolers) are important.
  - issues of cold nuisance are potentially important; i.e., where discomfort or interference might be caused by circulation of cold air from ASHP units.
- Industry respondents perceive that there is a need to avoid unnecessarily burdensome regulation of closed-loop GSHP (i.e. regulation of anything other than the largest schemes in the most vulnerable settings).

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[51] Standard Assessment Protocol - the methodology used by the government to assess and compare the energy and environmental performance of dwellings (https://www.gov.uk/guidance/standard-assessment-procedure)

[52] Energy Related Products Directive - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034456/energy-related-products-policy-framework.pdf

[53] Implicit in this is the argument that a “BUS”-type of subsidy might be applied not just to the heat pump, but also to the installation of ground loop.

- A stable, long-term policy / subsidy framework for GSHC and heat pumps. For example, the RHI was arguably beginning to yield results when it was exchanged for the unfavourable BUS. This would encourage drillers to confidently invest in staff and rigs, and designers to invest in training with confidence in a stable long-term workflow.

One respondent commented that there is a case for some form of “light touch” regulation of closed-loop GSHP systems, provided that it is founded in existing industry (i.e. GSHPA standards, MCS standards and Environment Agency 2011) standards and guidance, providing clarity around the right to extract or reject heat. Another respondent conceded that, in a few geographical areas, clarity over rights to extract heat from the ground *may* lend confidence to developers but believed that in most areas the density of GSHP is currently too low for conflicts over rights to access heat to be a serious issue. Another respondent commented that large GSHC schemes will largely be self-regulating, because if spacings are inadequate or if net thermal loads are excessive, the schemes will become internally thermally inefficient (usually before they have any opportunity to significantly impact other users).

One respondent commented that the permitting process for open-loop (groundwater abstraction) schemes was regarded by clients as a disincentive for selecting such schemes. They cited cases where hydrogeologically promising GSHC schemes had been abandoned due to the perceived regulatory burden, including delays associated with obtaining additional permits for development.

4.3 Summary of the current state of the GSHC industry and trajectory for the next 5 years

This section summarises the best available estimates of numbers of different categories of GSHP and GSHC systems as of spring / summer 2023. It is re-iterated that there is no single source of data on, or register of, GSHP or GSHC systems in the UK. The various data sources are incomplete to various degrees and there are some internal discrepancies between data sources which have not been possible to wholly resolve within the context of this report.

“Best estimate” and “high growth” projections are made of the likely development in the industry within the next 5 years. Uncertainty in policy[54] means there can be little confidence in projections beyond a 5-year time frame; key decisions regarding the implementation of the Future Homes Standard in 2025 and the possible future of hydrogen heating in 2026 make projections beyond 5 years highly uncertain.

4.3.1 Total numbers of GSHP

The most recent estimate of GSHP installations in the UK is that of Abesser & Jans-Singh (2022), based on heat pump sales, who estimated that a cumulative total of 43,700 GSHP units (UK) had been installed in the UK by late 2021. This figure likely overestimates the numbers of GSHP systems operating because it:

- takes no account of decommissioned / replaced units.
- is based on heat pump sales. Many larger commercial, public sector and shared loop systems will use several heat pumps.

Industry feedback tentatively suggests that the number of installed GSHC systems may be around 75-80% of the number of raw GSHP unit sales or installations (Section 3.2). Using this approximate scaling factor and allowing for a modest attrition due to decommissioning / replacement, it is possible that Abesser & Jans-Singh (2022)'s figure of 43,700 cumulative GSHP unit sales may only represent around 30,000 to 38,000 operational GSHC systems (UK).

Both Rees and Curtis (2014) and Curtis and Pine (2016) note that the GSHP installation rate peaked at around 4000 per year around 2009[55] and then decreased significantly. Over the subsequent decade, the installation rate has fluctuated significantly (Section 2.3, 2.7, 3.2; Appendix A; Curtis et al. 2013). The GSHP installation rate (2009-2021) has varied between about 1000 and 4000 GSHP per year (UK) with an average of 3200 per year (Table 5), based on sales figures.

During 2022, a further 5584 ground source heat pumps are reported to have been sold in the UK (Aylott 2023). From April 2022 to March 2023, the overall installation rate of MCS-accredited GSHP is about 1838 per year (UK) (Section 3.2). The discrepancy between

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[54] As background to this observation, in September 2023, as this report was being finalised, the Government delayed the implementation of the ban on new oil boilers in off-gas-grid rural areas from 2026 to 2035, and the ban on sale of new fossil fuel cars from 2030 to 2035 (Prime Minister's Office 2023).

[55] It is acknowledged that this relatively high reported (albeit short-lived – Curtis & Pine 2016) upturn in installation rate does not fully accord with other reported data sources: see for example Figure 3.

sales figures and MCS figures is largely due to MCS data being heavily skewed towards retrofits at existing properties, rather than new-builds, and partly due to the fact that many large GSHP systems incorporate multiple heat pumps.

4.3.2 Domestic GSHP Sector

From April 2022 to March 2023, the rate of installation of MCS-accredited GSHP in the domestic sector is low, around 493 per year (UK). This is widely held to be a result of the BUS, which offers few incentives to GSHP installation. However, MCS data are not believed to efficiently capture GSHP installations at new-build properties (Aylott 2023) (given the discrepancy between sales data and MCS data). Therefore, total domestic (new-build and retrofit) GSHP installation rate could exceed 2000 per year (UK).

Under the current subsidy framework (BUS), the prospects for growth at the domestic retrofit end of the market seem limited. The following factors could, however, change the domestic market significantly:

- A change to the subsidy framework, which recognises the investment in the ground loops associated with GSHP.
- A change in the pricing of electricity in comparison to gas.
- The adoption of the Future Homes Standard in 2025, which will effectively prohibit the installation of gas (and other fossil fuel) heating in new homes.

The current rate of construction of new dwellings in England is about 200,000 per year (Department for Levelling-Up, Housing and Communities 2022; geographical distribution in Wilson & Barton 2023) [56], with an ambition to reach 300,000 by the mid-2020s. Thus, if the Future Homes Standard is implemented as promised, this might create a demand for an additional 200,000 heat pump installations per year from 2025, given the lack of other low carbon heating alternatives. If 10% of the heat pumps are GSHP (reflecting the recent ASHP / GSHP ratio, Figure 7), this might create a market for around 20,000 domestic GSHP per year in England from 2025. A significant proportion of these could deliver ground source heat to suburban communities and social housing via the concept of the shared ground loop (Foster et al. 2022).

However, it should be noted that:

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[56] Housing supply: net additional dwellings, England: 2021 to 2022. Statistics on net additional dwellings in England up to 2021 to 2022. https://www.gov.uk/government/statistics/housing-supply-net-additional-dwellings-england-2021-to-2022

- There is some lack of clarity as to exactly how the Future Homes Standard will be adopted, or if it will result in a ban on fossil fuel heating in new homes (Woodfield & Pullen 2022).
- The domestic retrofit GSHP market is remarkably “flat” at present, which means that contractors are likely to be cautious about investing in new drilling equipment, training and staff.
- There is thus a danger that, if the Future Homes Standard is implemented in 2025, with such a short lead-in time, the ground source heat pump industry may not have the capacity to meet a demand for 20,000 quality-controlled GSHP installations per year.

Thus, over the next five-years, if the Future Homes Standard is implemented as anticipated in 2025, the demand for domestic GSHP may rise to around 20,000 per year (England). If the Future Homes Standard is not implemented as anticipated and if the BUS is not significantly amended, the 5-year prognosis may be much lower – i.e. about 5000 domestic GSHP installs per year (UK).

4.3.3 Commercial, industrial and public sector non-domestic GSHC

Of the GSHP schemes installed under the RHI (see Section 3.3 and BEIS 2022):

- 85.7% (N=15,290) were domestic installations,
- 11.8% (N=2,098) were smaller (<100 kW) non-domestic installations
- and 2.6% (N=456) were large (>100 kW) non-domestic installations.

Over the about 10 years (2011-2022) of the Non-domestic RHI:

- Smaller (<100 kW) non-domestic RHI GSHP were installed at an average rate of about 200 per year.
- Larger (>100 kW) non-domestic RHI GSHP were installed at an average rate of about 45 per year.

The rates of installation were not evenly distributed, but increased as the RHI scheme drew to its close (OFGEM 2022b). The MCS accredited around 1000 small (<70 kW) commercial GSHP systems in the UK in 2021 and 2022, around the time of the closure of the RHI scheme. Nevertheless, the MCS commercial accreditation rate has continued to grow with 1,345 installations being registered between April 2022 and March 2023. There might also have been MCS-accredited commercial GSHP or GSHC schemes that did not receive RHI funding (perhaps through lack of willingness to engage with the process, cooling-dominated schemes not meeting eligibility criteria for RHI, or other forms of non-eligibility). It is also possible that the “commercial” category might contain some shared loop housing systems (Kensa 2023c), although further research would be needed to confirm this. It is thus likely that the current figure of 1345 “commercial” MCS registrations between April 2022 and March 2023 represents a somewhat smaller number of GSHP “systems” – and so a very rough figure of around 500 – 1000 systems per year has been assumed for this report.

Note that the figures discussed above could include 5-6% water-sourced heat pumps, which could be based on groundwater or surface water.

Based on information provided by industry respondents (see Section 3.7), who represent a significant share of the UK closed-loop design market, the current total installation rate of large (>100 kW) closed-loop systems could be around 60-80 per year.

Thus, as regards commercial, industrial, or public sector GSHC systems, estimates of current installation rates in the UK are around 500 to 1000 smaller (<100 kW) systems of which 200-300 are likely to be in the range 45-100 kW, and at least 60-80 larger (>100 kW) systems.

The larger end of the GSHC market is, according to industry interviewees, currently showing moderately good growth, both in the commercial / public sector and in the social housing (for example, shared loop) sector. It is thus conceivable that, within five years, installation rates in the UK could reach 1000 to 2000 smaller (<100 kW) systems installed per year, with about 600 in the range 45 to 100 kW and over 150 larger (>100 kW) systems installed per year (UK)

4.3.4 Open-loop GSHC

As regards open-loop heat pump schemes, there are currently 149 active Environment Agency groundwater abstraction licences with “heat pump” listed as a usage, growing at a rate of about 13 per year. These licences may be performing both heating and cooling.

Additionally there are 174 groundwater abstraction licences listing “low loss” or non-evaporative cooling as a use. Many of these date back to the 1960s and probably do not resemble a modern GSHC scheme where warm water is returned to the aquifer. The number of schemes is currently growing at a rate of 3 per year and this growth rate presumably reflects modern non-consumptive passive ground source cooling.

There will also be a small number of very small open-loop schemes which fall below the 20 m^3/d licencing threshold, probably mostly serving domestic properties.

Feedback from industry respondents suggests that appetite for open-loop GSHC may have been limited by the need to obtain abstraction licences / environmental permits, and the inherent delays that these involve. Given that these are unlikely to change substantially in the immediate future, current trends will either continue (about 16 new groundwater-based open-loop GSHC systems per year) or grow modestly within the next 5 years (maybe up to 30 new open-loop GSHC per year). However, inclusion of closed-loop GSHC in the regulatory framework with the introduction of the Environmental Permitting (England and Wales) (Amendment) (England) Regulations 2023 could “level the playing field" between open- and closed-loop systems. However, current proposals involve extensive "binding rules" to exempt many closed-loop systems from the need to apply for licences or permits (Regulation 5: https://www.legislation.gov.uk/uksi/2023/651/regulation/5/made); it is thus likely that closed-loop systems will remain more attractive from the point of view of perceived regulatory "burden".

There are currently about 16 new groundwater-based open-loop GSHC systems licensed per year (England) which could increase to 30 new groundwater-based open-loop GSHC over the next 5 years.

Annual installation rate	Current (per year)	5 year prognosis (per year)
Total GSHP units (UK)	5584 (2022) 3200 (decade average) 1838 (MCS-accredited*)	
Domestic GSHP (UK)	about 2000 (total) 493 (MCS accredited*)	20,000 (high growth, England) about 5000 (medium growth, UK)
Smaller (<100 kW) non-domestic / public sector systems (UK)	500 to 1000, of which 200 to 300 in 45 to 100 kW range	1000-2000, of which about 600 in 45 to 100 kW range
Larger (>100 kW) non-domestic / public sector systems (UK)	60 to 80	>150
Groundwater-sourced open-loop GSHC systems (licensed, England)	16	30

Table 6. Summary of this study's best estimates of current and future (5 year) growth rates for GSHC in the UK and England. * April 2022 to March 2023, see Section 3.2. See 4.3.5 for proportion of systems in England relative to UK.

4.3.5 A note on context

It is recognised that the 5 year prognoses presented above are relatively conservative. Rogers (2003) proposed that many successful innovations experience a sigmoidal uptake curve – comprising three phases:

i. early adoption – shallow, but accelerating growth
ii. mass uptake – very rapid growth
iii. late adopters – mature market, shallow decelerating growth.

The prognoses in this report imply that, in a 5-year period, the UK may still be in the late stages of the “early adoption” phase of GSHC. It is recognised, however, that prediction of the timing of the onset of “mass uptake” is almost impossible: it is feasible that this phase could commence within a 5-year period, however, the development of the market is sensitive to a number of factors, including Government policy which can impact consumer confidence and therefore uptake.

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List of abbreviations

ASHP – air source heat pump

ATES – aquifer thermal energy storage

BGS - British Geological Survey

BHE – borehole heat exchanger (almost synonymous with a closed-loop borehole)

BTES – borehole thermal energy storage

BUS - Boiler Upgrade Scheme

COP_H / COP_C - coefficient of performance (in heating / cooling mode)

DESNZ – Department of Energy Security and Net Zero

DHW - domestic hot water

EGC – European Geothermal Congress

EHPA - European Heat Pump Association

EPSRC – Engineering and Physical Sciences Research Council

FLEQ - full load equivalent hours

GSHC - ground source heating and cooling. This may or may not involve the use of a heat pump.

GSHP - ground source heat pump. This is a sub-set of GSHC.

GSHPA - Ground Source Heat Pump Association (UK)

IEA – International Energy Agency

kW - kilowatt: unit of instantaneous rate of transfer of energy (including heat). 1 kW = 1 kJ/s

kW_e - kilowatt electrical: unit of rate of transfer, production or use of electrical energy

kW_{th} – kilowatt thermal: unit of rate of transfer, production or use of heat energy

kWh - kilowatt-hour. An amount of energy or heat equivalent to transferring 1 kW energy for 1 hour

LCBP - Low Carbon Building Programme

MCS - Microgeneration Certification Scheme

RHI - Renewable Heat Incentive

UK FIRES – Locating Resource Efficiency at the heart of Future Industrial Strategy. An EPSRC-funded consortium of academic institutions.

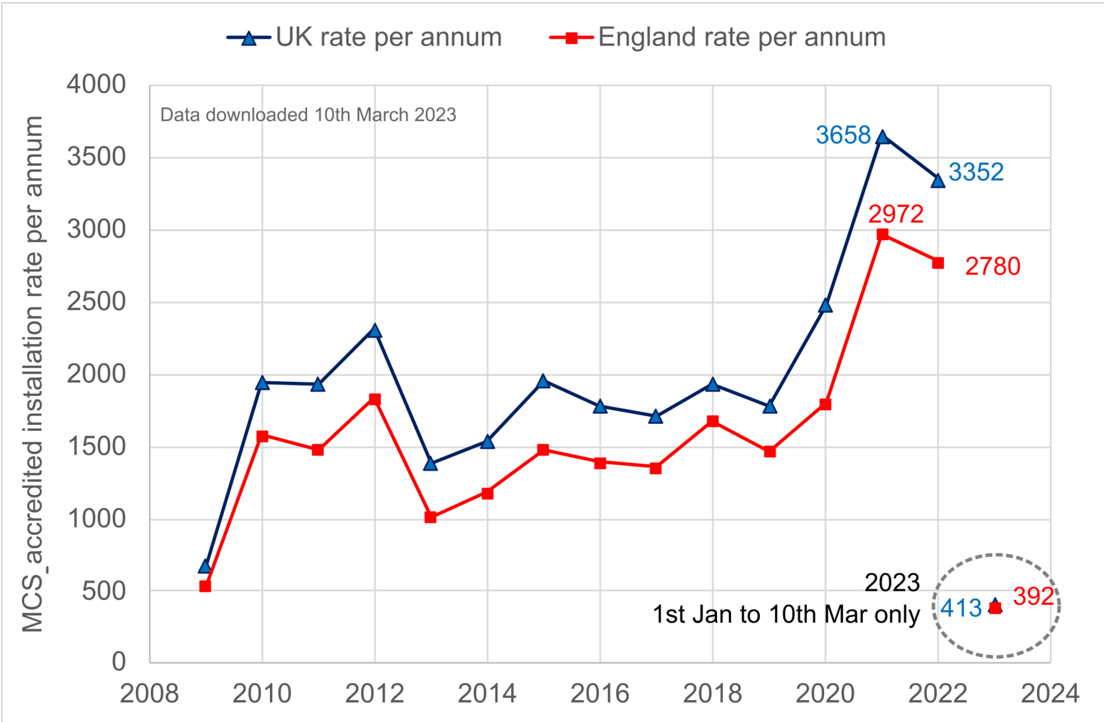
UKRI – UK Research and Innovation

UTES – underground thermal energy storage; includes both ATES and BTES

WGC – World Geothermal Congress

Appendix A. MCS data summary

The data in this Appendix document total MCS-accredited ground- (and water-) sourced heat pump installation rates per year over time.



Appendix Figure A1. Variation in rate per year of MCS-accredited installations of ground source (and water source) heat pumps from 2009 to March 2023. Note: 2023 figures are those reported to 10th March 2023 only. Graph derived from data downloaded from the MCS dashboard on 10th March 2023. (https://datadashboard.mcscertified.com/InstallationInsights)

Total MCS-accredited ground- (and water-) sourced heat pump installations in UK from 2009 to March 2023 was 28889.

Total MCS-accredited ground- (and water-) sourced heat pump installations in England from 2009 to March 2023 was 22969.

Overall ratio England/UK is 79.5%

Conversions

Unit			Conversion	
Units of power (rate of energy use, conversion or transfer)				
1	watt	=	**1**	J/s
1	kilowatt	=	**1000**	J/s
Units of energy				
1	kilowatt-hour (kWh)	=	**1000** J/s for 3600 s	
1	kilowatt-hour (kWh)	=	**3.6**	MJ
1	megawatt-hour (MWh)	=	**3.6**	GJ

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