Department for
Business, Energy
& Industrial Strategy

Opportunity areas for district heating networks in the UK

National Comprehensive Assessment of the potential for efficient heating and cooling

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Executive Summary

Introduction

Decarbonising heating and cooling is a central part of the UK Government's strategy to reach Net Zero. It underpins the Prime Minister's Ten Point Plan for a Green Industrial Revolution[1] and will be a focal point of our forthcoming Heat and Buildings Strategy[2].

It is a challenging undertaking that has no single solution and will require a combination of leading-edge technologies and increased customer options to make it happen. However, it is a certainty that heat networks will be vital to making net zero a reality in the UK. They are a proven, cost-effective way of providing reliable, efficient, low carbon heat at a fair price to consumers, while supporting local regeneration.

This study explores the geographic opportunities for low carbon heat network deployment across the country as a whole and for each of the four nations separately.

Study overview

The study provides:

- An overview of current heating and cooling demand and supply in the UK;
- Detailed maps showing the spatial distribution and density of supply and demand across the UK and each nation separately;
- A geospatial assessment of the economic potential for district heating as an efficient heating solution in the UK, accompanied by maps showing opportunity areas;
- A simplified cost benefit analysis (CBA) comparing heat networks with other, non-networked heating solutions based on highly stylised alternative future energy pathways; and
- An overview of existing, planned and possible policy measures that are or could support delivery of the economic potential.

The analysis was undertaken on behalf of the Department of Business, Energy and Industrial Strategy (BEIS) by Arup. A key output of the study is a geospatial model which will support ongoing analysis by the Government as it implements its strategy for the decarbonisation of heat across the country.

The study represents the second UK National Comprehensive Assessment (NCA) of the potential for efficient heating and cooling undertaken to meet the requirements of

[1] Link: https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
[2] The Government is developing options for a how a long-term framework of policy approaches, including regulation, can combine to provide a clear direction-of-travel for industry and accelerate the uptake of low-carbon heat, initiate a transformation of the building stock, and set the country on a path to decarbonising all homes and buildings.

Regulation 4 of the Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014[3]. The first NCA was published in 2015[4].

The study is focused on district heating networks which are seen as having a key role to play in the delivery of efficient low carbon heating. Aside from estimating current cooling demand in the UK, no further analysis on cooling was undertaken. The UK Government is undertaking work to better understand the needs for and provision of cooling however this work was not available for this study.

Policy context for heat networks

In the UK, heat is a devolved matter in Scotland and Northern Ireland and these nations are responsible for developing their own heat policies. For Wales, the production, distribution and supply of heat and cooling, the regulation of heat networks and the regulation of energy efficiency are non-devolved matters. However, heat networks, renewable energy incentive schemes and encouragement of energy efficiency are devolved. Wales is responsible for developing its own heat policies in relation to these matters.

The report includes details of the policy initiatives being undertaken to accelerate the deployment of heat networks and decarbonisation of heat more generally. The study includes descriptions of policy measures for each of the four nations and for the UK, as a whole, where relevant.

Overview of current heating and cooling in the UK

Space and water heating in the UK is predominantly provided by gas (73%), followed by oil (10%) and electricity (9%). This dependency on gas is even more dominant in the residential sector (76%) where individual natural gas boilers prevail. The penetration of heat pumps is increasing but is still at a very low base.

Given the UK's geography and climate, cooling demand is currently low, totalling around 39 TWh annually compared with 463 TWh of space and hot water heating. Cooling is predominantly fuelled by electricity and used in the service and industrial sectors; there is currently negligible cooling demand in the residential sector.

Heat networks currently meet circa 2% of heat demand in the UK, with the primary fuel source being natural gas[5].

[3] The Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014 transposed into UK law elements of the Energy Efficiency Directive of the EU 2012/27. This Directive was subsequently amended by Commission Delegated Regulation (EU) 2019/826 of 4 March 2019. Amendments were made to Annexes VIII and IX on the contents of comprehensive assessments of the potential for efficient heating and cooling.

[4] The 2015 National Comprehensive Assessment can be accessed here: https://www.gov.uk/government/publications/the-national-comprehensive-assessment-of-the-potential-for-combined-heat-and-power-and-district-heating-and-cooling-in-the-uk

[5] See Table 21 in Appendix 1

Overall, 8% of total heating and cooling demand is derived from renewable sources[6].

There is a significant amount of waste heat available from thermal power stations and industrial and commercial sites which could be used to supply heat networks. The research conducted for this report has identified some 310 TWh/yr of waste heat generated by various different installations located around the country. The ability to recover and utilise that heat will be influenced by local conditions and commercial arrangements.

For more information on the statistics presented in this section please see Appendix 1.

Methodology

To undertake the analysis a spatial model was created that maps current levels of heat demand and supply across the UK. Using this spatial data and combining it with cost data, the model identifies where heat networks could have economic potential. The model is demand led in that it looks to develop heat networks based on demand clusters rather than on sources of supply.

To determine the cost benefit of heat networks compared with alternative individual building heating options, a simplified cost benefit analysis (CBA) was undertaken, using outputs from the spatial model and projections for future energy consumption. The cost benefit analysis was undertaken separately from the geospatial model due to practical modelling constraints.

The analysis has been conducted at UK level, however in some cases datasets have been used which are specific to a particular nation. Thus, although efforts have been made to apply the methodology consistently across the UK, differences have arisen between the four nations that require specific interpretation. These are described in Appendix 7. In addition, with a model that seeks to undertake analysis at a country-wide rather than local scale, a balance has had to be struck between the desire to be as representative as possible and the need to have a workable model. A number of assumptions have therefore been made to simplify the analysis; a summary of the resulting study limitations can be found in section 2.3.

[6] See Digest UK Energy Statistics Renewables Chapter 6 (Table 6.7, 2019) here: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

Results

Economic potential based on current demand and supply

The potential for heat networks to provide heating across the UK has been the subject of several studies over recent years[7]. These studies use different methodologies to test different scenarios and have generated a range of estimates for the proportion of total UK heat demand that could be supplied by heat networks. The majority of results fall between 10% and 40%, with some scenarios generating values outside this range.

The results of this study, presented in Table 1 indicate that the economic potential of heat networks in the UK is circa 95 TWh. This estimate was derived in accordance with the criteria prescribed by the 2014 Regulations. The technical potential (i.e. actual deployment) is likely to be lower because, for example, local conditions are likely to differ from the UK wide assumptions used here, and some waste heat sources included in the model may be uneconomic to recover or cease to be available in future. The result should therefore not be considered an indicative target for heat network deployment through to 2050. It is rather an upper bound, or maximum potential, and it is most likely that less than 20% of total heating demand will be met by heat networks in practice.

Table 1: Potential contribution of heat networks to total heat demand[8] in the UK and by nation, TWh and % of total demand

	England	Northern Ireland	Scotland	Wales	UK
TWh	76	0.5	15	3.4	95
% of total heat demand	19%	3%	28%	15%	20%

The study represents the Government's most recent analysis and will be continually refined and updated as data becomes available. There is some variation in heat network uptake between nations which is attributed to variance in demand density between nations, as well as small differences in methodology used in Scotland and Northern Ireland, compared to England and Wales as noted in the section above (see Appendix 7 for further details). We will be working with the devolved administrations to actively develop and improve our evidence base to support delivery of the Heat Networks Transformation Programme and other national heat networks policies (see Section 4).

[7] Studies include: Element Energy for the Climate Change Committee (2015); BEIS's Clean Growth Strategy (2015); the Energy Technologies Institute (2018); the previous UK NCA (2015).
[8] Excludes heat for cooking and high temperature process heating.

Performance against competing technologies

The economic potential of district heat networks as derived by the geospatial model was based on the density of heat demand, proximity to possible supply points, and approximated cost of heat generation and distribution. A consideration of how heat networks perform against other competing technologies was investigated separately through the cost benefit analysis (CBA).

The CBA was done at a high level to explore how the economic potential estimated by the spatial model based on *current* demand and supply could be realised over time. It sought to show how heat networks might perform against individual building solutions under two different and highly stylised energy pathways over the period to 2050. The approach was deliberately simplified to illustrate how different pathways could impact on the relative social costs and benefits of heat networks, and should not be interpreted as an indication of the UK Government’s intention for current and future policies.

It should also be noted that the modelling was done based on UK climate change targets and was unable to account for the emissions reduction targets with earlier timescales of some devolved administrations and local authorities. This may impact on the applicability of the alternative pathways used in this cost benefit analysis. For more details on the Scottish context, see the policy section 4.3.

The stylised low carbon pathways chosen were an electrification pathway where heating moves to electric solutions such as heat pumps, and a simple hydrogen pathway where natural gas boilers are converted to hydrogen boilers from 2035. In addition, a baseline scenario was modelled where the primary energy source continued to be gas, similar to today. The analysis was undertaken at UK level only.

The modelling suggests that if gas were to remain the dominant fuel source for non-networked solutions, heat networks as modelled here that make maximum use of low carbon waste heat and environmental sources would perform well in carbon terms but would be considerably more expensive. In contrast, if we moved to a greater penetration of electric solutions, heat networks and individual building heat pumps would be fairly similar in carbon terms, but heat networks are likely to be cheaper where there are economies of scale and greater efficiencies. The hydrogen scenario is necessarily more speculative as we do not yet have the full set of data on which to base the analysis, but the output of this high-level assessment suggests that with hydrogen coming on stream from 2035, low carbon heat networks could lead to lower lifetime carbon emissions but would come at a higher net social cost than individual building solutions. It is worth noting that the analysis does not take into account any of the potential benefits of utilising hydrogen in centralised energy centres rather than directly within individual homes.

These results are particularly sensitive to input assumptions such as efficiencies and costs. Although these have been based on the best evidence currently held by BEIS, there remains a great deal of uncertainty around them and they will evolve over time.

It should be noted that the analysis cannot be used to make comparisons between scenarios as each one is supported by specific assumptions around infrastructure costs. For example, in the hydrogen scenario, the costs of distribution and storage have not been explicitly estimated as they are assumed to be common to both the heat network and single building solutions; and similarly, for the electrification scenario, the electrification infrastructure for supply and transmission that would support heat networks is the same as that which would support the single building solutions.

It should also be noted that the CBA was done at an aggregated national level based on average values while a more granular analysis would give a more nuanced picture. Thus in some areas a heat network may have a higher social economic value than single building solutions and in others the opposite, depending on local conditions and variations.

In the context of this study it is worth noting that there is uncertainty around how much waste heat could be made available from waste heat sites in the future. Some sources may become incompatible with the decarbonisation pathways pursued under the UK Net Zero Strategy; while others may emerge through more strategic development of industrial sites in closer proximity to areas of demand suitable for district heating networks[9].

Overall the analysis supports the suggestion that efficient district heating networks could play a significant role in the decarbonisation of heat across the UK.

[9] Note that some waste heat included in the electric and hydrogen scenarios is derived from technologies that use fossil fuels, such as gas-CHP. These sites have been included in the CBA since they may have long-standing functions or processes such as power production or incineration. In these cases it may be necessary to offset carbon emissions or employ CCUS measures, or the site could be converted to a non-fossil fuel technology.

Data sources: copyright and database rights

1 Introduction

1.1 Background

This study explores the geographic opportunities for low carbon heat network deployment across the UK as a whole and for each of the four nations separately.

It is the UK's National Comprehensive Assessment (NCA) of the potential for efficient heating and cooling. The focus of the study is on district heating networks which are seen as having a key role to play in the delivery of efficient low carbon heating. Aside from estimating current cooling demand in the UK, no further analysis on cooling was undertaken. The UK Government is undertaking work to better understand the needs for and provision of cooling however this work was not available for this study.

The study was undertaken by Ove Arup and Partners Ltd (Arup) on behalf of the Department for Business, Energy and Industrial Strategy (BEIS) and the devolved governments of the UK and is based on the requirements of regulation 4 of the Energy Efficiency (Encouragement, Assessment and Information) Regulations 2014[10] (the Regulations). These Regulations transposed into UK law elements of the Energy Efficiency Directive (EED) of the EU 2012/27[3].

This is the second NCA published by BEIS with the first one having been published in 2015[4].

The obligation to publish this 2020 assessment arose during the Transition Period. The UK has left the EU and the Transition Period ended on the 31 January 2021. Policies, strategies and objectives relating to energy efficiency are now developed through the UK's robust domestic decarbonisation framework.

The UK has set out a world leading commitment on net zero and as such we will continue to publish these assessments every 5 years to ensure transparency in this key area. This 2020 assessment will be submitted to the European Commission as required under the terms of the Withdrawal Agreement.

1.2 NCA requirements

Regulation 4 of the Regulations concerns the promotion of efficiency in heating and cooling. It requires the UK to undertake a NCA to establish the potential for the application of high-efficiency cogeneration (combined heat and power (CHP)) and efficient district

[10] Link: https://www.legislation.gov.uk/uksi/2014/1403/made

heating and cooling (DHC). The focus of the study is on district heating networks which are seen as having a key role to play in the delivery of efficient low carbon heating.

Due to the sizing stipulations of technologies identified in the Regulations[11] a specific focus of this work has been on identifying large sources of low carbon and waste heat. To do this, BEIS and the Scottish Government commissioned comprehensive Waste Heat Research to both identify opportunities and to develop an understanding of the potential for heat recovery from existing sites in the UK. As a result, throughout this report, unless explicitly referenced otherwise, heat pumps and high-efficiency cogeneration have been assumed to be capable of providing heat to district heating networks, rather than to individual buildings.

A summary of the requirements for this 2020 assessment is given in Table 2.

Table 2: Summary of the requirements of the UK Regulations as detailed in the EED

Reference in the regulations	Summary requirement
Part I: Overview of heating and cooling	Provide details of: - demand: heating and cooling demand by sector - supply: heating and cooling supply by technology; identification of certain types of installation that generate waste heat or cold and the potential quantity of heat/cold available; the share of energy from renewable sources and waste heat used in district heating and cooling - maps: across the national territory of demand, supply and existing and planned district heating installations - forecast: of trends in demand for heating and cooling over the next 30 years, with a focus on the next 10 years
Part II: objectives, strategies and policy measures	Planned contributions of the UK to its national objectives, targets and contributions across the five categories of energy security; internal energy market; energy efficiency; decarbonisation; research, innovation and competitiveness; general overview of the existing policies and measures as described in the most recent report submitted in accordance with Articles 3, 20, 21 and 27(a) of Regulation (EU) 2018/1999[12].

[11] For details see Part I, para 2b of the EED
[12] Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?toc=OJ:L:2018:328:TOC&uri=uriserv:OJ.L_.2018.328.01.0001.01.ENG

Reference in the regulations	Summary requirement
Part III: analysis of the economic potential for efficiency in heating and cooling	Undertake a cost benefit analysis (CBA) to determine the economic potential of different technologies for heating and cooling, taking into account high efficiency cogeneration, waste incineration, waste heat and cold sources, renewable sources, heat pumps and reduction of losses from existing district networks. The CBA should consider different scenarios including a baseline based on existing policies and alternatives taking into account new policies related to energy efficiency and renewable energy. Both an economic and a financial analysis (from investors point of view) should be undertaken.
Part IV: potential new strategies and policy measures	Provide an overview of new legislative and non-legislative measures to realise the economic potential identified in Part III.

1.3 Overview of Current Heating and Cooling in the UK

As shown in Figure 1, in 2019, the most recent year where data is available, space heating and water heating account for 74% of total heating demand in the UK and is predominantly provided by gas (73%), followed by oil (10%) and electricity (9%). This dependency on gas is even more dominant in the residential sector (76%) where individual natural gas boilers are the dominant technology for heating homes. The penetration of heat pumps is increasing but is still at a very low base.

As is consistent with the UK's geography and climate, cooling demand is currently low, totalling around 39 TWh annually compared with 463 TWh of space and hot water heating. Cooling is predominantly fuelled by electricity and used in the service and industrial sectors; there is less evidence available for cooling demand in the residential sector, however, BEIS are currently developing this evidence base.

Currently heat networks meet approximately 2% of heat demand in the UK, with the primary fuel source used by existing heat networks being natural gas.

Overall, 8% of total heating and cooling demand is derived from renewable sources[13].

[13] See Digest UK Energy Statistics Renewables Chapter 6 (Table 6.7, 2019) here: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

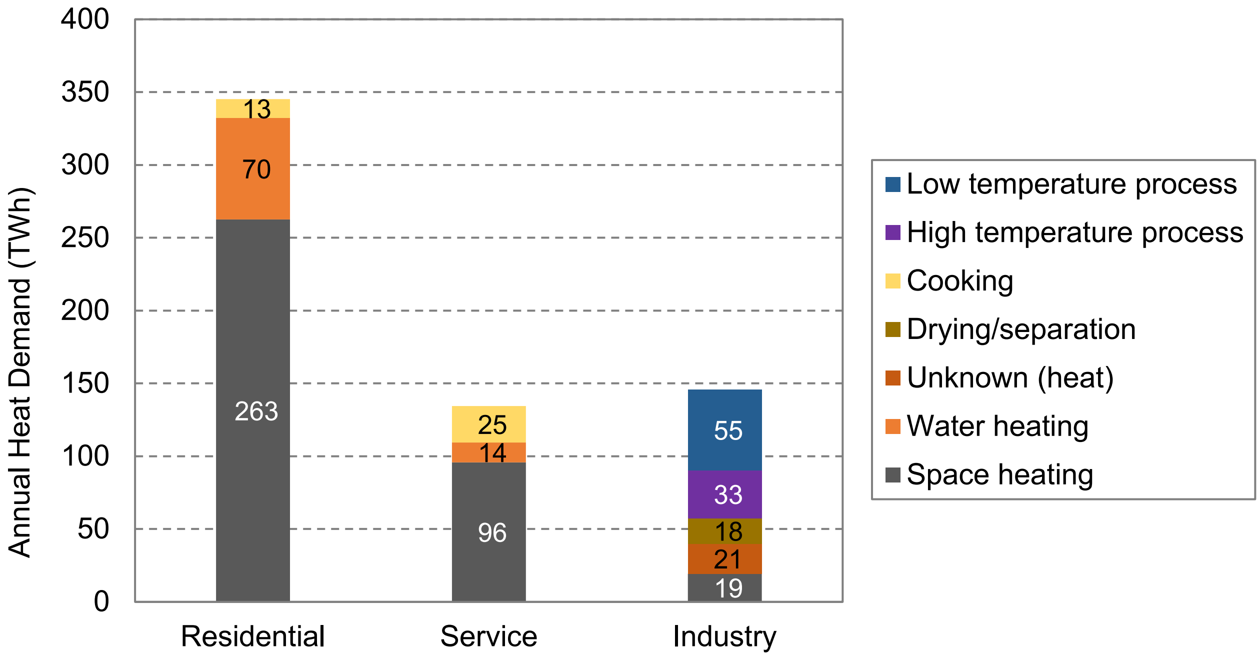

Figure 1: Annual heat demand by sector and by end use, 2019 (see Table 17)

There is a significant amount of waste heat available from thermal power stations and industrial and commercial sites which could be used to supply heat networks. The research conducted for this report has identified some 310 TWh/yr of waste heat generated by various different installations located around the country. The ability to recover and utilise that heat will be influenced by local conditions and commercial arrangements.

For detailed breakdowns of heating and cooling in the UK, please see Appendix 1.

1.4 Structure of this report

The introduction (**Chapter 1**) gives an **outline of current heating and cooling in the UK**. This sets the scene for the analysis of economic potential that forms the core element of the study. The introduction also outlines the requirements of the Regulations.

Chapter 2 describes the **methodology** used to undertake the assessment. It describes how an estimate of national heating and cooling demand has been made. For heating, it describes the geospatial analysis of demand clusters, and how clusters have been matched to appropriate heat sources to estimate the proportion of heat demand that could technically and economically be served by heat networks. Cooling was not taken forward into the district network analysis.

Chapter 3 presents the **results** of the analysis used in this report. It presents modelled heating and cooling demand estimates for the UK, in 2020 and 2050. It also presents the results of the economic potential analysis for heat networks and cost benefit analysis as required by Part III of the Regulations. Maps of heat demand and supply, and of areas where heat networks could be economically viable are included.

Chapter 2 and Chapter 3 follow a similar structure, presenting methodology and results respectively for:

- estimating heating and cooling demand
- estimating heat supply from sources of low carbon and waste heat
- using a geospatial model to assess the economic potential for heat networks
- cost benefit analysis for heat network against individual building counterfactuals

Readers may wish to review Chapters 2 and 3 in tandem to help with the interpretation of results.

And finally, **Chapter 4** gives an overview of **policies**, both planned and in place, aimed at supporting the roll out of efficient and low carbon heating. Policies are provided for each of the four UK nations where matters are devolved. This covers requirements for Part II (objectives, strategies, and policy measures) and Part IV (potential new strategies and policy measures).

Appendices are provided to give more detail on methodology and results, on assumptions and limitations, and on data sources.

2 Approach and methodology

This section provides a high-level description of the approach and methodology followed in undertaking the analysis. Further details are provided in Appendix 3.

2.1 Overview

The analysis was undertaken through the creation of a geospatial model (the 'spatial model') which maps heating and cooling demand and potential heat supply opportunities, and allows for an assessment of the economic potential for heat networks in the UK. The spatial model, written in PostgreSQL and R software, is made up of three distinct methodology stages, outlined below. A fourth stage was used to undertake a cost benefit analysis (CBA) to compare heat network solutions against alternative approaches. Cooling demand for the UK has been mapped, but due to the low demand for cooling in comparison to heating, it was not analysed any further as part of the network modelling.

Spatial model:

1. Spatial mapping of *current* **heating and cooling demand** at building-level, built up from individual building data and energy use benchmarks, calibrated locally against measured gas consumption and other heating fuels. Total heating and cooling consumption used in the spatial model slightly differs from national totals presented in section 1.3 of this report, due to limitations of the analysis which are explained in the study limitations section 2.3.

2. Spatial mapping of known **heat sources** in the UK, to determine potential of *current* **supply** of low carbon and waste heat. This was achieved by collating datasets that provide information on existing sites/technologies with potential for waste heat recovery or low carbon heat generation.

3. An assessment of proximity of areas of **supply/demand** and the costs associated with connection through a district heat network, to quantify the economic potential for heat networks in the UK.

Cost Benefit Analysis of heat networks compared with individual building counterfactuals:

4. The outputs of the spatial model were combined with energy projections and costs for socio-economic, environmental and financial impacts to produce a CBA for heat networks compared with non-networked solutions. Two highly stylised low carbon energy pathways to 2050 were modelled, along with a 'baseline' scenario where natural gas continues to be the primary heating fuel.

Further detail on the methodology employed under each stage is provided in the following sections.

2.2 Methodology

Current heating and cooling consumption

Heating and cooling demand in the UK was determined initially using an energy demand benchmark approach. This is dependent on building floor areas and building typologies. Benchmarked heat demand in England and Wales was then calibrated against sub-national heating estimates derived from estimates of Lower layer Super Output Area (LSOA) gas consumption data and national consumption of non-gas heating fuel.

The heating and cooling building-level consumption estimates were estimated for the UK by three similar methodologies for: England and Wales, Scotland, and Northern Ireland. This was based on the availability of data used in the heating/cooling demand methodology, which is listed in Table 3 for each nation.

Table 3: Address and building level data sources

Nation	Address data	Building data	Supplementary data	Calibration data
England and Wales	Ordnance Survey Address Base Premium (OSABP)	Ordnance Survey MasterMap (OSMM)	Valuation Office Agency (VOA)	Energy Consumption in the UK[14] (ECUK) and metered gas consumption data in Lower layer Super Output Areas (LSOA)
Scotland	Scotland Heat Map[15]			
Northern Ireland	Address Base Premium Islands (OSABPI)	OS NI Fusion (OSNIF)	N/A	ECUK

Table 4 gives the data sources of benchmarks which were applied to each of the building typologies in England, Wales and Northern Ireland. Building typologies were derived by joining the Building Energy Efficiency Survey (BEES) sector and sub-sector definitions to

[14] Energy Consumption in the UK https://www.gov.uk/government/statistics/energy-consumption-in-the-uk
[15] Scotland Heat Map User Guide is available at https://www.gov.scot/publications/scotland-heat-map-documents/

the typology codes in OSABP. In Scotland, heat demand data was provided by the Scotland Heat Map.

Where non-domestic ratings data from the VOA were available for a building, the OSABP floor area was superseded by VOA data as it provides more accurate information. The non-domestic VOA data was processed to exclude non-heated spaces such as storage areas or car parks, which, if included, would give an over-estimation of internal floor area.

Table 4: Data sources for heating and cooling benchmarks for England, Wales, and Northern Ireland

Sector	Source
Non-domestic (heating and cooling)	**Building Energy Efficiency Survey (BEES)**[16] A 2014/2015 report on non-domestic building stock in England and Wales. Survey of energy consumption across different building sectors.
Domestic (heating only)	**National Energy Efficiency Data-Framework (NEED)**[17] A study that aimed to better understand energy use and energy efficiency in buildings. Matches gas and electricity consumption data with information on installed energy efficiency measures.

England and Wales

The heating and cooling consumption for England and Wales was calculated from the building's floor area taken from OSABP and applying the relevant heating / cooling demand benchmark for the building typology in question. Where required, building floor area was calculated from the Building Height attribute in OSABP and an assumed building storey height.

The resulting benchmarked heat demand was calibrated against known gas consumption values in each Lower layer Super Output Area (LSOA) by comparing the proportion of benchmarked heat from buildings known to be on the gas grid, to the gas consumption data for that LSOA. This was adjusted to account for the use of alternative, non-gas fuel types also used for heating, based on figures from ECUK. Gas consumption for catering and high temperature industrial processes was excluded from the analysis since these types of end use have been assumed to have low viability for district heating in the analysis and are therefore omitted from the heat demand figures.

[16] Link: https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees
[17] Link: https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework

The relative difference between the *sum of benchmarked heating demand in an LSOA and estimates for LSOA heating from metered consumption of gas and other fuels* provided a 'calibration factor' for each LSOA that described how much the benchmarked demand should be adjusted by to match that estimated from LSOA metered fuel consumption.

The resulting calibration factor was used to adjust to benchmarked building-level heat consumption estimates for each LSOA in England and Wales.

Cooling demand was not calibrated to local demand and is based on benchmarks only.

Scotland

Building level heating demand in Scotland was based on the underlying data from the Scotland Heat Map. This dataset does not contain data for cooling demand therefore, to estimate this demand, cooling benchmarks were applied to Scottish buildings using the same method as was used for England and Wales.

The Scotland Heat Map uses a variety of data sources to estimate demand for heat. Whilst following, in principle, a floor area benchmarking model for the majority of non-domestic buildings, it utilises CIBSE TM46[18] energy benchmarks that include both space heating and hot water demand. In general, these represent a larger demand per unit area than the benchmarks applied in the rest of the UK. For the majority of domestic properties, heat demand is obtained from Energy Performance Certificates (EPCs) or the Energy Saving Trust's Home Analytics dataset (which uses EPCs as a basis for modelling). Heat demand from these two sources includes both space heating and hot water. More details of the data sources and methodology can be found in the Scotland Heat Map User Guide[19].

Northern Ireland

Heating and cooling demand were benchmarked using a similar process to that used for England and Wales, i.e. with use of BEES and NEED benchmark values. It is assumed that BEES and NEED studies can be generalised for application in Northern Ireland. The methodology uses Ordnance Survey address data[20] to determine building use type, and OSNIF data to determine building footprint. OSNIF does not provide the number of storeys per building and therefore this was estimated for common building types using the averaged value of the number of storeys for a given building type in England and Wales.

Mapping

Mapping was carried out to show:

- heating and cooling demand;
- heating supply;

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[18] CIBSE TM46: https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7evAAC
[19] The Scotland Heat Map User Guide (2.0 user guide) is available at: https://www.gov.scot/publications/scotland-heat-map-documents/
[20] Link: Address Base Premium Islands

- areas with potential for economically viable heat networks; and
- existing and planned heat networks.

Maps were produced for England, Northern Ireland, Scotland and Wales separately and for the UK as a whole. Heating demand, cooling demand and heating supply have been aggregated to MSOA (England and Wales), IZ (Scotland) and SOA (Northern Ireland) census geographies in preference to lower-level census geographies, such as LSOA, to display data more clearly at the scale of the mapping areas chosen.

Heating demand and heating supply estimates have been presented as GWh/km^2/year; cooling demand estimates have been presented as kWh/km^2/year. The mapped outputs are presented in Section 3.2 and Appendix 2.

Heat source analysis and mapping

Various heat sources have been analysed through this study. These are classified within three categories:

- **location specific sources** of heat, i.e. existing sources of heat at known locations;
- **water sources** such as rivers, marine, lakes and canals and other surface water; and
- **location agnostic sources** of heat, i.e. generation plant that can be installed largely regardless of location.

Details on how these sources are treated in the model are described in this section.

Location specific sources

Data on known current heat sources were processed to enable the mapping of heat sources in the UK. A range of sources have been captured through this study, as shown in Table 5.

Table 5: Location specific heat source summary, see Appendix 6 for further details on data sources

Source category	Sources included	Data source
Combined heat and power plant	Existing gas and biogas fired combined heat and power plant (CHP)	CHP Quality Assurance Programme, BEIS
Incinerators[21]	Energy from Waste incinerators (EfW), Advanced Conversion Technology (ACT) EfW incinerators, Biodrying Mechanical & Biological Treatment (BMBT), Landfill Mechanical & Biological Treatment (LFMBT) & Other incineration plants	DEFRA and devolved environment agencies
Thermal Power Stations[21]	Gas, biomass/biogas and nuclear power plants *(Coal omitted)*	Digest UK Energy Statistics, BEIS
High grade waste heat sources	Cement, lime and iron and steel production, crematoria *(Petrochemical plants / refineries omitted)*	Waste Heat Research conducted by Arup for England, Northern Ireland, and Wales and BRE for Scotland.
Low grade waste heat sources	Chemical, cold stores, data centres, food and drink, other mineral industries, paper and pulp, electricity substations, supermarkets, wastewater treatment works, underground railways and active minewater pumping stations.	Waste Heat Research conducted by Arup for England, Northern Ireland, and Wales and BRE for Scotland. Minewater stations from the Coal Authority.

[21] Where an incinerator or thermal power station is included in the CHPQA programme, it is included as CHP.

Water sources

Information has been used from the Water Source Heat Map[22] to estimate the availability of heat from sources like rivers, canals, marine, lakes and other surface water in England. For the rest of the UK, only coastal areas have been included in the analysis.

Location agnostic sources

The sources listed in Table 5 are located at existing sites and are therefore specific to a location. In contrast ‘location agnostic’ sources are technologies which we assume could be deployed anywhere where there is demand for heating. The following technologies are included in the definition of ‘location agnostic’ heat sources:

- air source and ground source heat pumps
- biomass boilers and biomass CHP
- gas boilers and gas CHP
- electric boilers
- hydrogen boilers

The study did not include geothermal sources at this time due to difficulties in sourcing appropriate data for use in the model. The intention is to include these at a later date as the model is developed.

Treatment of heat sources in the model

For each heat source category, assumptions are used to determine the temperature at which heat can be captured from the source. If an uplift in temperature is required to meet the assumed network supply temperature of 80°C, the associated heat pump efficiency is calculated.

Assumptions on the availability of sources are made to determine the heat output per annum and peak output. System capital and operational costs are also captured in the model, including any likely tariffs payable to heat suppliers, e.g. incinerator operators, water companies or Distribution Network Operators (DNO).

These assumptions are used to generate a Levelised Cost of Generation (LCOG) for each source type, which feed into calculations on how far heat can be distributed from a source (see Appendix 3 for further explanation of the calculations).

Heat source maps

Heat source availability has been mapped by aggregating available heat supply to MSOA, IZ and SOA level, which are comparable sizes of census geography between nations in the UK. Values are given in GWh/km^2/year heat available, i.e. no distinction between source temperature is made.

[22] Link: https://www.gov.uk/government/publications/water-source-heat-map

Assessing the Economic Potential for heat networks in the UK

The geospatial assessment to determine where heat networks could have economic potential was conducted by first determining where there were suitable demand clusters. These demand clusters were then matched to sources of low carbon waste heat where available and to non-site specific sources where not. The analysis simulates where conditions are economically viable for heat networks to form and does not consider the trade-off with any other competing technology. The latter is explored through the separate CBA model as described below.

At a high level, the economic potential for a heat network is dependent on the cost of heat generation and supply, the proximity of supply to demand, and the density of heat demand. A key task of the spatial model was therefore to combine these factors in all areas to test viability.

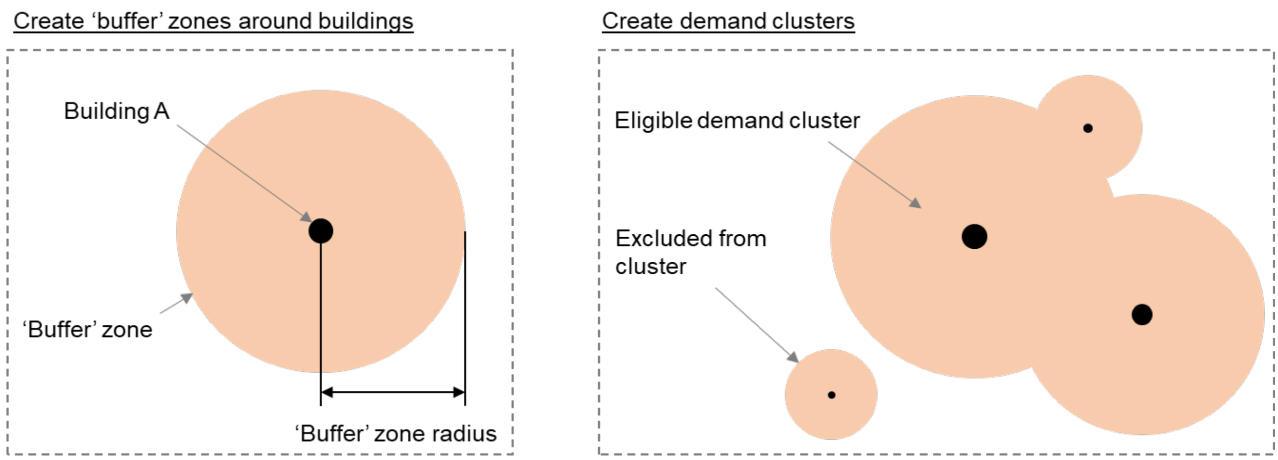
Two methods were developed to assess the potential for heat networks in the UK.

- The first method uses estimates of heat demand at LSOA-level to assess where it would be technically viable to connect heat supply to demand and generates potential heat networks by exhausting supply from these sources; this method only applies some limited economic constraints.
- The second method uses estimates of heat demand at the more granular building level; it also gives consideration to a wider range of economic constraints associated with deploying a heat network to show where they might have the greatest economic potential.

Of the two methods, the second method was selected as the preferred option due to the greater perceived level of modelling granularity as a result of the building-level data and additional economic factors considered. This method is described below; see Appendix 4 for a description of the first method and results.

Under the preferred method, to calculate the extent of economically viable heat network deployment in the UK, the model follows the steps shown in the flowchart in Figure 3. It starts by generating demand clusters as illustrated in Figure 2 and then matches these with suitable heat sources according to a series of prioritisation rules based on cost and distance.

Cost and distance are encapsulated in the linear heat density (LHD) which is a key component of the analysis. The LHD gives the minimum heat demand required per metre of distance from the building (kWh/m) in order that the heat revenues generated can pay back the costs associated with generation and distribution within a given time frame. The LHD is dependent on the source – and hence cost – of heat in the network, and in the analysis three levels of LHD are used to categorise types of heat source depending on their relative costs and revenue margins. A detailed description of the LHD calculation is given in Appendix 3.



$$\text{Radius} = \frac{Building\ heat\ demand\ (\frac{kWh}{annum})}{Linear\ heat\ density\ (\frac{kWh}{annum.m})}$$

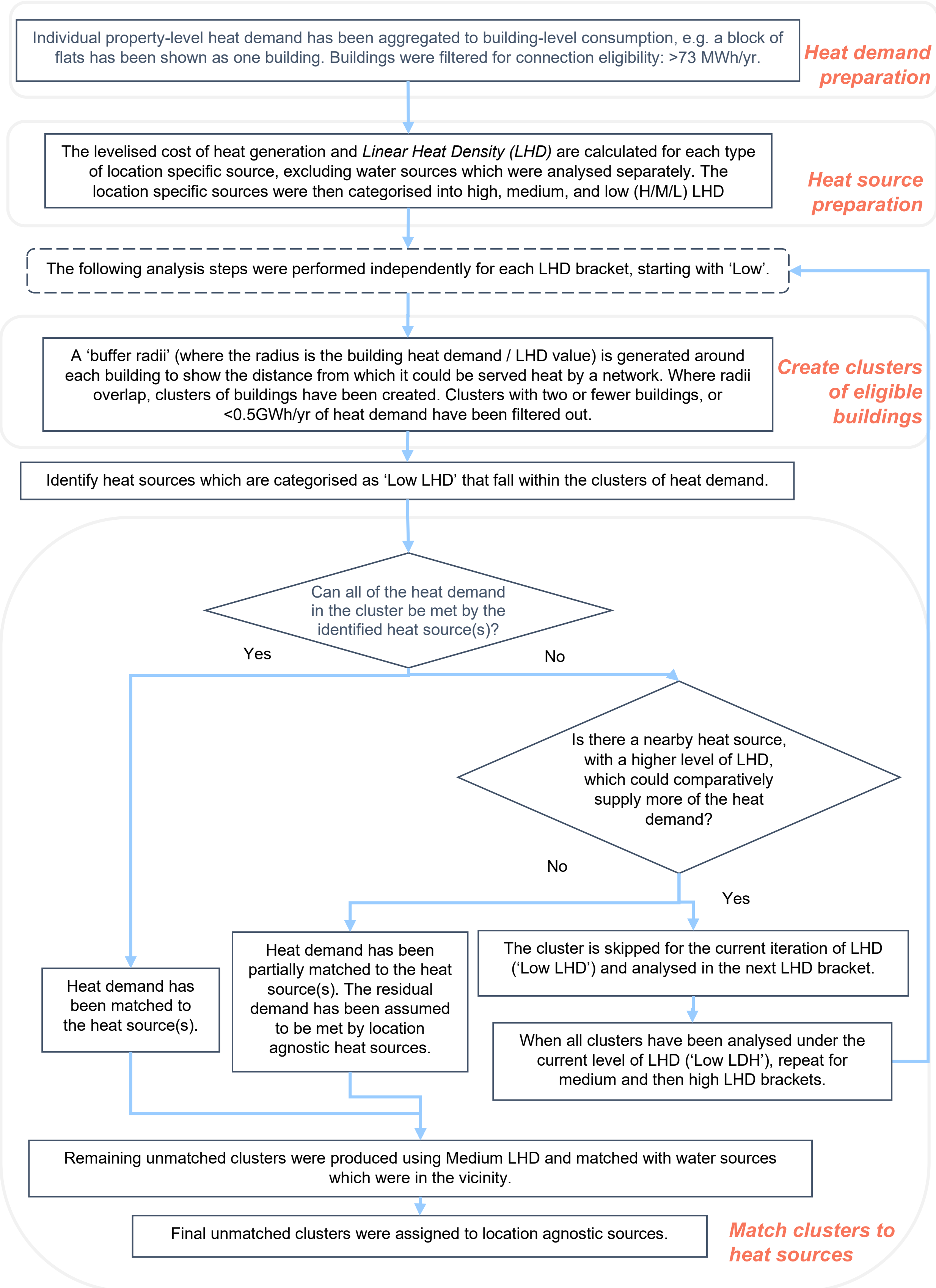
Figure 2: Illustration of how building clusters are generated by the model

The value of 73 MWh/yr has been used as the minimum heat demand from a given building for it to be viable to connect to a heat network. This value was chosen to be consistent with the gas consumption threshold used by BEIS to determine whether an address is domestic or non-domestic[23]. Domestic buildings are therefore only included in networks if they form part of a communal block; standalone domestic buildings are not considered viable for heat network connection in this analysis.

The process presented in Figure 3 was undertaken three times in total reflecting three separate model scenarios ('High', 'Medium' and 'Low' uptake scenarios), each with distinct underlying economic assumptions in the LHD calculation. See Appendix 3 for further details.

[23] Link: https://www.gov.uk/government/publications/regional-energy-data-guidance-note

Figure 3: Flowchart of the methodology used to assess the Economic Potential for heat networks



Projections of heating and cooling consumption to 2050

The UK energy demand projections are derived from the BEIS Energy and Emissions Projections (EEP) model suite[24]. This is a set of tools for projecting future energy demand and greenhouse gas emissions for the UK based on economic, demographic, and other drivers and taking into account expected impact of current and planned Government policies. From the EEP, further steps are taken to derive specific heating[25] demand projections from the overall energy demand projections.

Projections are not carried out within the spatial model; rather, they are calculated separately, outside of the spatial model, and are included within the CBA as described below.

Cost benefit analysis for heat networks against individual building counterfactuals

The spatial model used cost and operational inputs to determine where, based on current demand and supply, networks could be deemed to be technically and economically viable. The CBA was a separate exercise that took the outputs from the spatial model and used these to compare network solutions with individual building solutions in the period to 2050. The analysis was undertaken at a UK level only. An overview of the methodology is provided here, with more detail available in Appendix 3, Appendix 5 and Appendix 6.

The NCA is required to be published every 5 years, with this version coming at a time of rapid change within the UK energy policy environment. In particular, evidence gathering to inform policy that will support the rapid decarbonisation of heat in a way that is consistent with our net zero commitment is at an intense stage. Given this other ongoing work, a high level and stylised approach to the CBA has been undertaken. As such, it is important to note that the results should not be interpreted as any indication of the UK Government's intention for current and future policies. Importantly, the CBA does not capture the benefits of climate change mitigation (except in the limited case of the social cost of carbon) which would likely outweigh the capital investment costs required. It simply assesses the cost benefit of heat networks compared with individual building solutions under a continuation of gas (baseline) and two highly stylised alternative future low-carbon energy pathways.

It should also be noted that the modelling was done based on UK climate change targets and was unable to account for the emissions reduction targets with earlier timescales of some devolved administrations and local authorities. This may impact on the applicability of the alternative pathways used in this cost benefit analysis. For more details on the Scottish context, see the policy section 4.3.

The basic premise of the analysis is simple in that it assumes that the economic potential for heat networks as assessed by the spatial model (as shown in Table 10) is achieved by

[24] Link: Energy and emissions projections, BEIS

[25] Forecasts of cooling demand to 2050 have not been possible to compile for this report. BEIS is currently developing the evidence base for cooling in the UK, as part of a separate study.

2050). The change in energy demand to 2050 follows the Government's energy projection model suite EEP[24] and is based on assumptions of current Government policies, future economic growth, fossil fuel prices, electricity generation costs, UK population and other key variables.

The low carbon pathways chosen were an electrification pathway where heating moves to electric solutions such as heat pumps, and a hydrogen pathway where natural gas boilers are converted to hydrogen boilers from 2035[26]. In addition, a baseline scenario was modelled where the primary energy source continued to be gas, similar to today.

The CBA then compared a heat network solution with an individual building solution for each pathway. Calculations were only carried out on the proportion of the heat demand in the UK that was modelled to be economically feasible for supply by heat networks.

The spatial model identifies two types of heat network, one that relies predominantly on location specific heat sources such as waste heat from thermal power plants, industry, or buildings, and one that relies predominantly on location agnostic sources such as boilers and heat pumps. Using this classification, the location specific heat sources are the same for the heat networks in all three scenarios and the location agnostic heat network sources mirror the single building solutions.

The three scenarios are:

1. **Continuation of current primary heating fuel (gas):** Location agnostic heat sources for heat networks are gas CHP and gas boilers; any supplementary supply required to cover periods where the primary source is unavailable is provided by gas boilers. Single building solutions in the counterfactual are gas boilers. This is a baseline position representing the current UK energy system. A NPV is calculated comparing the heat network solution against the building level gas boiler solution.

2. **Electrification pathway**: Location agnostic heat sources for heat networks are large heat pumps; any supplementary supply required to cover periods where the primary source is unavailable is provided by electric boilers. Single building solutions in the counterfactual are smaller heat pumps. This is a simplified decarbonisation scenario achieved essentially through electrification of heat through heat pumps only. A NPV is calculated comparing the heat network solution against a single building level heat pump solution.

3. **Hydrogen pathway**: Location agnostic heat sources for heat networks are large natural gas boilers which are gradually replaced by hydrogen boilers from 2035: any supplementary supply required to cover periods where the primary source is unavailable is provided by gas boilers to 2035 and hydrogen boilers thereafter. Single building solutions are smaller gas boilers which are replaced by hydrogen

[26] It is important to note that results cannot be compared between scenarios and each should be considered independently. This is because the approach taken to modelling the individual building solutions in the counterfactuals are different for each scenario and as such are not directly comparable.

boilers over the same period. The choice of 2035 for the start of the transition is somewhat arbitrary but would roughly coincide with the gas boilers installed in 2020 coming to the end of their technical lifetime.[27] A NPV is calculated comparing the heat network solution against a single building level hydrogen boiler solution.

The heat network solutions are compared against the single building solutions in each case and a NPV (using HM Treasury Green Book[28] social time preference rate of 3.5%) is calculated accounting for:

- capital costs;
- fixed and variable operating costs;
- energy costs;
- air quality damage costs; and
- costs of carbon.

The long-run variable costs (LRVC) of energy are used, which represent the costs of energy supply to society as a whole. BEIS has not yet developed LRVCs for hydrogen and therefore as a proxy production costs of hydrogen which exclude any network and storage costs have been used. However, as these excluded costs are common to both the heat network and single building solutions, their net value is assumed to be zero.

The baseline scenario, where gas remains as the primary heating fuel, is effectively a continuation of the status quo, whilst the electrification and hydrogen scenarios represent pathways with a higher degree of decarbonisation; inputs such as fuel prices and carbon prices have been set to reflect this.

The CBA has not been modelled from the investor point of view in any great detail as this assessment is at the national level and there would be a large variation in cost and benefits at specific site level. The financial NPV is therefore derived similarly to the social NPV with the following changes in input parameters as indicated in Table 6:

- A higher discount rate;
- Use of retail fuel prices instead of LRVC [29]; and
- With no environmental and air quality impact costs considered.

[27] This analysis is based on a stylised scenario in which the hydrogen price is set by blue H_2 by 2030. https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base

[28] Link: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf

[29] Tables 4-8 in https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal except for hydrogen which has been developed separately.

Table 6: Differences between the social and financial NPV

	Discount rate	Fuel prices	Carbon prices	Air quality
Social NPV	3.5%	LRVC	yes	yes
Financial NPV	7.5%	retail	no	no

2.3 Study limitations

This analysis is based on the most comprehensive collation of data and datasets which could be accessed at the time of the assessment. A number of assumptions and simplifications have been applied in order to make the analysis meaningful, while at the same time managing model complexity.

Table 7 summarises key limitations identified with the study inputs; Appendix 7 provides a description of how the analysis should be interpreted for nations in the UK; and Appendix 5 and Appendix 6 detail the specific assumptions and data sources used in the analysis.

Table 7: Summary of study limitations

No.	Description
Heat demand limitations	
1	In the heating and cooling demand mapping, figures have been estimated using a benchmarking approach. Resulting estimates of heat demand have then been aligned to total with aggregated (LSOA level) metered consumption data but have not been split by sector. Due to the simplicity of the methodology, it is likely that there are areas where estimated heating and cooling demands do not accurately reflect the reality of heating and cooling demand at low levels of geography.
2	The sectoral split of heat demand in the UK is determined by the benchmarking approach. Since benchmarks for the domestic sector and non-domestic sector originate from separate studies (NEED and BEES respectively) there may be inconsistencies in how the benchmarks have been determined.
3	Since network viability is based around the demand of individual buildings, the difference between modelled and expected demand may affect that viability. The heating and cooling demand results are dependent on the chosen benchmarks (in this case BEES and NEED), which have a certain survey size and are only correct at the time of the survey.
4	The study does not include heat consumption for high temperature industrial processes; it is limited to heat used for space heating, water heating and a small amount of low temperature process heating. Due to the inclusion of a subset of

No.	Description
	heating end uses, heat demand estimates in the NCA model may not match other estimates for heat demand in the UK, for example those made by ECUK.
5	Gas consumption data was used to calibrate the building heat demand values for England and Wales. The calibration exercise was carried out at LSOA level by applying the calculated calibration ratio to all buildings within that LSOA. The LSOA level gas consumption has been adjusted to remove some large consumers of gas due to disclosure reasons, therefore, some LSOA gas consumption is not fully represented. We estimate that approximately 10% of total UK gas consumption has been omitted from the NCA analysis for disclosure reasons. This has had a significant effect on total modelled heat demand in the UK, as presented in section 3.2. Since calibration has been undertaken at LSOA level, this may have resulted in some individual buildings' heat demand being under or overestimated.
6	In areas where gas calibration data was not available due to LSOAs being off the gas grid, heat demand has not been calibrated and therefore relies on benchmarked heat demand.
7	Fuel consumption data for heating was not available at a low level of geography in Northern Ireland and therefore Northern Ireland demand data was not calibrated with sub-national heat demand estimates and relies on benchmarked heat demand only.
8	Benchmarks and building height assumptions derived from studies in England and Wales have been assumed to be generalisable for application in Northern Ireland. The number of storeys in individual buildings in Northern Ireland was not available in the data and therefore was estimated using average number of storeys of buildings in England and Wales, based on the building typologies.
9	No correction for climatic considerations has been made, other than the natural allowance made for weather included through the gas consumption calibration step.
10	Individual buildings included in this study are limited to those which are in the relevant Ordnance Survey (or equivalent) dataset (according to nation), and for which a data processing match between location and typology was possible. Buildings not appearing in the OS data sets or for which no match between location and typology was possible, have been excluded.
Heat supply limitations	

No.	Description
11	The availability of heat from a known potential source is estimated and will need further investigation and verification.
12	All heat sources have an assumed availability factor, indicating what percentage of the year they are available to supply heat. The remaining annual heat demand is assumed to be met using top-up gas boilers. The low carbon heat sources are also assumed to create a base load with limited short-term variability and therefore peak demand periods are assumed to be met by more easily variable gas boilers. The use of thermal storage to balance and manage heat supply to mitigate the use of gas was not considered in this model. This would further reduce gas consumption in the heat networks.
13	Back up and top up heat supply is assumed to be from gas boilers as a current enabling technology, which would be replaced with a low/zero carbon alternative in the future.
14	Location agnostic supply is a blend of various technologies that could be used to supply a heat network to enable decarbonisation therefore technical and economic assumptions are generalised for the group of technologies. In reality different technologies could have different supply potentials. Geothermal heat has been excluded in this version of the model.
Economic potential limitations	
15	The model assumes no individual domestic dwellings have sufficient demand to warrant connecting to a heat network. To reflect this a cut off of 73MWh/yr heat demand was used. This value was selected as a standard unit used in categorising gas consumers. This distinction could have a significant impact on the buildings that are within scope of the economic potential assessment.
16	Heat network areas determined by the model to be economically viable are indicative only and must be subject to further analysis and design development before any investment decision is taken or construction commences.
17	Three LHD values have been used across the economic potential modelling, whereas in reality, LHD would vary from network to network depending on the nature of the heat supply technology, off-takers and other network properties. This may over- or underestimate the contribution from certain sources.
18	Where there is no location specific heat source within a demand cluster the model assumes that demand will be met by a location agnostic source i.e. a purpose built energy centre. This means that some viable waste heat sources that are just outside a cluster may not be taken into account when in practice they could supply

No.	Description
	some adjacent demand. This could have resulted in the share of heat network demand met by waste heat sources being underestimated.
19	For the economic potential assessment, demand:supply matching is carried out for location specific heat sources first, followed by water sources. This limits the heat supplied from water sources compared to its full potential but mitigates overestimation of a water source's heat supply potential from a single source.
20	The model does not assign a heat generation technology to clusters that are assigned to 'location agnostic sources'. The assumption is that the specific technology applied in each case would be subject to further investigation.
CBA limitations	
21	The CBA assumes the economic potential estimated by the spatial model is delivered by 2050. Projected changes in heat demand out to 2050 are included in the analysis however no attempt has been made to quantify possible changes in heat supply. This could be relevant in the case of the location specific sources which could change over time, both in terms of heat availability and location. This could affect NPVs presented in the result section of this report.
22	The CBA was assessed on an aggregated national average rather than on a granular scale where each scheme or geographic cluster was assessed. As such, the CBA does not capture any location specific variations in NPV.
23	The CBA is based on current costs and efficiencies; however these may change over time.
24	The scenarios have been deliberately chosen to be simplistic to avoid over-interpretation and cannot be compared between pathways.

3 Results

This section presents demand for heating and cooling in the UK as determined by the spatial model, showing how heat networks could contribute to meeting this demand and quantifying their social and economic benefits when compared to alternative decarbonisation pathways. The results presented in this section should be interpreted in accordance with limitations presented in Section 2.3 and Appendix 7.

3.1 Results context

The economic potential for heat networks, which is the main output of the analysis, is an estimate for the UK as determined by the geospatial model described in Section 2. The model identifies areas with suitable economic conditions to develop heat networks and is based on current levels and locations of heat supply and demand. It does not however compare heat networks to any other competing technology such as heat pumps installed in individual buildings; and does not consider temporal factors such as improvements to building energy efficiency and continuity of waste heat sites. The model is also demand led thus networks are built around demand clusters rather than, for example, waste heat sources.

To achieve a cost-effective comparison between heat network solutions and individual building solution counterfactuals over time, a CBA was carried out at UK level. The CBA is dependent on the economic potential as identified by the geospatial model but is undertaken separately in Excel. In addition, the analysis is at an overall UK level and does not optimise solutions at a local level. This approach was taken as there is currently insufficient data available to make an optimised local level analysis meaningful. Given that the CBA has been conducted at a UK level only, it is acknowledged that some local benefits of heating solutions will not be captured, and therefore that the results of the CBA are not generalisable at the sub-national level. The analysis also does not take into account emissions reduction targets with earlier timescales of some devolved administrations and local authorities.

BEIS, in collaboration with the devolved administrations, intends to improve on the evidence and analysis underlying this report, through a programme of continuous development. The geospatial model will help to refine evidence to contribute to the development of heat networks policies as part of the Heat Networks Transformation programme, including Heat Networks Zoning, (see Section 4), as well as consolidation with wider heat decarbonisation pathways and whole systems modelling, such as UKTIMES.

3.2 Heating and cooling demand

Modelled Heating demand

The purpose of modelling heating demand at building level in the UK is to assess the density of heat demand and hence identify areas where there is the potential for a viable heat network. The breakdown of current heating demand in the UK by region, as modelled for 2020 and projected in 2050, is given in Table 8.

Please refer to section 2.2 for a description of the methodology underpinning the projections.

Table 8 provides a regional and national breakdown of heating demand (space, water, and low temperature process heating) by sector in 2020 as modelled by the NCA geospatial model. The corresponding heat demand from ECUK has been included in the table to present a comparison between the two studies. The ECUK values are higher than those generated by the spatial model as they include high temperature process heating and cooking. Differences also arise due to the limitations associated with creating a granular map of heat demand as discussed below and in section 2.3.

The two key limitations of heat demand modelling in the spatial model are:

1. Heat demand in the spatial model is calibrated on subnational estimates of fuel consumption. Large consumers of gas have not been included in LSOA consumption tables for disclosure reasons, therefore, some LSOA gas consumption is not fully represented. We estimate that approximately 10% of total UK gas consumption has been omitted from the NCA analysis for this reason. A decision was taken not to adjust for omitted gas consumption, since inclusion of the consumption at a higher level of geography would affect the consumption of all buildings in that level of geography which would impact on the assessment of viability for heat networks.

2. The sectoral split of heat demand in the spatial model is determined by the benchmarking approach. Since benchmarks for the domestic sector and non-domestic sector originate from separate studies (NEED and BEES respectively) there may be inconsistencies in how the benchmarks have been determined. A separate methodology[30] has been used in ECUK to split consumption of heating fuels by sector.

[30] See end uses data tables available here: https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

Table 8: Spatial model 2020 heat demand and 2050 projections, TWh/yr

		2020 estimates, TWh/yr			2050 Projections
Devolved administration / English region,		**Non-domestic**	**Domestic**	**Total**	**Total**
England	North East	3.6	17.0	20.6	22.8
	North West	9.8	43.9	53.7	59.6
	Yorkshire and the Humber	8.0	33.9	41.8	46.7
	East Midlands	6.7	28.7	35.4	39.5
	West Midlands	7.9	34.3	42.2	47.0
	East of England	6.9	36.1	43.0	47.5
	London	9.7	50.1	59.8	65.9
	South East	9.1	53.1	62.2	68.3
	South West	5.7	32.1	37.8	41.6
Northern Ireland		1.0	12.4	13.4	14.3
Scotland		17.9	35.1	53.0	62.3
Wales		3.8	18.9	22.7	25.1
UK total		**90.1**	**395.6**	**485.6**	**540.5**
ECUK derived total (as comparison)		**223.5**	**333.7**	**557.1**	**NA**

See section 2.2 for a description of the NCA heat demand mapping methodology and 2.3 for study limitations.

Figure 4 shows the heat demand by region (from Table 8) as a stacked chart for domestic and non-domestic demand, as well as the projected 2050 uplift.

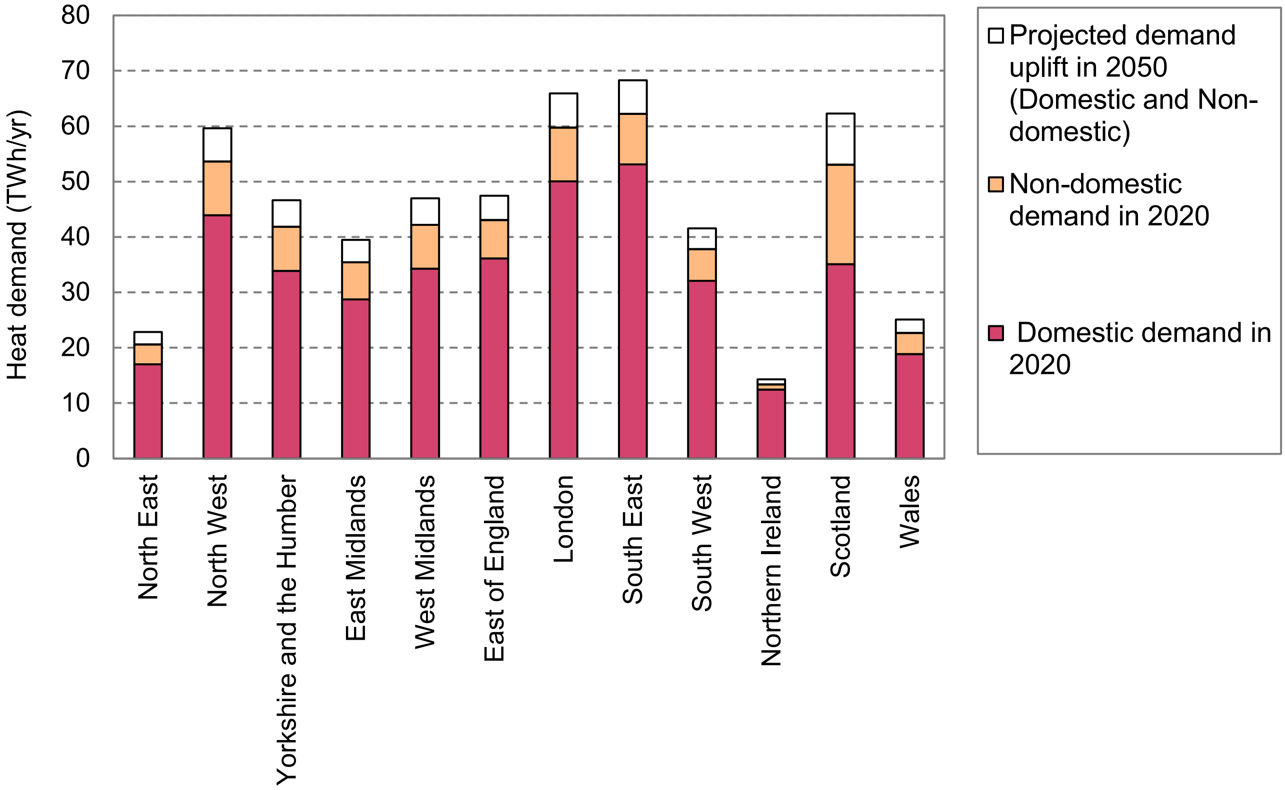


Figure 4: 2020 and 2050 heat demand by region

Modelled Cooling demand

Current modelled cooling consumption by region is given in Table 9[31].

Table 9: Spatial model 2020 cooling demand, TWh/yr

Devolved administration / English region		Non-domestic, TWh/yr	Domestic, TWh/yr	Total, TWh/yr
England	North East	1.6	No assumed domestic cooling	1.6
	North West	5.2		5.2
	Yorkshire and the Humber	3.8		3.8
	East Midlands	3.7		3.7
	West Midlands	3.8		3.8
	East of England	3.7		3.7
	London	4.8		4.8
	South East	5.0		5.0
	South West	3.3		3.3
Northern Ireland		0.5		0.5
Scotland		3.2		3.2
Wales		1.8		1.8
UK total		**40.5**		**40.5**
ECUK derived total (as comparison)		**39.1**		**39.1**

[31] Forecasts of cooling demand to 2050 have not been possible to compile for this report. BEIS is currently developing the evidence base for cooling in the UK, as part of a separate study.

3.3 Economic potential for heat networks in the UK

The potential for heat networks to provide heating across the UK has been the subject of a number of studies over recent years[32]. These studies use different methodologies to test different scenarios and have generated a range of estimates for the proportion of total UK heat demand that could be supplied by heat networks. The values are mostly between 10% and 40%, with some scenarios generating values outside this range. The Climate Change Committee Sixth Carbon Budget references a figure of 18% of homes being heated by heat networks by 2050[33].

In this study, the economic potential analysis was conducted to estimate the potential for heat networks in the UK by first determining where there were suitable demand clusters and then matching these clusters with sources of low carbon waste heat where available and with other non site specific sources where not. The analysis simulates where conditions are economically viable for heat networks to form and does not consider the trade-off with any other competing technology. This is explored through the separate CBA analysis (Section 3.5). See section 2.2 and Appendix 3 for a more detailed description of the methodology.

This section reports the results of the analysis for the medium scenario using base case assumptions as outlined in Appendix 5. The results for scenarios that could lead to higher or lower heat network uptake are presented below.

The UK total heat network economic potential by technology and nation for the medium network uptake scenario is given in Table 10. These results are also shown in Figure 5 by technology and nation. The table also separates out technologies that are location specific (existing sites), location agnostic (could be built at a non-specific location to serve local demand), as well as back-up boilers which are used to supplement all types of heating technology.

The results reflect a high-level analysis undertaken at a national scale, and therefore may not accurately capture the most optimal technology solution that might be identified using a local level analysis.

This economic potential was assessed by following the assessment criteria prescribed by the 2014 Regulations however it is important to note that the output of the model is not considered to be an indicative target for heat network deployment through to 2050. It is seen as an upper bound, where actual deployment could be lower depending on local conditions and deliverability. The relative share of the heat source types used to supply the heat networks could also differ from the estimates generated here. In particular, the fact that the model builds networks based on demand rather than supply has resulted in some

[32] Studies include: Element Energy for the Climate Change Committee (2015 and referenced in 6th Carbon Budget); BEIS's Clean Growth Strategy (2015); the Energy Technologies Institute (2018); the previous UK NCA (2015).

[33] Link: https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Buildings.pdf

site-specific heat sources with high potential being omitted from the analysis as they are outside any demand cluster identified by the model. In reality such a site could be sufficiently near an area of demand that it could usefully serve. Thus it is likely that the relative share of heat from waste heat sources is underestimated and that of location agnostic sources is overestimated.

BEIS considers the spatial model to be a valuable tool in assessing the potential for heat networks in the UK. However we also recognise that further work is required to make a better assessment of the potential for heat networks in the decarbonisation of heat and will be working with the devolved administrations to actively develop and improve our evidence base to support delivery of the Heat Networks Transformation Programme and other national heat networks policies (see Section 4).

Table 10: UK Economic potential for heat networks under current economic constraints by source technology and nation

Total TWh/yr	England	Northern Ireland[34]	Scotland	Wales	Total[35]
CHP Plant	3.4		0.1	0.0	3.6
Incinerators (including EfW)	3.7		0.0	0.6	4.4
Thermal Power Stations	2.5		0.2	0.2	3.0
High Grade Waste Heat Sources	0.3		0.0	0.1	0.4
Low Grade Waste Heat Sources	4.5		0.1	0.1	4.7
Location Agnostic Sources	44.8		12.9	1.9	59.9
Water Source Heat Pumps	11.8		1.2	0.2	13.3
Back-up Boilers	4.9		0.6	0.2	5.7
Total, TWh pa	**76.0**	**0.5**	**15.0**	**3.4**	**95.0**
As % of total heat demand	**19%**	**3%**	**28%**	**15%**	**20%**

Table 10 shows there is disparity between heat network uptake in each nation. This is attributed to variance in demand density between nations, as well as a difference in heat demand calculation methodology used in Scotland and Northern Ireland, compared to England and Wales.

[34] A breakdown of economic potential for heat networks by technology is not currently available for Northern Ireland. This has been caused by an error in one of the clusters identified through the economic potential analysis. The total economic potential in Northern Ireland has been adjusted to remove the impact of the error.

[35] The total breakdown of economic potential for heat networks by technology has not been adjusted to remove the effects of the error described in the previous footnote, due to the relative impact of the error being small.

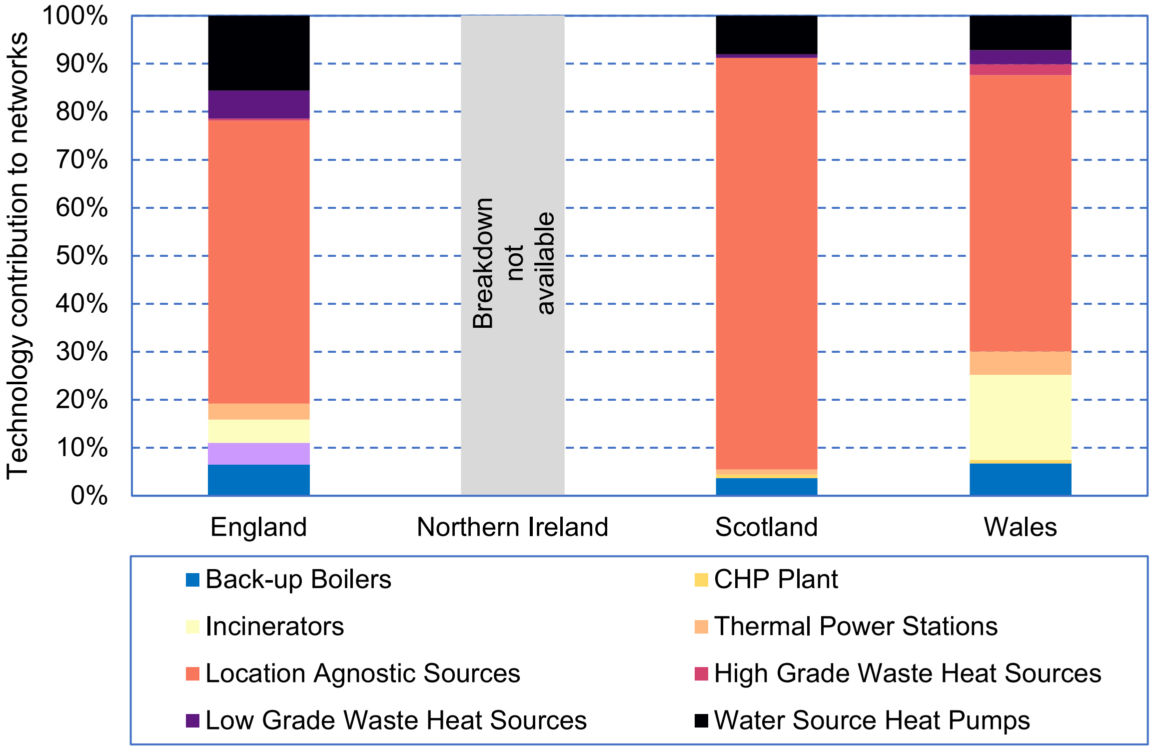


Figure 5: Contribution of each technology to modelled heat networks[36]

Further analysis was undertaken to verify this. As shown in Table 11, the median and average heat demands per building are highest in Scotland, a result of using the Scotland Heat Map data as opposed to the benchmarking and calibration methods used in the other regions.

The Scotland Heat Map uses a variety of different data sources and an alternative methodology to that used for England, Wales and Northern Ireland. Whilst in principle following a floor area benchmarking model for the majority of non-domestic buildings, it utilises CIBSE TM46 energy benchmarks[37] that include both space heating and hot water demand but which in general reflect greater energy demand per unit area than the more recent BEES Study[38]. More detail can be found in the Scotland Heat Map methodology documentation[39].

[36] It has not been possible to present a technology breakdown for Northern Ireland. See footnotes to Table 10.

[37] Link: CIBSE Guide TM46

[38] Link: Building Energy Efficiency Survey

[39] Link: Scotland Heat Map User Guide

Table 11: Heat consumption per building and buildings per unit area of nation

Consumption per building, kWh/yr/building		Domestic	Non-domestic	Total	Average no. buildings / km2
England	Median	10,700	7,300	10,400	208
	Average	13,100	34,900	14,700	
Northern Ireland	Median	13,900	1,800	10,700	58
	Average	16,300	17,500	16,400	
Scotland	Median	11,900	21,700	12,600	36
	Average	13,200	94,000	18,700	
Wales	Median	10,400	6,300	10,100	78
	Average	12,700	30,300	14,100	
Total	Median	10,800	8,300	10,700	133
	Average	13,200	39,100	15,000	

Due to the higher levels of heat demand, present in the analysis, for buildings in Scotland, heat network uptake is greater as buildings are calculated to support greater lengths of pipework and the resultant heat network clusters are larger. There is likely to be some inconsistency in the representation of potential for heat networks in Scotland relative to the rest of the UK due to the differing models and levels of sophistication in heat demand mapping.

Heat network potential is lower in Northern Ireland than the rest of the UK. This can be explained in part by the greater proportion of domestic heat demand relative to other regions (c. 93%, compared to the UK average of 81%). Building density in Northern Ireland is also generally lower than the rest of the UK (c. 58 buildings per km2, compared to the UK average of 133 buildings per km2).

The methodology for heat demand mapping used in Wales is closest to that used for England. Heat network potential in Wales is lower than in England due to lower heat demand density in the nation, illustrated in Table 11.

Of all UK regions, the modelling shows that London could have the highest potential for heat networks due to the high density of heat demand.

Scenario testing

Two additional scenarios were modelled to reflect alternative underlying cost assumptions that drive the LHD calculation (see Appendix 3 for more information). These have been called 'Low' and 'High' to reflect the likely impact of the changed assumptions on the UK total potential for heat networks.

Table 12 compares the Low and High results with the Medium case presented above.

Table 12: UK Economic heat network potential based on current levels of demand and supply, by source technology for three uptake scenarios

Total TWh/yr	Network uptake scenario – UK total		
	Low	Medium	High
CHP Plant	2.1	3.6	1.8
Incinerators	2.2	4.4	3.1
Thermal Power Stations	0.8	3.0	6.1
High Grade Waste Heat Sources	0.4	0.4	0.4
Low Grade Waste Heat Sources	4.9	4.7	9.2
Location Agnostic Sources	60.8	59.9	61.1
Water Source Heat Pumps	14.2	13.3	14.3
Back-up Boilers	5.3	5.7	6.6
Total, TWh/yr	**90.9**	**95.0**	**102.4**
As % of total heat demand	**19%**	**20%**	**21%**

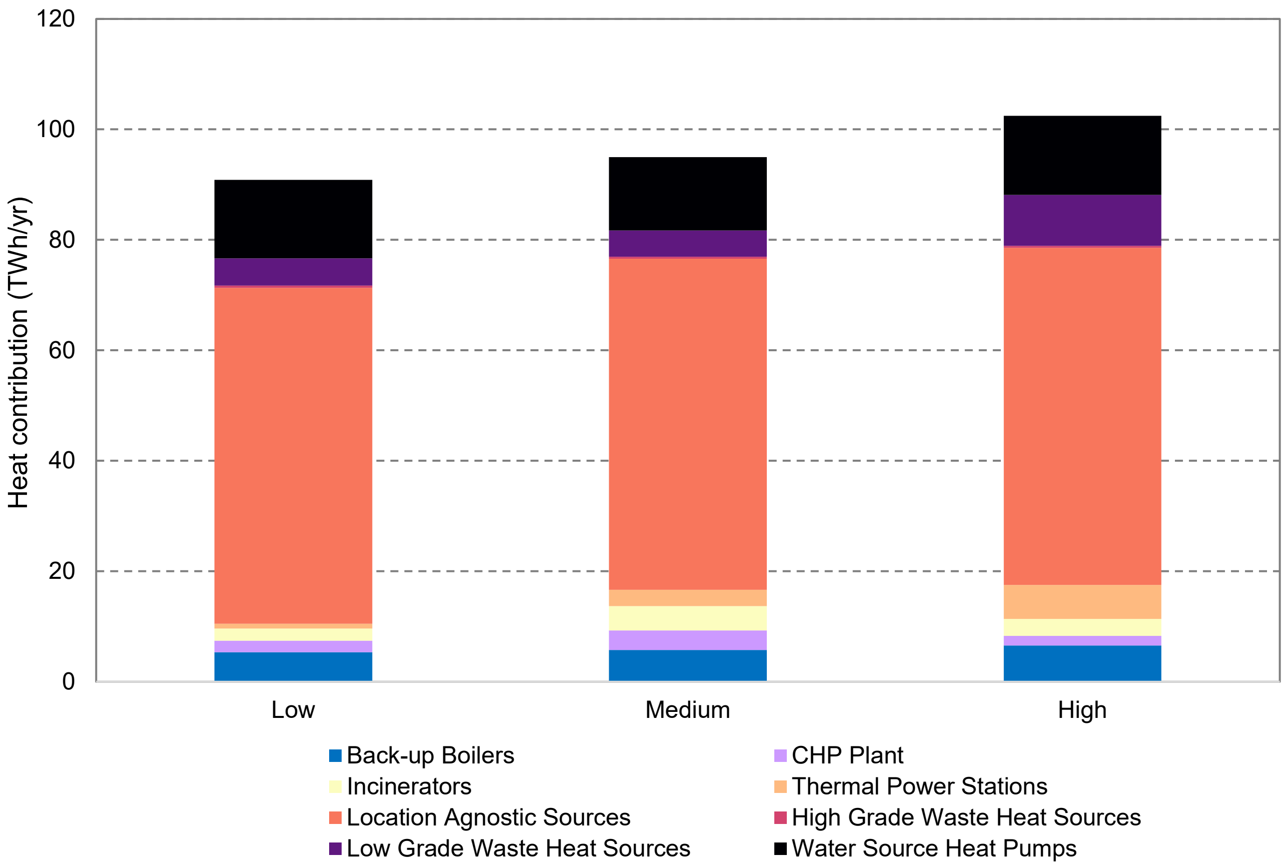


Figure 6: Economic heat network potential scenario results

Results show that location agnostic heat sources like ASHP and GSHP contribute the highest proportion of heat to the modelled networks in all scenarios. This result is a reflection of the model methodology being demand led i.e. clusters are centred around heat demands. Under a different methodology, for example where waste heat sources were purposely connected to the most amenable heat demand, the relative difference between supply from waste heat and location agnostic sources would be significantly different.

Overall, the trend is as expected: high heat network uptake occurs when network costs are reduced (i.e. in the High uptake scenario). The high uptake scenario also has less variation between levels of LHD compared with the other scenarios, which allows greater competition between technologies. In the high scenario, thermal power stations are found to contribute more heat proportionally: as a low cost form of heat generation, they rely on low cost *distribution* (i.e. low LHD) to reach demand in their vicinity.

The location of an individual demand cluster and its proximity to different heat sources affects how it is supplied, as well as the LHD value assigned to each heat supply technology under each scenario. For the same cluster, the chosen heat supply may differ between scenarios depending on the LHD values. As such, some technologies are found to be more prevalent in the Low uptake scenario, and some more prevalent in the High uptake scenario. Regional results for the three heat network uptake scenarios are given in Table 13.

Table 13: UK network uptake results by region for Low, Medium and High network uptake scenarios

Devolved Administration / English Region		Heat supplied by networks, TWh/yr			As percentage of heat demand		
Network uptake scenario		L	M	H	L	M	H
England	North East	3.2	3.3	3.6	15%	16%	18%
	North West	9.3	9.7	10.6	17%	18%	20%
	Yorkshire and the Humber	7.1	7.4	7.5	17%	18%	18%
	East Midlands	5.6	5.7	6.2	16%	16%	17%
	West Midlands	7.2	7.5	7.9	17%	18%	19%
	East of England	6.0	6.2	6.6	14%	14%	15%
	London	21.6	21.7	22.8	36%	36%	38%
	South East	8.4	9.4	10.3	13%	15%	16%
	South West	4.9	5.2	5.7	13%	14%	15%
Northern Ireland[40]			0.5			3%	
Scotland		14.3	15.0	17.3	27%	28%	33%
Wales		2.7	3.4	3.2	12%	15%	14%
UK total		90.9	95.0	102.4	19%	20%	21%

London can be seen to have the highest heat network potential of all regions – a result of the high heat demand density in the city. Results for Northern Ireland, Scotland and Wales are discussed under Table 10. In general, heat network potential is greatest in the scenarios where costs in the LHD calculations are low (where the lowest costs are included in the high uptake scenario).

Whether a heat network cluster is assigned to one region or another depends on the location of the heat source supplying that cluster. As described above, the heat source assigned to a cluster may differ between scenarios. In some instances, this means that the same cluster can be assigned to one region in one scenario, and another region in the

[40] See footnote to Table 10

next. In Wales this happens between the medium and high uptake scenarios, where a cluster in Chester (England) connects a number of buildings in Wales in the high uptake scenario (thereby allocating Welsh heat demand to England). For this reason network uptake in Wales is slightly lower in the high uptake scenario than the medium uptake scenario.

3.4 Mapping

Maps showing the distribution and density of demand and supply and of heat network potential are seen as an important output of the study. They are produced for England and Wales, Scotland, Northern Ireland, and the UK. Heat demand, cooling and supply have been aggregated within MSOA (England and Wales), IZ (Scotland) and SOA (Northern Ireland) census geographies in preference to lower-level census geographies, such as LSOA, to display data more clearly at the scale of the mapping areas chosen.

Heating demand and heating supply estimates have been presented as GWh/km^2/year; cooling demand estimates have been presented as kWh/km^2/year. The mapped outputs are presented here in Section 3.4 and in Appendix 2.

The range of scaled heat values were then placed into eight classes that reflect equal intervals across the whole data range. Because heat values have a very large range and are highly skewed (lower heat values show several orders of magnitude higher frequency than higher values), classification was based around quartile ranges of log-transformed heat that were then recast back to their non-log values.

Heat networks with potential for economic viability have been shown as a combined layer including both location specific and location agnostic sources.

The following figures represent the mapped results outputs for:

Figure 7: UK annual heat demand density

Figure 8: UK annual cooling demand density

Figure 9: UK heat supply density (location specific sources)

Figure 10: UK areas with potential for economically viable heat networks

Maps for the individual nations of the UK are presented in Appendix 2.

The heating and cooling demand maps are as expected, as they strongly correlate with population density around urban centres. The supply map is less correlated with population density with some available heat supply in and around urban centres, as well as heat supply in areas that are more rural such as thermal power stations and incinerators.

Areas that show potential for heat network viability are concentrated around areas with high levels of heat demand and low-cost heat supply. Large clusters form near sources of cheap heat, since the LHD associated with those sources is lower and resultant building buffer radii are larger. In London, for example, heat network potential is high, but clusters are smaller than some other areas due to the type of heat sources available in London generally being at the upper end of the cost scale for heat generation.

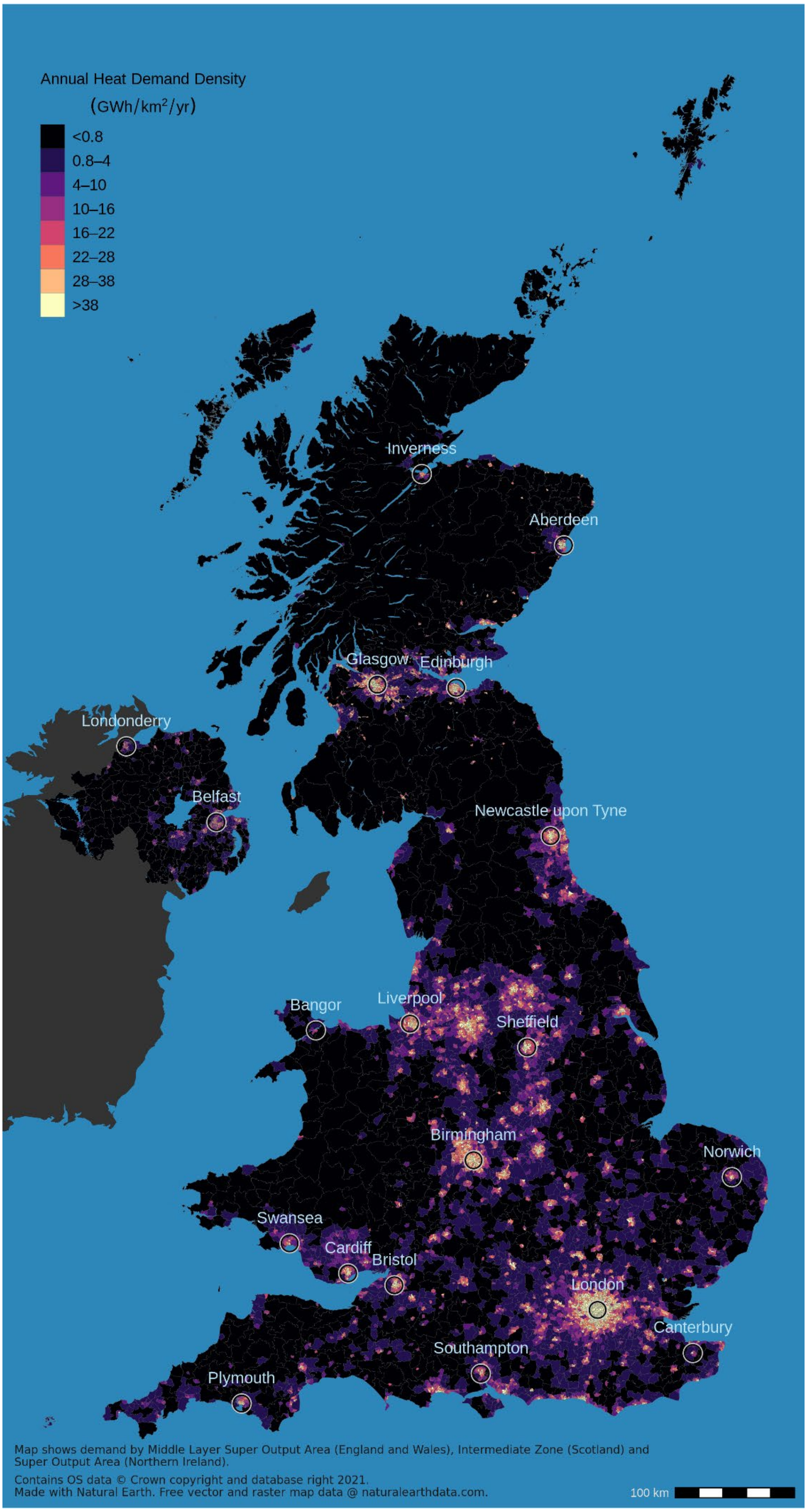


Figure 7: UK annual heat demand density

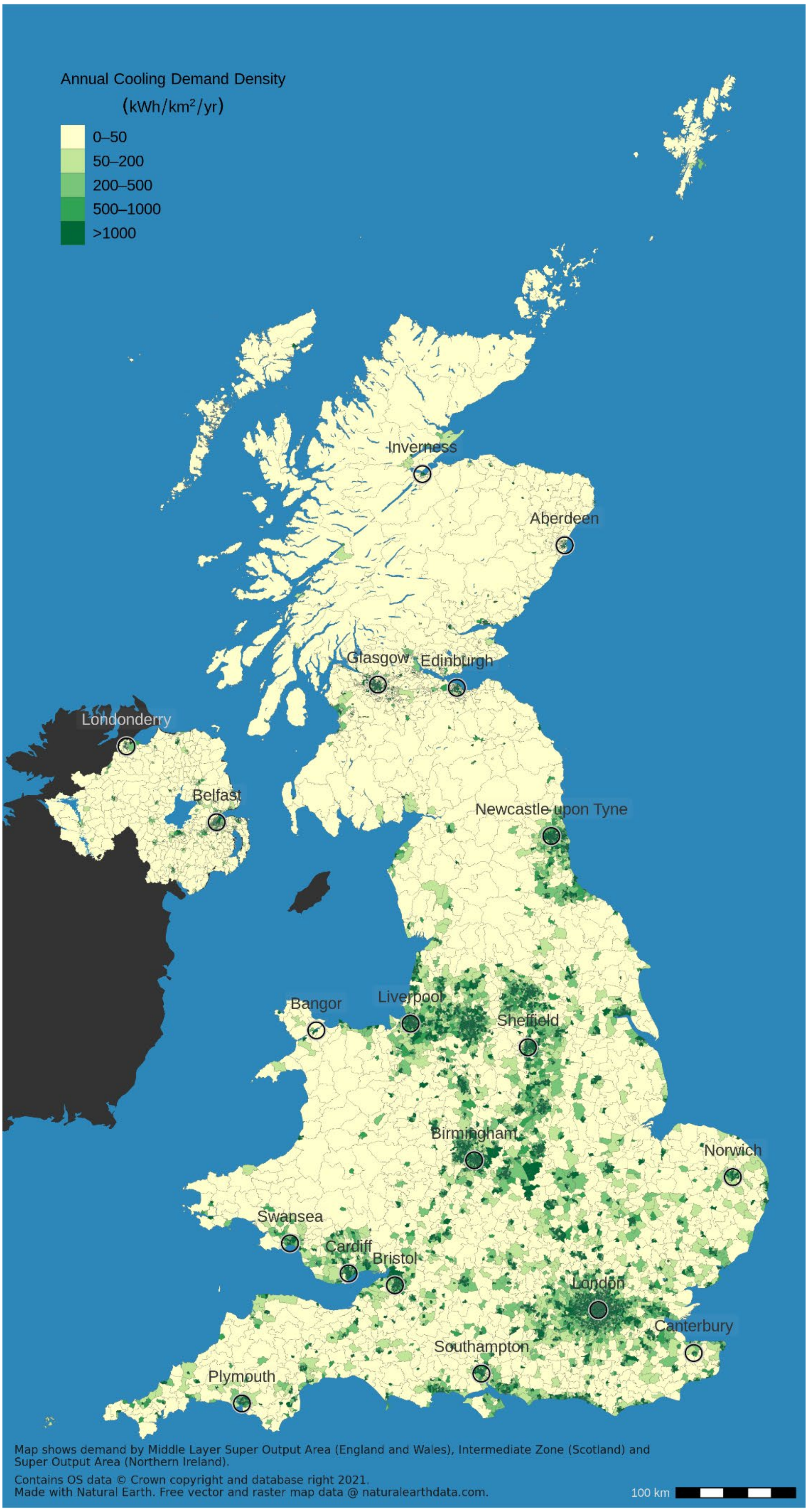


Figure 8: UK annual cooling demand density

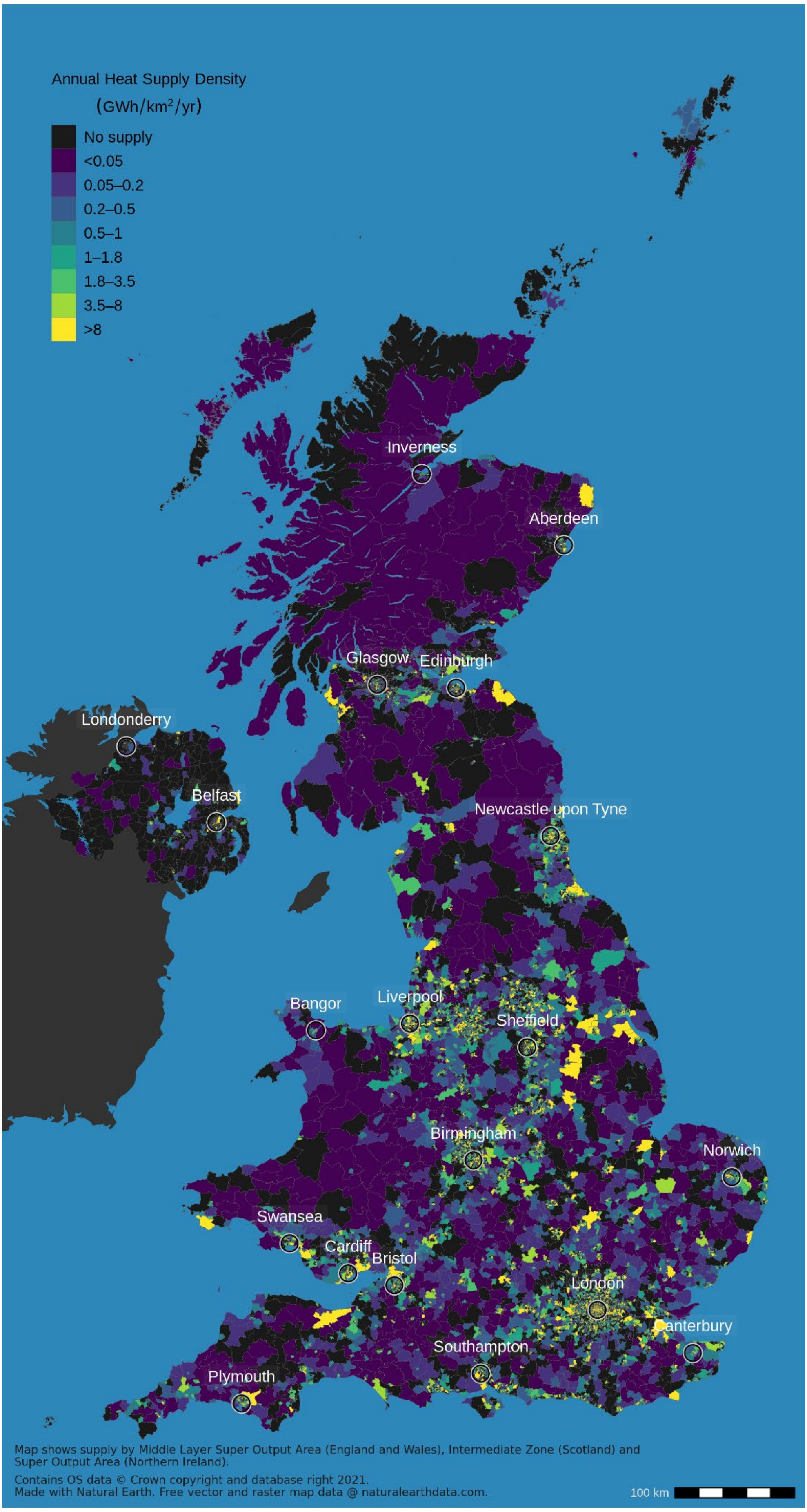


Figure 9: UK heat supply density (location specific sources)

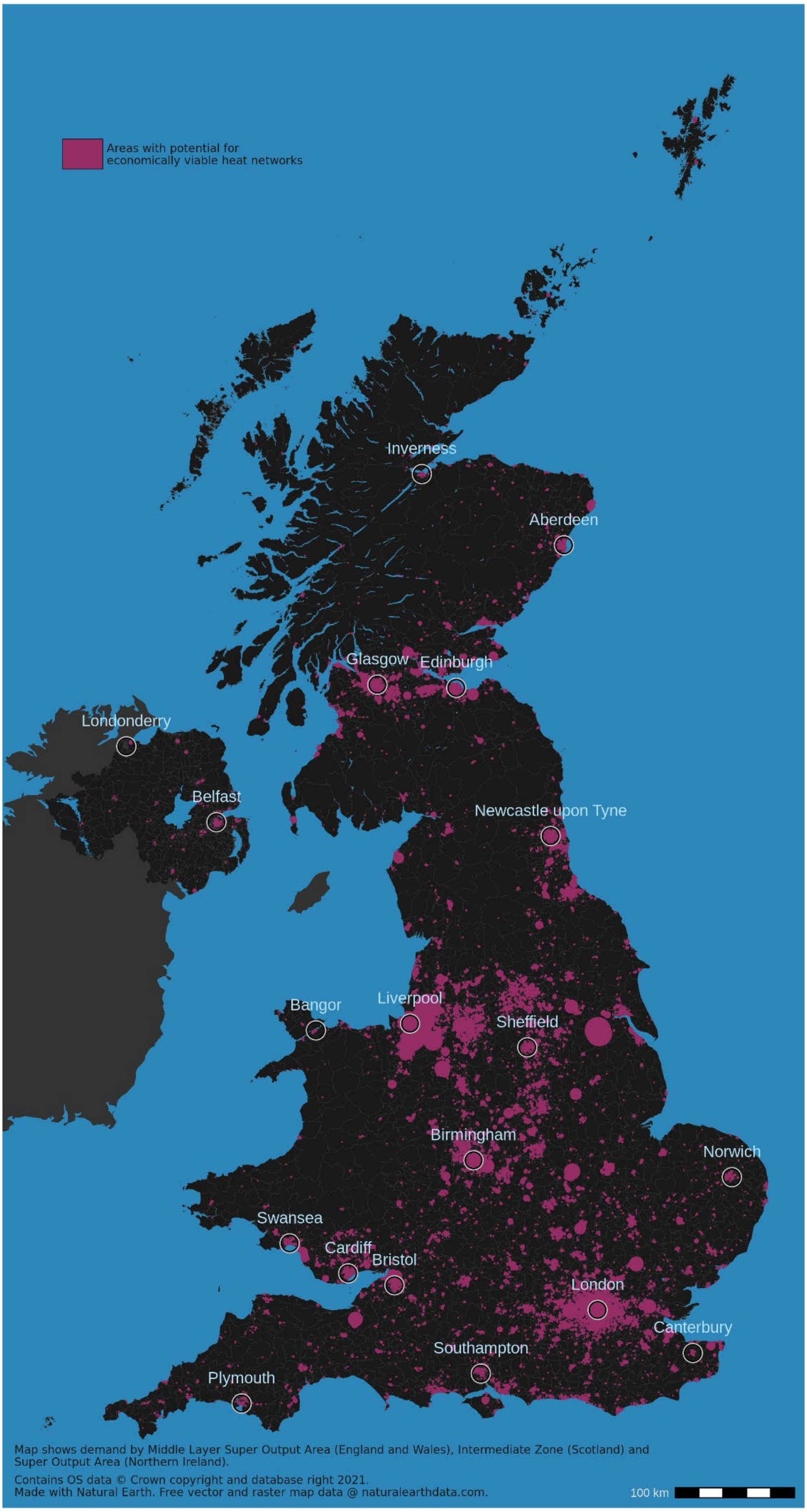


Figure 10: UK areas with potential for economically viable heat networks

3.5 Cost Benefit Analysis against individual building counterfactuals

Using the outputs of the assessment of economic potential for heat networks under the medium scenario based on current heat demand and supply, a UK level analysis was undertaken. This analysis explored how this potential could be realised over time and how heat networks might perform against individual building solutions under different low carbon energy pathways[41]. Under each scenario a constant level of heat supply for heat networks is assumed to come from waste heat sources (including water sources), with the remainder of the economic potential assumed to be supplied by technologies and back-up systems that are specific to the scenario.

The two pathways chosen each have a different energy source dominating. These are:

- electricity, where decarbonisation of the electricity grid is emphasised and the main source of heat is from heat pumps; and
- hydrogen, where the high level assumption is that hydrogen replaces natural gas from 2035.

In addition, a baseline scenario was modelled to reflect a continuation of natural gas as the primary heating fuel.

All scenarios are highly stylised and are based on simplified extremes while a more realistic pathway would likely involve a mix of technologies.

The results are sensitive to input assumptions such as efficiencies and costs. Although these have been based on the best evidence currently held by BEIS, there remains a great deal of uncertainty around them and how they will evolve over time.

It should be noted that the analysis cannot be used to make comparisons between scenarios as each one is supported by specific assumptions around infrastructure costs. For example, in the hydrogen scenario, the costs of distribution and storage have not been explicitly estimated as they are assumed to be common to both the heat network and single building solutions; and similarly, for the electrification scenario, the electrification infrastructure for supply and transmission that would support heat networks is the same as that which would support the single building solutions.

The analysis was done at an aggregated national level based on average values while a more granular analysis would give a more nuanced picture. Thus in some areas a heat

[41] As noted in the methodology (Section 2.2), the CBA undertaken for the purposes of this study was high level and should not be interpreted as an indication of the UK Government's intention for current and future policies. It simply assesses the cost benefit of heat networks compared with individual building solutions in a baseline scenario and two alternative high level future energy pathways. The UK government is undertaking in-depth analysis into potential decarbonisation pathways to achieve net zero the outputs of which are not available at this time. The low carbon pathways chosen here, while being net zero compatible, are therefore illustrative only.

network may have a higher social economic value than single building solutions and in others the opposite, depending on local conditions and variations.

Continuation of gas for heating (baseline)

As indicated in Table 14, against a baseline of gas, carbon emissions from heat supplied via heat networks in the period 2020-2050 would be significantly lower than those from the single building counterfactual (113MtCO2e lower), while discounted social costs would be higher (£52bn higher). The lower carbon emissions would arise due to the use of waste heat and heat pumps in the heat network solution, while the higher costs are due mainly to the higher capital costs of installing a heat network compared with the low capital cost of single building gas boilers using existing gas infrastructure.

The discounted financial costs of the networked solution in contrast are lower than those of the counterfactual (indicated by the positive £4bn in the table); this is due to the inclusion of electricity sales from gas CHP in the networked option. The fuel use is 52TWh/yr higher than the single building heating solution due to the CHP also generating electricity.[42]

Table 14: Comparison of heat network solution against individual building counterfactual where gas continues to be the main fuel source (baseline)[43]. Results are for the UK as a whole.

Comparative emissions 2020-2050	Comparative social NPV	Comparative financial NPV	Comparative average fuel saving
-113 MtCO2e	-£52bn	+£4bn	-52[44] TWh/yr

Figure 11 presents the breakdown of supply by source through the district heat network solution were we to continue using gas as the predominant heating fuel. The breakdown is derived from the results of the economic potential analysis, presented in Table 10, with gas CHP and boilers being used in place of location agnostic energy centres and back-up supply for all heat networks coming from gas boilers.

42 The fuel use to generate electricity from the grid has not been accounted for.
43 Note that the figures presented are the heat network CBA less the individual building CBA. Thus a negative number (e.g. on emissions) indicates that the value for the heat network is less than that for the counterfactual.
44 The net comparative average fuel input is -52 TWh/yr; note that this includes fuel for the gas CHP to generate 30 TWh of electricity.

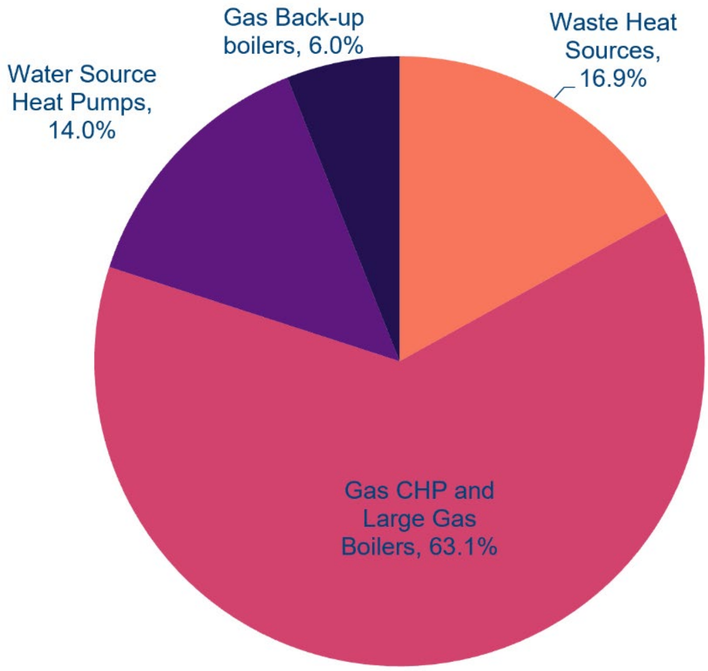


Figure 11: Proportion of heat supply, by source, for the district heat network solution using gas (baseline)

Electricity scenario

As shown in Table 15, in the electricity scenario, heat networks are still the lower carbon solution, but this is marginal compared to the single building solutions. Both approaches use electricity and heat pumps as the primary heating source hence the similarity in emissions, however the heat network option does marginally improve heat pump efficiency through the use of waste heat; this also accounts for the fuel savings of around 2TWh/yr. Note that the CBA assumes heat losses from heat networks remain constant over time[45], while in practice they are likely to reduce as installation works improve and as networks evolve to make use of lower temperatures.

The costs of the heat network solution are lower than those of the individual building solution in both social and financial terms (i.e. social costs are £18bn less and financial costs are £12bn less).

[45] The same figure of 20% is used in the CBA as was used in the spatial model.

Table 15: Comparison of heat network solution against individual building counterfactual where dominant energy pathway is electrification. Results are for the UK as a whole.

Comparative emissions 2020-2050	Comparative social NPV	Comparative financial NPV	Comparative average fuel saving
-3 MtCO2e	+£18bn	+£12bn	+2 TWh/yr

Figure 12 presents the breakdown of supply by source through the district heat network solution in the electricity scenario. The breakdown is derived from the results of the economic potential analysis, presented in Table 10, with large heat pumps boilers being used in place of location agnostic energy centres and back-up supply for all heat networks coming from electric boilers.

In the context of the net zero target for 2050, the assumptions for this scenario are that heat would effectively decarbonise in line with the national grid. In the networked solution, this decarbonisation would be enhanced through the use of waste heat captured from industry and other sources which is deemed to be zero carbon from a heat perspective.

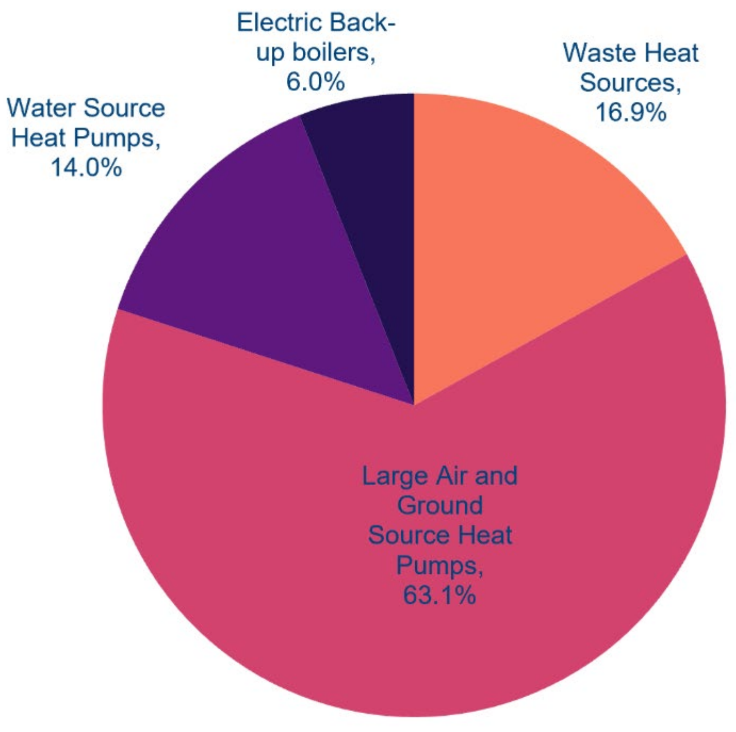


Figure 12: Proportion of heat supply, by source, for the district heat network solution in the electricity scenario

Hydrogen scenario

As shown in Table 16, in the hydrogen scenario, carbon emissions from heat supplied via heat networks are lower than from the single building solutions while both social and financial costs are higher (£20bn and £13bn respectively). The lower carbon emissions largely result from the use of waste heat in the heat network solution, while the higher costs are due mainly due to the low capital cost of single building hydrogen boilers compared with the infrastructure costs of installing a heat network supplied by hydrogen boilers.

As noted elsewhere, the hydrogen scenario is highly simplified and speculative as we await the outputs of detailed research into hydrogen currently being undertaken by BEIS. In particular, the analysis does not take into account any of the potential benefits of utilising hydrogen in centralised energy centres rather than directly within individual homes. For example, considerations such storage and flexibility (e.g. through demand side response) could add financial and social value to a heat network solution that is not captured here. In addition, the study has been done at an aggregated national level, while at a local level more granular analysis may demonstrate that a heat network supplied with hydrogen has higher social economic value than use of single building hydrogen boilers.

Table 16: Comparison of heat network solution against individual building counterfactual where dominant energy pathway is hydrogen (from 2035). Results are for the UK as a whole.

Comparative emissions 2020-2050	Comparative social NPV	Comparative financial NPV	Comparative average fuel saving
-43 MtCO2e	-£20bn	-£13bn	+7 TWh/yr

Figure 13 presents the breakdown of supply through the district heat network solution, by source, in the hydrogen scenario. The breakdown is derived from the results of the economic potential analysis, presented in Table 10, with hydrogen boilers being used in place of location agnostic energy centres and back-up supply for all heat networks coming from hydrogen boilers.

In the context of the net zero target for 2050, the assumptions for this scenario are that heat would decarbonise through the deployment of hydrogen, both to generate electricity and to use directly within heating systems. As for the electricity scenario above, in the networked solution, this decarbonisation would be enhanced through the use of waste heat captured from industry and other sources.

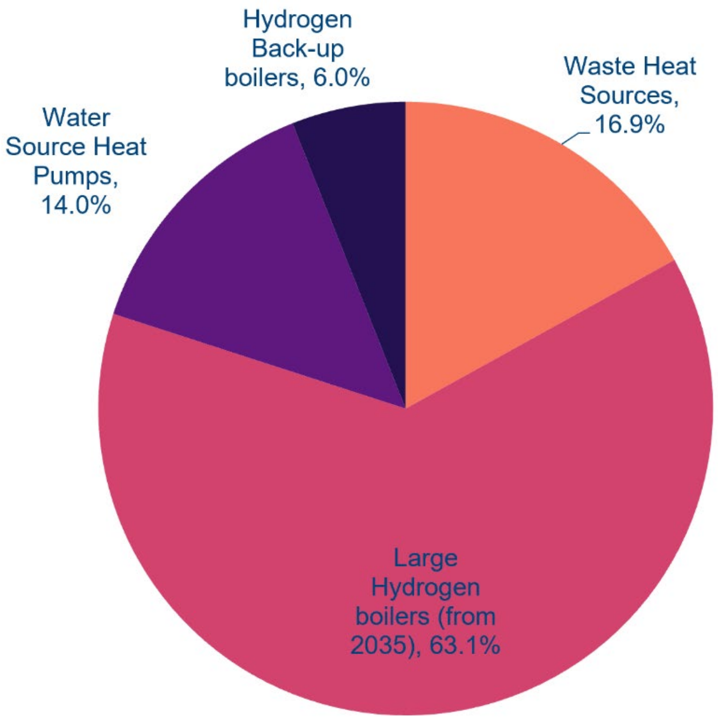


Figure 13: Proportion of heat supply, by source, for the district heat network solution in the hydrogen scenario

Waste heat sources in future scenarios

In the context of this analysis it is important to note that there is uncertainty around how much waste heat could be available from identified sites in the future. Some sources of waste heat used in this study may not be available in the future due to compatibility with the decarbonisation pathways under in the UK Net Zero Strategy; alternatively, there could be more opportunities to recover waste heat via greater levels of strategic development of industrial sites to provide district heating.

Some waste heat in the electric and hydrogen scenarios is currently derived from technologies that use fossil fuels, such as gas-CHP. These sites have been included in the CBA since they may have long-standing functions for processes such as power production or incineration, and therefore carbon offsetting or carbon capture utilisation and storage (CCUS) measures would need to be employed, or the site could be converted to a non-fossil fuel technology. In this report heat recovered from technologies providing a process, such as CHP, is deemed to be zero carbon from a heat perspective, therefore no costs have been assumed for offsetting or CCUS for waste heat from fossil fuel technologies.

Share of renewables used by heat networks

A particular requirement of the EED is to provide the share of renewable energy that would be used to supply the heat networks. These estimations only account for the aerothermal, geothermal and hydrothermal heat energy captured by heat pumps and exclude that captured from waste heat. In addition, these estimates do not capture the element of electricity generated from renewables in the national grid (wind, hydro, solar etc).

While noting that all the CBA scenarios are highly simplified, the analysis suggests the following:

- For the baseline, the share of renewables on the heat networks is estimated at around 10% with the majority of this coming from water source heat pumps. The proportion of gas from renewable sources is assumed to be negligible.
- For the electricity scenario, the share of renewables on the heat networks is around 60%. Here the supply is from water source heat pumps and other heat pumps extracting ambient heat from the air and ground.
- For the hydrogen scenario, the share of renewables on the heat networks is around 10%, with the majority coming from water source heat pumps as the proportion of the hydrogen assumed to be from renewable sources to be negligible.

4 Strategies, policies and measures

The Government is committed to achieving net-zero greenhouse gas emissions by 2050. Meeting this legal commitment will require virtually all heat in buildings to be decarbonised, and heat in industry to be reduced to close to zero carbon emissions. The Heat and Buildings Strategy, which the government intends to publish later this year, will set out the immediate actions we will take for reducing emissions from buildings, including deploying energy efficiency measures and transitioning to low carbon heating.

Heat networks are a crucial aspect of the path towards decarbonising heat. In the right circumstances, they can reduce bills, support local regeneration and can be a cost-effective way of reducing carbon emissions from heating.

This section sets out an overview of the district heating policies and support for high-efficiency cogeneration with Combined Heat and Power units that apply across the UK and Great Britain. It also outlines the district heating policy landscape across Scotland, Wales and Northern Ireland. The policy overview is split by nation due to the varying devolution arrangements in this area between the four nations of the UK.

4.1 Overview of district heating policies

The Climate Change Committee have projected that we need to invest £17.5 billion in heat networks by 2030[46]. Whilst we are still working through the analysis and timing of investment, we anticipate that this scale of investment will need to continue through to 2040 if we are to decarbonise heating in the most cost-effective manner. The UK Government's aim is therefore to create the conditions to accelerate growth towards a self-sustaining heat networks market that does not require further government subsidy by:

- attracting new entrants to the market and enabling market expansion;
- enabling market competition and effective choices by demonstration through data;
- helping industry to develop the right skillset across the supply chain and build capacity;
- and linking up market players to form an independent ecosystem through building connections.

To support this growth, BEIS is investing over half a billion pounds in the Heat Network Transformation Programme. This programmatic approach brings together several heat networks initiatives into a single transformation programme resulting in the following benefits:

[46] Link: https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Buildings.pdf.

- Building on existing Government funding to **deliver more low-carbon heat networks** that are the most cost-effective way to decarbonise areas with high heat demand and are uniquely able to unlock large scale, low or zero carbon sources of heat, such as waste heat from industry and heat from rivers and mines.
- Creating **new and more efficient heat networks using sector regulation and by raising consumer standards,** by assigning statutory powers to heat networks that are equivalent to other utilities.
- Encouraging **investment and jobs growth in the heat networks sector** to grow the market and encourage new entrants. This will help to shore up the existing pipeline and ultimately lead to a self-sustaining market.
- Supporting the rest of the heat networks market to **continue to grow and decarbonise**. This will be combined and supported by increased supply-chain capacity in the UK, improving the efficiency of existing projects as well as supporting market players to tap into and deliver lower-carbon solutions.

The different elements of the Heat Network Transformation Programme are outlined below, and the territorial extent is indicated in the headings.

Heat Networks Delivery Unit (England and Wales)

The Heat Networks Delivery Unit (HNDU) in BEIS was set up in 2013 specifically to support local authorities in England and Wales through the early stages of heat network project development. Its remit has since expanded in response to stakeholder needs to include facilitating the delivery of a wider range of projects, both public and private, including major housing developments, hospitals, and utilising energy from waste heat sources. The HNDU has led progress in sharing of best practice and knowledge across the market by promoting new guidance on technical standards, creation of standardised documentation and facilitating project development.

Local authorities apply for HNDU support through bidding rounds and a total of £23m has been awarded to date. All bids are reviewed by a panel of engineering, financial and commercial experts with significant experience in heat networks development.

Heat Networks Investment Project (England & Wales)

Government are providing a major boost to the market by investing up to £320m through the Heat Networks Investment Project (HNIP) to support the commercialisation and construction of heat networks across England and Wales. Through the provision of capital grants and loans we want to accelerate market growth and reduce carbon emissions. It is expected that the HNIP will leverage in approximately £1bn of private and other investment.[47]

[47] BEIS (2018), Heat Networks Investment Project: https://www.gov.uk/government/publications/heat-network-case-studies

To date, we have already announced up to £165m funding to successful projects within the scheme. Additionally, Triple Point Heat Networks Investment Management, our delivery partner on the HNIP, has a dedicated investor relations team that engages with the investor community and broadens the reach of heat networks investment by raising third party finance for projects applying to the HNIP. The HNIP will deliver a step-change in the heat networks market, improving skills and capability and demonstrating to banks and investors that heat networks are a viable investment proposition, thereby reducing costs and improving returns.

Green Heat Network Fund (England)

The Green Heat Network Fund is intended to be a targeted successor to the HNIP and was announced in the 2020 Budget alongside a package of measures designed to provide funding for low carbon heat for individual buildings.

The proposed Green Heat Network Fund is a capital grant support scheme which will provide targeted financial support for the decarbonisation of existing and development of new low carbon heat networks across England. This support is intended to incentivise the transition of the heat network market to low carbon heat sources, helping the sector overcome the current market barriers and supporting the contributions of heat networks towards the carbon budgets and the 2050 Net Zero target. Funding is expected to open for applications in April 2022 and is anticipated to run for three years to 2025.

With the proposed funding for the fund at £270m as per the outcome of a spending bid in the March 2020 budget, analysis presented alongside the consultation, which ran from November 2020 to January 2021, estimated that the Green Heat Network Fund will support the delivery of 1.15TWh of low carbon heat annually. This means, in comparison to the gas-fired counterfactual, an estimated 10.3Mt of total carbon savings could be achieved by 2050[48].

It should be noted that the scheme is still undergoing development and therefore is subject to funding and scheme design decisions. The estimates presented above therefore reflect the analysis as it was during that point in time, and therefore are also subject to change as the analysis is refined.

Heat network zoning (England with application in Wales to be determined)

BEIS stated in the 2020 consultation ‘Heat Networks: Building a Market Framework’, that heat network zoning would be trialled, and the Energy White Paper included a Government commitment to introduce heat network zoning by 2025. By the term ‘zoning’, we are referring to when a municipal authority uses local heat planning to identify a defined locality for a strategic heat network development. The municipal authority can use supportive policy to drive the network forward, such as:

[48] Link: https://www.gov.uk/government/consultations/green-heat-network-fund-proposals-for-the-scheme-design

- Using existing planning powers to ensure that new buildings in the zone connect to the heat network;
- Incorporating public sector buildings in the zone as anchor loads to incentivise investment;
- Offering discounts on connection fees to encourage early connections to the network.

These measures work most effectively where there is strong commitment and alignment.

The Cities Decarbonisation project, which is being led by the HNDU, has since been launched to look at how the heating systems of six cities across England could be decarbonised and these trials have shown that heat network zoning has the potential to help local authorities meet net zero. Notably, we have also learned from leading authorities about how heat network zoning could overcome practical impediments to development of their city-wide network. BEIS intends to consult on proposals for heat network zoning in 2021.

Market Framework and Technical Standards (Great Britain)

In 2018, the Competition and Markets Authority (CMA) set out recommendations for introducing sector specific heat networks regulation to protect consumers, and this was accepted by the government.

A key role of the market framework is to deliver continued market growth beyond the lifetime of the HNIP.

The government published the ‘Heat Networks: Building a Market Framework’ consultation on 6 February 2020. The consultation period was extended to account for COVID-19 and closed on 1 June 2020. The proposals are designed to protect consumers and grow the heat networks market.

BEIS will use the consultation responses to refine the policy proposals, and will continue to discuss emerging issues with stakeholders. A government response to the consultation will be published in due course and the government has committed to legislating for heat network regulation over this parliament (2019-2024).

Heat Network Skills Programme (geographic scope to be determined)

In 2020, BEIS published the Heat Network Skills Review[49] which explores skills currently required by the heat network sector and the likely existing and future skills shortages and potential skills interventions needed. BEIS is working closely with the Heat Network Industry Council and wider industry to further develop the evidence base and test potential interventions needed. Further details will be announced later this year.

[49] Link: https://www.gov.uk/government/publications/heat-network-skills-review

Heat Network Efficiency Scheme (geographic scope to be determined)

BEIS has recently been carrying out work on improving performance across a number of existing heat networks and communal heating systems. This provides an evidence base for the development of the Heat Network Efficiency Scheme which will part-fund operational performance improvements and carbon emissions reductions in existing systems. Further details will be announced later this year.

Additional policies of relevance to heat network market growth:

Public Sector Decarbonisation Scheme (England)

The Public Sector Decarbonisation Scheme provides grant funding to public sector organisations in England and to reserved public services across the UK for energy efficiency and heat decarbonisation measures, which could include funding a connection to a heat network. It supports the public sector to take a 'whole building' approach when decarbonising their estates.

The scheme is managed by the BEIS delivery body, Salix Finance and applications for Phase 2 of the scheme open on 7 April 2021[50].

The Energy Company Obligation (ECO) (Great Britain)

ECO is a government energy efficiency scheme in Great Britain that is intended to aid in reducing fuel poverty and reducing carbon emissions. Heat networks are currently eligible for ECO (ECO 3) and will continue to be in the next iteration of the scheme launching in 2022 (ECO 4). There is a commitment to extending ECO to 2028.

There are several proposed changes for ECO 4 which could help Heat Networks access ECO funding, and these measures will be consulted upon in due course.

Currently for a heat network to be eligible for any form of ECO funding, the network must be registered with the Heat Trust[51] or another equivalent scheme. This will be continued in ECO 4, as this can be used to incentivise heat networks to uphold a set of standards, this is favourable given the current lack of regulation.

4.2 Policies supporting high-efficiency cogeneration

Beyond the schemes mentioned above, there are various UK policies to support efficient cogeneration with Combined Heat and Power units (CHPs):

[50] More information on the scheme can be found on gov.uk: https://www.gov.uk/government/publications/public-sector-decarbonisation-scheme-psds
[51] Link: https://heattrust.org/

CHP Quality Assurance programme (UK)

The UK Government has introduced several fiscal and financial support mechanisms designed to improve the economics of developing and operating CHP plants certified, either fully or partly, as “Good Quality” by the CHP Quality Assurance programme (CHPQA). CHPQA is consistent with the EU definition of high-efficiency CHP/cogeneration.

CHPQA certification may be used to support a claim for a range of benefits including:

- Exemption from the main rates of climate change levy (CCL) and fuel-oil duty
- Exemption from the carbon price support (CPS) tax
- Exemption from Business Rates of Power Generating Plant and Machinery

Renewable CHP technologies may also qualify for support from the:

- Renewables Obligation
- Contracts for Difference
- Feed-in Tariff

Any support so received is in addition to the commercial value of any heat and power generated.

Overall CHP policy and the benefits associated with CHPQA certification are currently under review. Policy changes will aim to ensure the key benefits of CHP technology (such as flexible dispatch and efficient use of low carbon fuels), are retained and that the CHPQA supports the UK’s transition to net zero emissions by 2050. Further stakeholder engagement is planned for 2021.

There are some variations in treatment across the nations of the UK, which are noted in the following sections.

Climate Change Levy exemption (UK)

The Climate Change Levy (CCL) was introduced by the UK Government in 2001 and is an energy efficiency tax applied throughout the UK on most non-domestic supplies of energy. CHP schemes that are certified as Good Quality are exempt from the main rates of CCL on the fuel they use and electricity they supply to themselves and directly to other consumers (i.e. that which is not supplied via a utility). As announced in both 2016 and 2018 Budgets, CCL rates for electricity and natural gas continue to be rebalanced with rates expected to level up by 2025[52]. Spring Budget 2020 announced main and reduced rates up to 2024[53].

Carbon Price Support exemption (Great Britain)

The Carbon Price Support (CPS) was introduced on 1 April 2013 as a tax on fossil fuels used to generate electricity where the generating station has a capacity of 2 MWe or more. This was introduced by the UK Government in response to the low price of carbon in the European Union Emissions Trading System (EU-ETS). The CPS does not apply in Northern Ireland due to the common electricity market with the Republic of Ireland.

With effect from the 1 April 2015, the Government introduced an exemption from the CPS rates for fuels that are used by a CHP plant to generate Good Quality electricity for use ‘on site’.

Hydrocarbon Oil Duty Relief (UK)

CHP schemes that are certified as “Good Quality CHP” under CHPQA are able to claim a refund of Hydrocarbon Oils duty on oil used to generate electricity on an annual basis.

Business Rating Exemption (Great Britain)

A business rating exemption applies to specified plant and machinery contained within Good Quality CHP schemes that are fully or partially certified as “Good Quality CHP” under CHPQA and have obtained a Secretary of State (CHP) Exemption Certificate. The exemption extends to accessories associated with the power generating plant and machinery but not to heat recovery plant and machinery[33].

In Northern Ireland the business rating exemption is restricted to micro-CHP on or attached to an existing building. Micro-CHP means a maximum electrical capacity of 50kWe and/or a maximum heat capacity of 45kW.

Renewables Obligation (UK)

The Renewables Obligation (RO) was introduced to support electricity generation from renewable sources. For renewable fuelled CHP plants certified under the CHPQA scheme, and accredited for the RO before 31st March 2017, the power output of the plant is eligible for Renewable Obligations Certificates (ROCs). Certified CHP generating stations receive a higher number of ROCs per unit of Good Quality electricity than power only biomass generating stations. In order to maintain

[52] Link: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/508159/reforming_business_energy_efficiency_tax_response_final.pdf

[53] Link: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/872423/Overview_of_Tax_Legislation_and_Rates_2020.pdf

their RO accreditation, such generating stations must continue to be certified under the CHPQA and must report against and meet sustainability criteria.

The RO closed to new generating capacity in March 2017, however CHP plants which were accredited to the RO prior to this date and continue to maintain their accreditation are eligible to continue receiving support for the Good Quality electricity generated for 20 years from the date of their accreditation.

Contracts for Difference (Great Britain)

Since the closure of the Feed-in Tariff and RO to new entrants, Contracts for Difference (CfD) have become the main mechanism for supporting new large-scale low carbon electricity generation. There have been 3 auctions, or allocation rounds, to date[54]. Dedicated biomass and energy from waste schemes are only eligible for CfD support if they are deployed with CHOP. Other fuelled technologies including Advanced Conversion Technologies (ACT), are eligible to apply with or without CHP but they do not need to accredit under the CHPQA quality assurance standard. A recent consultation regarding proposed amendments to the CfD scheme closed at the end of May 2020. Any agreed amendments will be announced in due course[55].

Northern Ireland

Northern Ireland has its own Renewable Heat Incentive (RHI) schemes, both domestic and non-domestic. Northern Ireland makes its own regulations for the schemes and sets its own tariffs and technologies. As a consequence of flaws in its original tariffs, the Non-Domestic Scheme was suspended to new applicants with effect from 29 February 2016. No CHP plants were accredited prior to suspension. The Scheme was the subject of a Public Inquiry which reported in March 2020. A consultation on its future was launched in February 2021.

Feed-in Tariff (Great Britain)

The Feed-in Tariff (FiT) was introduced by the UK Government in order to support renewable electricity generating technologies of up to 5 MWe in capacity. The scheme closed to new applicants in April 2019 with future funding being provided via Contracts for Difference schemes. Schemes pre-dating the April 2019 cut-off are set to run for 20 years from the date of inception.

The Feed-in Tariff does not apply in Northern Ireland and there is no alternative policy in place.

[54] Link: www.gov.uk/government/publications/contracts-for-difference/contract-for-difference
[55] Link: www.gov.uk/government/consultations/contracts-for-difference-cfd-proposed-amendments-to-the-scheme-2020

4.3 Relevant policy measures specific to Scotland

In Scotland there are a number of policies and programmes which support energy efficiency and heat decarbonisation across all sectors and they target a variety of energy efficiency improvements and low carbon heat technologies which provide emissions savings. The Scottish Government is now focussing on support for heat networks which are run from renewable and low carbon sources.

Heat Networks (Scotland) Act 2021

The Climate Change (Emissions Reduction Targets) Act 2019, was passed by the Scottish Parliament in September 2019. The Act requires Scotland to reach net zero greenhouse gas emissions by 2045, with interim reductions of 75% required by 2030, and 90% by 2040.

Scotland has devolved competence over heat and energy efficiency. In March 2020 the Scottish Government introduced the Heat Networks (Scotland) Act 2021 to the Scottish Parliament. On 23 February 2021 the Act was passed unanimously by the Scottish Parliament[56] and received Royal Assent on 30 March 2021[57]. The aim of the Act is to accelerate the deployment of heat networks in Scotland, and in turn, to drive down emissions and tackle fuel poverty. The Act will do this by:

- Creating a new licensing regime to ensure operators are solvent, fit and proper, while driving up standards across the sector;
- Introducing regulatory measures such as heat network consents, heat network zoning and heat network zone permits to ensure that new networks are developed where they will have most-benefit, are tailored to the needs of an area, and can provide greater certainty to attract investment;
- Levelling the playing field with other utilities, by creating new rights for heat network developers and operators helping to reduce the costs of construction;
- Putting in place arrangements to protect heat network users by enabling a transfer of operational rights to occur to ensure continued supply; and
- Introducing heat network supply targets (2.6 TWh by 2027, and 6 TWh by 2030) alongside a heat networks delivery plan setting out how the targets will be delivered.

In bringing forward this legislation, the Scottish Government is also responding to a very clear recommendation given to us by the statutory Competition and Markets Authority (CMA) that regulation of the heat networks market is now needed[58].

[56] Link: bill-as-passed.pdf (parliament.scot)
[57] Link: https://www.legislation.gov.uk/asp/2021/9/introduction/enacted
[58] Link: heat_networks_final_report.pdf (publishing.service.gov.uk)

The Act and its provisions have been developed following extensive consultation with stakeholders and communities and are based on advice and recommendations from an expert working group of stakeholders[59].

The Act is just one part of wider supportive policy for heat networks deployment in Scotland. Further supportive policy is described in the sections below.

Wider Heat Decarbonisation Policy

Heat in Buildings Strategy

In February 2021, the Scottish Government set out its vision for energy efficiency and heat decarbonisation in Scotland in a combined Draft Heat in Buildings Strategy[60], bringing together the Energy Efficient Scotland update and planned Heat Decarbonisation Policy Statement. The previous Energy Efficient Scotland route map, published in 2018, aligned with Committee on Climate Change advice and identified buildings not using mains gas and district heating in appropriate areas, as low regret options for the decarbonisation of heat in Scotland. This new Draft Strategy identifies heat networks as a strategically important technology and sets out the near term actions, medium term milestones and long term vision necessary to ensure that a significant proportion of Scottish homes are using renewable or zero emissions heating systems by 2030, to meet the targets set by the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019.

The Draft Heat In Building Strategy set out that heat networks will play an important role in the heat transition. The Heat Networks (Scotland) Act 2021 will build confidence among consumers and attract investment for development. A new regulatory regime for heat networks will be operational by the end of 2023. In order to support the delivery of Scotland's climate change targets, new heat networks will need to be powered using renewables or other low or zero emissions sources of heat. From 2023 the Scottish Government will only consent renewable and low or zero emissions heat networks.

As outlined in the draft Strategy, the Scottish Government will be redoubling its efforts to deploy heat networks in Scotland. It will consult later this year on the use of powers under the Climate Change (Scotland) Act 2009 and the Non-Domestic Rates (Scotland) Act 2020 so that heat pumps, and other technologies, have a means through which to distribute their renewable heat at a large-scale.

2024 New Build Heat Standard

The 2020-21 Programme for Government set out a commitment for the Scottish Government to work with the building industry to develop regulations which would ensure that new buildings, consented from 2024, use heating systems which produce zero direct greenhouse gas emissions at the point of use. As these regulations are being developed, the Scottish Government is seeking views on the role that heat networks could play in

[59] Link: Heat Networks Regulation Working Group: recommendations - gov.scot (www.gov.scot)
[60] Link: Heat in buildings strategy - achieving net zero emissions: consultation - gov.scot (www.gov.scot)

providing zero emissions heating to new builds from 2024 onwards, while also welcoming evidence on ways in which other technologies can deliver zero direct emissions from heating. The Scottish Government's first, initial Scoping Consultation on the New Build Heat Standard[61] is now closed and it is currently analysing the responses received. Stakeholders will have a further opportunity to input into the standard in due course, as the Scottish Government now moves to develop it in more detail.

Heat Mapping

In order for local authorities and other stakeholders to gain a greater understanding of the heat demand and supply needs across Scotland the Scottish Government developed the Scotland Heat Map with data provided by Scottish public sector organisations. Data sets have been provided to all Scottish local authorities and a web version of the heat map is available which allows the user to produce a report which can be downloaded for a specific geographic area either set by the user or using standard geographies such as local authority, settlement or data zone.

The Scotland Heat Map[62] brings together a number of data sources available to the Scottish Government in order to provide the most reliable estimates of heat demand at a building and area level, and incorporates a number of additional layers to provide a consistent foundation for informing energy developments by both public and private bodies. This can be further enhanced through local development of the map.

The 2020 update of the Scotland Heat Map focuses on updating and improving heat demand estimates which is the core of the heat map. In future it is intended that heat demand estimates will be updated and released annually, while other layers of data that make up the heat map resource will be updated on a roughly three year cycle, though only where it is reasonable to expect considerable change (for example geological data is unlikely to be updated with such frequency). New data on heat networks is also included in the latest release.

Local Heat and Energy Efficiency Strategies

Local Heat and Energy Efficiency Strategies (LHEES) will set out the long-term strategic plan for each local authority area for heat decarbonisation and energy efficiency, tailored to local circumstances. This will include, where appropriate, the identification of heat network zones, which will highlight areas where heat networks are particularly suitable and are the optimal solution to decarbonising the heat supply to buildings. LHEES will also support local authorities to undertake duties set out in the Heat Networks (Scotland) Act 2021 to review heat network zoning in their area.

LHEES has been piloted with all 32 Scottish local authorities and the final phase of pilots finished at the end of March 2021. The Scottish Government have consulted on placing a statutory duty on local authorities to produce LHEES, and in the Programme for

[61] Link: New Build Heat Standard: scoping consultation - Scottish Government - Citizen Space
[62] Link: Scotland Heat Mapping information

Government 2019-2020 committed to work with local government to put the strategies on a statutory footing and bring forward the timescale for implementation. In the draft Heat in Buildings Strategy, the Scottish Government set out the ambition to have LHEES in place across all local authorities by the end of 2023.

The planning system

Current Scottish Planning Policy (SPP) strongly supports the development and implementation of heat networks. In particular the SPP states that local development plans should:

- Support new build developments, infrastructure or retrofit projects which deliver energy efficiency and the recovery of energy that would otherwise be wasted both in the specific development and surrounding area.
- Use heat mapping to identify the potential for co-locating developments with a high heat demand with sources of heat supply. Heat supply sources include harvestable woodlands, sawmills producing biomass, biogas production sites and developments producing unused excess heat, as well as geothermal systems, heat recoverable from mine waters, aquifers, other bodies of water and heat storage systems. Heat demand sites for particular consideration include high density developments, communities off the gas grid, fuel poor areas and anchor developments such as hospitals, schools, leisure centres and heat intensive industry.
- Support the development of heat networks in as many locations as possible, even where they are initially reliant on carbon-based fuels if there is potential to convert them to run on renewable or low carbon sources of heat in the future. Local development plans should identify where heat networks, heat storage and energy centres exist or would be appropriate and include policies to support their implementation. Policies should support safeguarding of pipe-runs within developments for later connection and pipework to the curtilage of development.
- Policies should also give consideration to the provision of energy centres within new development. Where a district network exists, or is planned, or in areas identified as appropriate for district heating, policies may include a requirement for new development to include infrastructure for connection, providing the option to use heat from the network.

The Scottish Government is currently reviewing SPP which will for the first time be incorporated into the National Planning Framework (NPF). Work has commenced on NPF (NPF4) and a final version is expected to be in place in 2022. In November 2020, the NPF4 Position Statement[63] signalled that potential policy changes that may be needed in NPF4 include encouraging new buildings to connect to existing heat networks where feasible. A draft NPF4 will be published for consultation in Autumn 2021.

[63] Link: Fourth National Planning Framework: position statement

Heat Network Partnership for Scotland

The Heat Network Partnership (HNP) has played a key part for many years in the development of heat networks in Scotland and aims to increase the uptake of low carbon heat technologies in Scotland. The Scottish Government will repurpose the Heat Network Partnership in 2021 with a refreshed membership and remit focussed on pipeline development and subsequent delivery.

Financial Support

The Scottish Government committed to implementation of the Heat Networks (Scotland) Act 2021 by the end of 2023. Meanwhile it will continue to offer financial support to building owners to move to heat networks, and other forms of low carbon heating.

Business and Industry

Energy efficiency and heat decarbonisation is supported in the SME sector by Scottish Government annual investment into the Energy Efficiency Business Support Service (EEBS) (formerly RES) and the SME loan scheme. The EEBS offers information, advice and support to SMEs, and third sector organisations to implement energy efficiency and heat decarbonisation measures. Since April 2015 to the end of February 2021, EEBS has supported over 5,700 unique organisations. This support has resulted in lifetime reduced energy use of 787 GWh, lifetime energy savings costs of £78.7 million and total lifetime cost savings of £88.9 million.

EEBS is focusing efforts on Scotland's nine most energy and heat intensive sectors to develop a programme of advice and support for decarbonisation, energy efficiency and heat recovery. In October 2020, a new Cashback grant was launched through the SME Loan Scheme to stimulate the uptake of Energy Efficiency and Renewable Heat measures in non-domestic properties. £4.0 million of additional funding was made available in 2020/21 for the Cashback grant on a first-come-first-served basis to support the non-domestic sector as part of wider efforts to support a green recovery. The cashback grant budget for the financial year 2021-22 has been increased to £4.75 million.

Public Sector

The Scottish Government will establish and deliver the Green Public Sector Estates Programme in 2021, providing a variety of support mechanisms including capital grants, loans and other revenue funding to further facilitate heat decarbonisation across the public sector.

As outlined in the draft Heat in Buildings Strategy published for consultation in February 2021, the Scottish Government will set up a Green Heat Finance Taskforce in early 2021. The Green Heat Finance Taskforce will provide advice and recommendations to Scottish Government on potential new financing models and routes to market for low and zero carbon heat.

Interest free loan funding from Scottish Government is available to the public sector in Scotland through Salix Finance to improve the energy efficiency of existing buildings with over £50 million invested since 2008.

The Scottish Government launched the Non Domestic Public Sector Energy Efficiency (NDEE) Framework in 2016. This framework was designed to support Public and Third Sector organisations procure Energy Efficiency retrofit work. The economies of scale and standardised approach offered by the pan public sector framework being attractive to both the public sector and private sector, offering both better solutions and better value for money.

Thirty two projects are currently in progress or have completed using the Framework across Local Authority, University, College and NHS estates. Projects at tender stage and beyond have, to date, committed circa. £27.5m towards energy conservation measures providing 'guaranteed' annual energy cost savings of circa £3.3 million.

Building on the success of the initial framework, a further procurement exercise in 2020 resulted in the creation of a Scottish Government NDEE over £1 Million Projects Framework and NDEE sub £1 Million Projects Framework.

District Heating Loan Fund

The District Heating Loan Fund (DHLF) offers low interest unsecured loans for both district heating low carbon and renewable technology projects in Scotland. The loans are designed to help overcome a range of infrastructural issues and the costs of developing these projects. The loans are repaid over a period of up to 15 years at, for low risk projects, an interest rate of 3.5%. The scheme is open to local authorities, registered social landlords, small and medium sized enterprises and energy services companies (ESCOs) with fewer than 250 employees. Since 2011, DHLF has provided £18.5m to 53 low carbon/renewable heat projects.

Cross cutting schemes

The following schemes are not specifically targeted at district heating but may support it.

The Low Carbon Infrastructure Transition Programme (LCITP), supported by the European Structural Funds, was launched in March 2015. Since 2015, the LCITP has provided support to large scale low carbon energy demonstrator projects. The LCITP has made expertise and financial support available for project development and capital investment in order to help projects secure investment in innovative low carbon infrastructure projects with potential for replication while helping Scotland to meet its climate change targets. Since its launch, LCITP has awarded over £59 million of financial support to low carbon demonstration projects across Scotland which encourage replication and wider uptake of innovative renewable technology.

The LCITP is due to be replaced in Autumn 2021. A Call for Evidence[64] was launched in February 2021, seeking views on the support and interventions necessary to accelerate future deployment of low and zero carbon heat infrastructure projects in Scotland.

The latest Community and Renewable Energy Scheme (CARES) contract commenced on 1 April 2021 and will run until 31 March 2025. It will continue to support the delivery of our community and locally owned energy target of 2GW by 2030, build upon our shared ownership ambition, and support our net zero emissions goal. Greater focus will be given to decarbonisation, particularly how we heat our buildings, as a key driver for community led action within the next iteration of CARES.

Since its inception CARES has supported over 600 community and locally owned energy projects across Scotland, offering over £54 million in funding support.

Non-domestic Rates Relief

The Scottish Government has introduced a District Heating Relief which provides a discount of up to 50% on rates bill for premises used for District Heating. This relief is unique to Scotland and is not offered anywhere else in the UK. And to provide certainty, the Scottish Government laid regulations this year which will extend that relief out to 2032.

Further regulations that were laid see a 90% relief for renewable heat networks – as well as those running from waste heat or energy from waste – which began from 1 April 2021, incentivising clean heat networks prior to the implementation of the Heat Networks (Scotland) Act 2021.

4.4 Relevant policy measures specific to Wales

In 2019 the Senedd was first national Parliament in the world to declare a climate emergency. On 9 February 2021 a suite of legislation was laid in the Senedd which includes statutory target in Wales for net zero greenhouse gas emissions in 2050 and significant increases in the 2030 and 2040 targets. This reflects the recommendations of the Climate Change Committee (CCC) last December, which recommended the Welsh Government should increase its ambition from the previous 95% target.

The Welsh Government's Low Carbon Delivery Plan (LCDP), Prosperity for All – A Low Carbon Wales, was published in 2019 and sets the foundations for Wales to transition to a low carbon nation. The plan describes the following policies and proposals which relate to decarbonising heat:

- **Policy 21** - Provide continued support to identify, develop and invest in district heat systems;

[64] Link: Low Carbon Infrastructure Transition Programme (LCITP): call for evidence

- **Policy 57** - Energy Efficiency Scheme (UK Government policy) - including the use of industrial waste heat;
- **Policy 59** - Industrial heat recovery - Consider waste heat recovery and use as part of the approach to heat policy;
- **Proposal 5** - Public Sector buildings should be supplied with renewable electricity by 2020, or as soon as contractually able and, where practicably possible, are supplied with low carbon heat by 2030;
- **Proposal 10** - Scoping out the challenges and opportunities around low carbon heat;
- **Proposal 11** - Increasing the use of Waste Heat and low carbon heat.

The plan also outlines the leadership role for the public sector in decarbonising of heat. Welsh Government has an ambition for the public sector in Wales to be carbon neutral by 2030. The Welsh Government Energy Service (WGES) is supporting the delivery of this ambition. The WGES is a four year programme (2018-2022) funded by the Welsh Government, providing free support to public sector organisations and community groups to help them progress their energy efficiency and renewable energy projects. The programme supports the Welsh Government's ambition for a carbon neutral public sector and 1GW of locally owned renewable energy in Wales by 2030. Since the energy service was launched in July 2018, it has supported 12 heat network and renewable heat projects in Wales. Sitting alongside the WGES, is the Wales Funding Programme, which is facilitated through Salix Finance. The programme offers interest free loans to public sector organisations, to develop energy efficiency and renewable energy projects. Many of these projects are developed with the WGES, but applicants are also able to secure funding independently. To date, the Welsh Government has invested in excess of £100m through the Wales Funding Programme.

The Welsh Government's second statutory decarbonisation plan, Low Carbon Delivery Plan 2 (LCDP2), is scheduled to be published in the autumn of 2021. It will describe the policies and approach we intend to take on the path to meeting net zero, and to meet Wales' second Carbon Budget (2021–25) and propose policies and actions for the longer term.

The Welsh Government considers the delivery of heat decarbonisation to be a local issue and maintains the need for Wales to have devolved powers in this area, as is the case in Scotland. In order that plans for heat decarbonisation are properly informed and deliverable, Welsh Government considers they must be developed with a focus on place.

Wales is developing a nested approach to spatial planning for heat decarbonisation. At the national level, Future Wales, the Welsh Government's National Development Framework, sets the direction for development in Wales to 2040. Future Wales assesses the potential for identifying spatial areas where heat networks should be considered. The final version of Future Wales was published in February 2021. Its Policy 16 states that within Priority

Areas for District Heat Networks, planning authorities should identify opportunities for District Heat Networks and plan positively for their implementation.

Large scale mixed-use development should, where feasible, have a heat network with a renewable / low carbon or waste heat energy source. Planning applications for such development should prepare an Energy Masterplan to establish whether a heat network is the most effective energy supply option and, for feasible projects, a plan for its implementation.

At the regional level, Welsh Government has co-developed energy strategies with each region of Wales. These strategies set out the scale of change required to meet net zero ambitions, and consider heat, transport and power decarbonisation.

A further level of detail is needed in order to assess the options at a street by street level. Welsh Government is working in partnership with Newport and Conwy Councils to develop local energy plans, with plans to extend the work to other places later this year. These will identify the preferred combination of technological and system changes needed to decarbonise heat and local transport and realise opportunities for local renewable energy production. Energy planning will also help identify areas for which district heat networks are viable solutions to deliver low carbon heat.

Welsh Government's Innovative Housing Programme (IHP) includes housing developments which aim to build low carbon homes and has brought forward exciting developments such as Sero Homes' approach of active buildings. The Optimised Retrofit (ORP) Programme is doing similar for existing homes and there may be potential to incentivise heat network schemes from commercial or public developers through both the ORP and IHP programmes. Similarly for future iterations of the Warm Homes Programme heat networks could unlock potential for reuse of low carbon and waste heat potentially benefiting fuel poverty homes.

A number of priority areas for district heat networks in Wales have been identified by the Welsh Government, including Cardiff and Bridgend. These are being developed with support from WGES, the Heat Network Development Unit, and funding from the Heat Network Investment Project (HNIP).

The Welsh Government has worked closely with Cardiff Council since 2017 to support the development and funding of the Cardiff Bay heat network project, including an £8.6m interest-free loan. Cardiff Council has also received a £6.6 million HNIP construction grant for the Cardiff Heat Network.

Following a successful HNIP application, Bridgend County Council has received a £1.2 million commercialisation and construction grant for a heat network. The Bridgend Heat Network has also been supported by WGES and the Energy Systems Catapult, which is helping to develop Bridgend Council's smart systems and heat strategy.

In keeping with Wales' Zero Waste Strategy, Welsh Government has put in place a moratorium on new large-scale energy from waste plants. The moratorium will cover new energy from waste plants with capacity of 10MW or more and came into effect immediately. The moratorium also means small-scale plants, of less than 10MW, will only be allowed if applicants can show there is a need for such facilities in the regions in which they are planned. Small plants would also need to supply heat, and – where possible – be carbon-capture and storage enabled, or ready.

4.5 Relevant policy measures specific to Northern Ireland

Northern Ireland is currently developing a new Energy Strategy, which will include policy to support the achievement of the UK Government's legislated target of net-zero carbon by 2050. The new Energy Strategy will be published by the end of 2021.

As part of an overall approach to decarbonising heat in Northern Ireland, decentralised solutions built around heat networks will be considered. This includes understanding the implications of heat networks more broadly for Northern Ireland's legislative and regulatory frameworks, and consideration of conducting trials in relation to geothermal, waste and biomass heat networks.

List of Abbreviations

Abbreviation	Definition
ACT	Advanced Conversion Technology
BEES	Building Energy Efficiency Survey
BMBT	Biodrying Mechanical & Biological Treatment
CBA	Cost Benefit Analysis
CCL	Climate change levy
CHP	Combined heat and power
CHPQA	Combined heat and power Quality Assurance
CIBSE	Chartered Institute of Building Services Engineers
COP	Coefficiency of Performance
CPS	Carbon price support
DHC	District heating and cooling
DHW	Domestic Hot Water
DisCo	Distribution Company
DUKES	Digest of UK Energy Statistics
ECUK	Energy Consumption in the UK
EEP	Energy and Emissions Projections
EfW	Energy from Waste
GenCo	Generation Company
GHNF	Green Heat Networks Fund
GW / GWh	Gigawatt / Gigawatt hour
HNDU	Heat Networks Delivery Unit
HNIP	Heat Networks Investment Project

Abbreviation	Definition
HNTP	Heat Networks Transformation Programme
IZ	Intermediate Zone
kW / kWh	Kilowatt / kilowatt hour
LCITP	Low Carbon Infrastructure Transition Programme
LCOC	Levelised cost of capture
LCOG	Levelised cost of generation
LFMBT	Landfill Mechanical & Biological Treatment
LHD	Linear Heat Density
LSOA	Lower Layer Super Output Area
MSOA	Middle Layer Super Output Area
MW	/ MWh Megawatt / Megawatt hour
NCA	National Comprehensive Assessment
NEED	National Energy Efficiency Data-framework
NI	Northern Ireland
OSABP	Ordnance Survey Address Base Premium
OSABPI	Ordnance Survey Address Base Premium Islands
OSMM	Ordnance Survey Mastermap
OSNIF	Ordnance Survey Northern Ireland Fusion
PipeCo	Pipe Company
RHI	Renewable Heat Incentive
SOA	Super Output Area
TW / TWh	Terawatt / Terawatt hour
VOA	Valuation Office Agency

Appendices

Appendix 1: Overview of Current Heating and Cooling in the UK

This Appendix presents statistical tables describing the current state of heating and cooling in the UK using latest available data from 2019.

The following is a list of tables:

- Table 17: Annual heating demand by end use and fuel source, UK (TWh)[1,2]
- Table 18: Annual cooling demand by end use and fuel source, UK (TWh)[1,2]
- Table 19: Annual supply of heat by technology, UK, TWh
- Table 20: Renewable sources used to indicate progress of the UK under the Renewable Energy Directive (RED)
- Table 21: Fuel used by existing heat networks in the UK (TWh)[1]
- Table 22: Identification of sites that generate waste heat, UK, TWh

Table 17: Annual heating demand by end use and fuel source, UK (TWh)[1,2]

		Gas	Oil	Solid fuel	Electricity	Heat sold	Bioenergy & Waste	Total
Residential	Space heating	198	20	3	18	3	22	264
	Water heating	59	5	0	5	-	1	70
	Cooking[3]	7	-	-	6	-	-	13
	Residential total	265	25	3	28	3	23	347
Service	Space heating	60	16	-	9	3	8	96
	Water heating	8	3	-	2	0	1	14
	Cooking[3]	7	9	-	9	0	-	25
	Service total	75	28	-	19	3	9	135
Industry	Space heating	10	1	1	7	-	-	19
	High temperature process	18	2	4	9	-	-	33
	Low temperature process	35	3	2	16	-	-	55
	Drying/separation	10	1	1	6	-	-	18
	Unknown (heat)	-	-	-	-	8	14	21
	Industry total	73	6	8	38	8	14	146
Total	Space and water heating only	336	45	4	40	6	32	463
	All heating excluding cooking	398	50	11	71	14	46	590
	All heating excluding cooking and high temperature process	381	48	7	62	14	46	557
	All heating	413	59	11	85	14	46	628

'-' represents a null value

1) Information presented in this table has been derived from estimates of consumption of fuel used for heating that is presented in Energy Consumption UK (Table U2, 2019): https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

2) To estimate heating demand from fuel consumption, estimates of efficiency of boilers have been used.

3) To estimate useful heating for cooking, the efficiency of cooking appliance in turning fuel into heat has been assumed to be 100%.

Table 18: Annual cooling demand by end use and fuel source, UK (TWh)[1,2]

		Gas	Oil	Solid fuel	Electricity	Heat sold	Bioenergy & Waste	Total
Residential[3]	Cooling and ventilation	#	#	#	#	#	#	#
Service	Cooling and ventilation	0	1	-	27	0	-	28
Industry	Refrigeration	-	-	-	11	-	-	11
Total	All cooling	0	1	-	38	0	-	39

'-' represents a null value

'#' has been used where data is not available.

1) Information presented in this table has been derived from estimates of consumption of fuel used for heating that is presented in Energy Consumption UK (Table U2, 2019): https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

2) To estimate cooling demand from fuel consumption, estimates of efficiency of cooling systems have been used.

3) There is not a process for estimated residential cooling from consumption of fuels, therefore domestic cooling has been omitted.

Table 17: Annual supply of heat by technology, UK, TWh

Heating technology	Total	Residential	Service	Industry[1,2]
Heat only boilers	#	333	96	#
Combined Heat and Power (CHP)[3]	42	-	4	38
Heat Pumps[4]	12	1	10	0
Cooking appliances	38	13	25	-
Other[5]	#	0	0	#
Total heating[6]	**628**	**347**	**135**	**146**
Of which is off-site supply[7]	**10**	**#**	**#**	**#**

'-' represents a null value

'#' has been used where data is not available.

1) A proportion of CHP supply is supplied to a sector named 'other', therefore, it has been grouped with 'industry'.

2) Some forms of industrial process heat will use 'Other' forms of heating technology. The technology split between 'Heat only boilers' and 'Other' heating systems is not known.

3) Supply from CHP is taken from CHP generation figures (Table 7.8, 2019) here: https://www.gov.uk/government/statistics/combined-heat-and-power-chapter-7-digest-of-united-kingdom-energy-statistics-dukes

4) Supply from heat pumps is taken from heat pump generation figures (Table 6.6, 2019) here: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

5) Includes technologies such as solar thermal which make up a small proportion of total heating supply. Also includes technologies used for industrial processes. We are unable to quantify the split between 'Heat only boilers' and 'Other' technologies used for industrial process heat, therefore this information has been omitted.

6) Total heating supplied by technologies has been assumed to match heating demand tables.

7) Information on off-site heat supply has been sourced from the heat networks experimental statistics: https://www.gov.uk/government/publications/energy-trends-march-2018-special-feature-article-experimental-statistics-on-heat-networks. A sectoral breakdown of heat supply has not been possible to produce due to data quality issues.

Table 20: Renewable sources used to indicate progress of the UK under the Renewable Energy Directive (RED)

Fuel source	Annual generation (TWh)
Renewables used for heating and cooling	52

1) Reported as NCV in Digest UK Energy Statistics (DUKES, Table 6.7, 2019): https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes

Table 21: Fuel used by existing heat networks in the UK (TWh)[1]

Fuel source	Annual supply (TWh)
Bioenergy & Waste	0.3
Coal & Solid Fuel	0.0
Electricity	0.7
Natural Gas	12.6
Oil	0.2
Other / Unknown	0.1
Total[2]	**14.0**
Of which is district heat networks	10.1

1) Information sourced from the heat networks experimental statistics (Tables 4 and 5, 2018): https://www.gov.uk/government/publications/energy-trends-march-2018-special-feature-article-experimental-statistics-on-heat-networks. Tables provide heat supplied to heat networks by primary fuel only. Some secondary fuel consumption may have erroneously been allocated to the wrong category, where the secondary fuel is different to the primary fuel.
2) Includes district and communal heat networks in the UK.

Table 18: Identification of sites that generate waste heat, UK, TWh

Type of installation	**Annual heat generation (TWh)**
Thermal power[1]	168.5
Of which uses renewable fuel	*26.9*
Combined Heat and Power (CHP)[2]	41.7
Of which uses renewable fuel	*0.1*
Incineration[3]	40.0
Waste heat from industrial sites[4]	61.1
Total	311.3

1) Includes all UK Major Power Producers (MPP) that use biomass, natural gas, nuclear and waste as fuel and are not peaking plants. Excludes power stations that produce Combined Heat and Power (CHP). Annual heat generation is estimated using information on electrical capacity of each site and assumptions to retrofit to CHP.
2) Includes actual generation from CHP plants registered under the Combine Heat and Power Quality Assurance (CHPQA) scheme. Data taken from the 2019 edition of the CHP chapter in DUKES: https://www.gov.uk/government/statistics/combined-heat-and-power-chapter-7-digest-of-united-kingdom-energy-statistics-dukes
3) Includes incineration sites that are not MPP or CHP. Annual heat generation has been estimated from permitted tonnage of waste incineration per year and assumptions have been used to retrofit to CHP.
4) Includes estimated annual waste heat from cement, chemicals, cold store, crematoria, data centres, food and drink, iron and steel, lime, minerals, mine water treatment, paper and pulp, substations, supermarket, water treatment and underground rail; from BEIS and Scottish Government Waste Heat Research.

Appendix 2: Heat maps by nation

This appendix shows mapped results outputs for England, Northern Ireland, Scotland, and Wales. Also shown are maps of existing and planned networks.

The following is a list of figures:

England

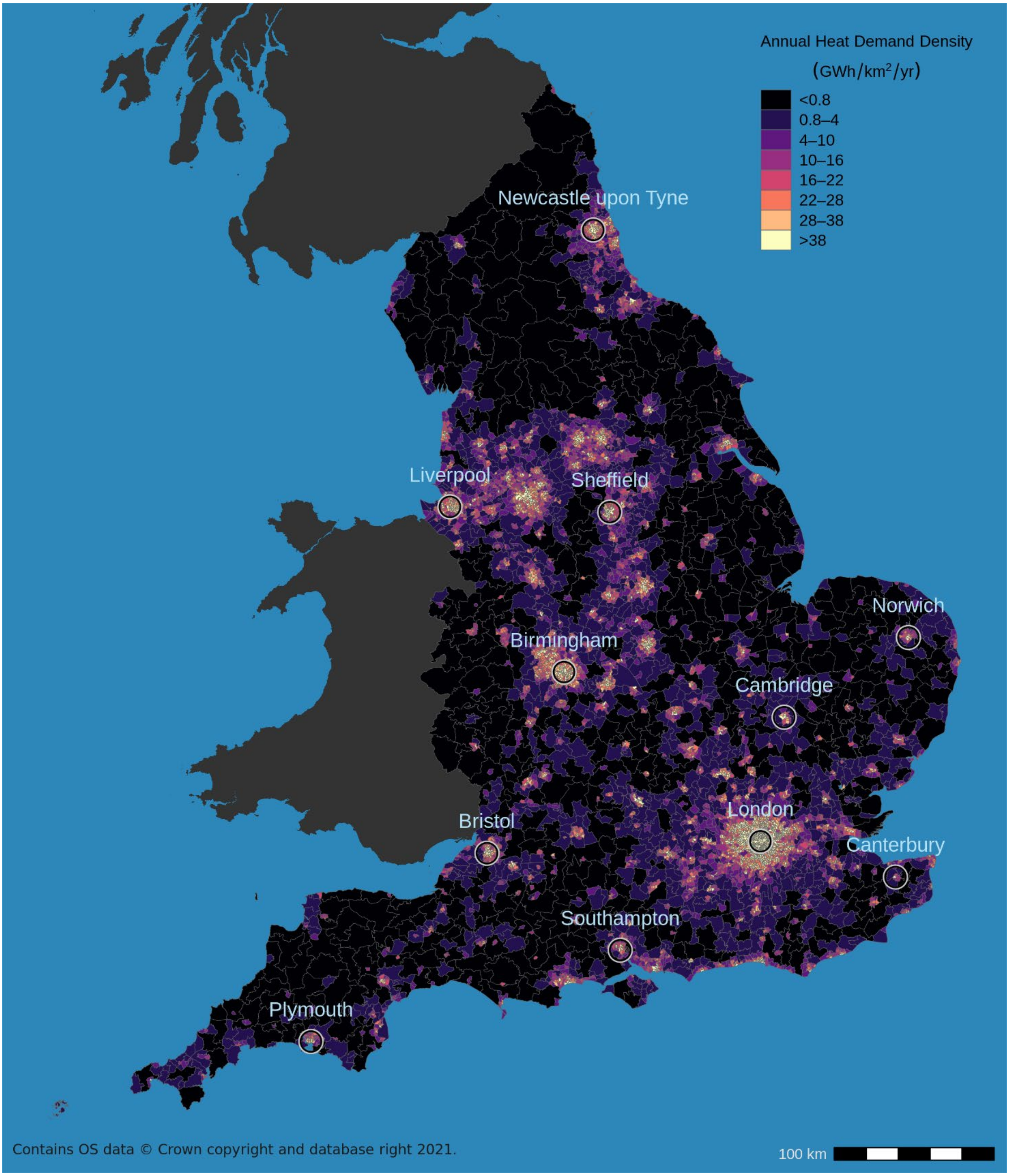


Figure 14: England heat demand density

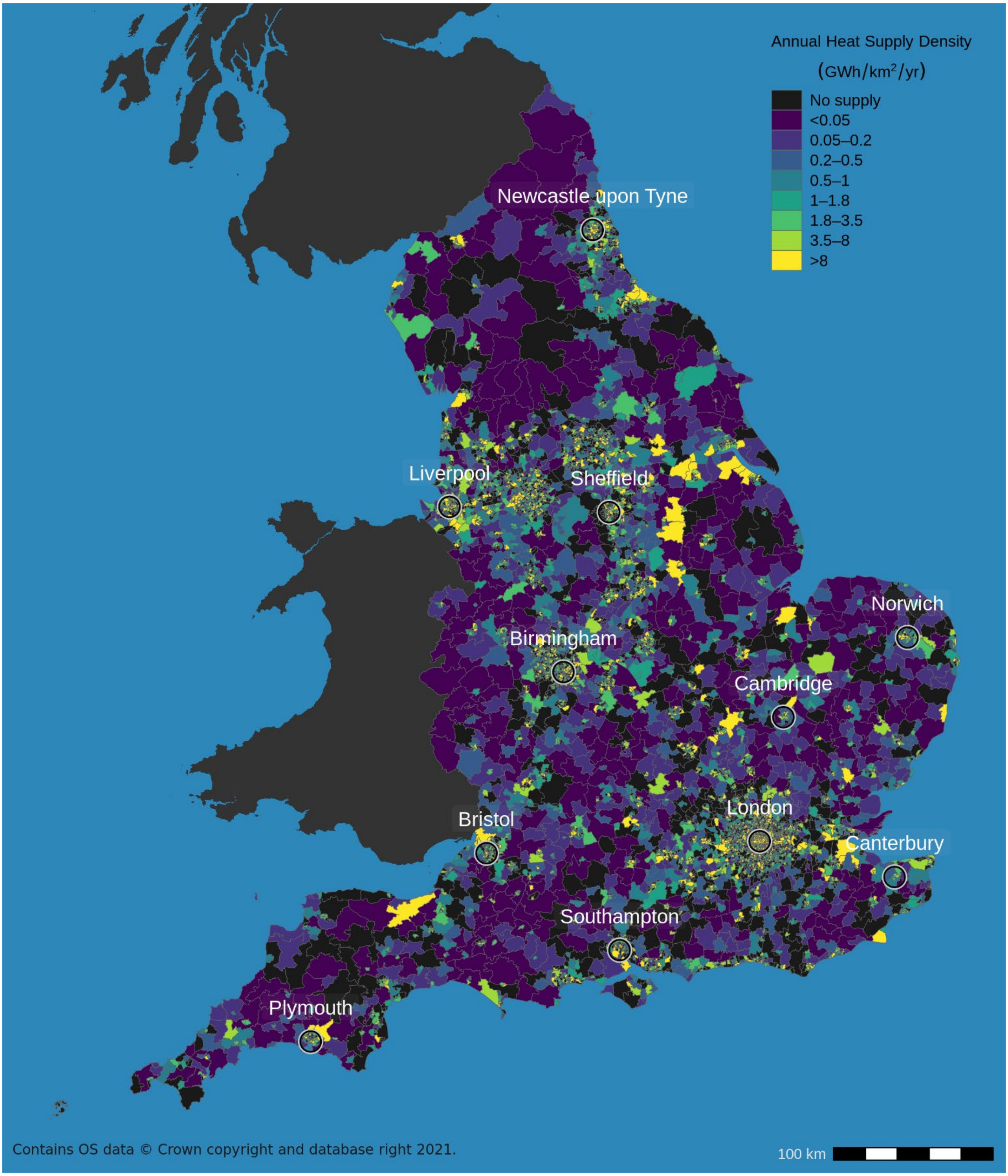


Figure 15: England heat supply density

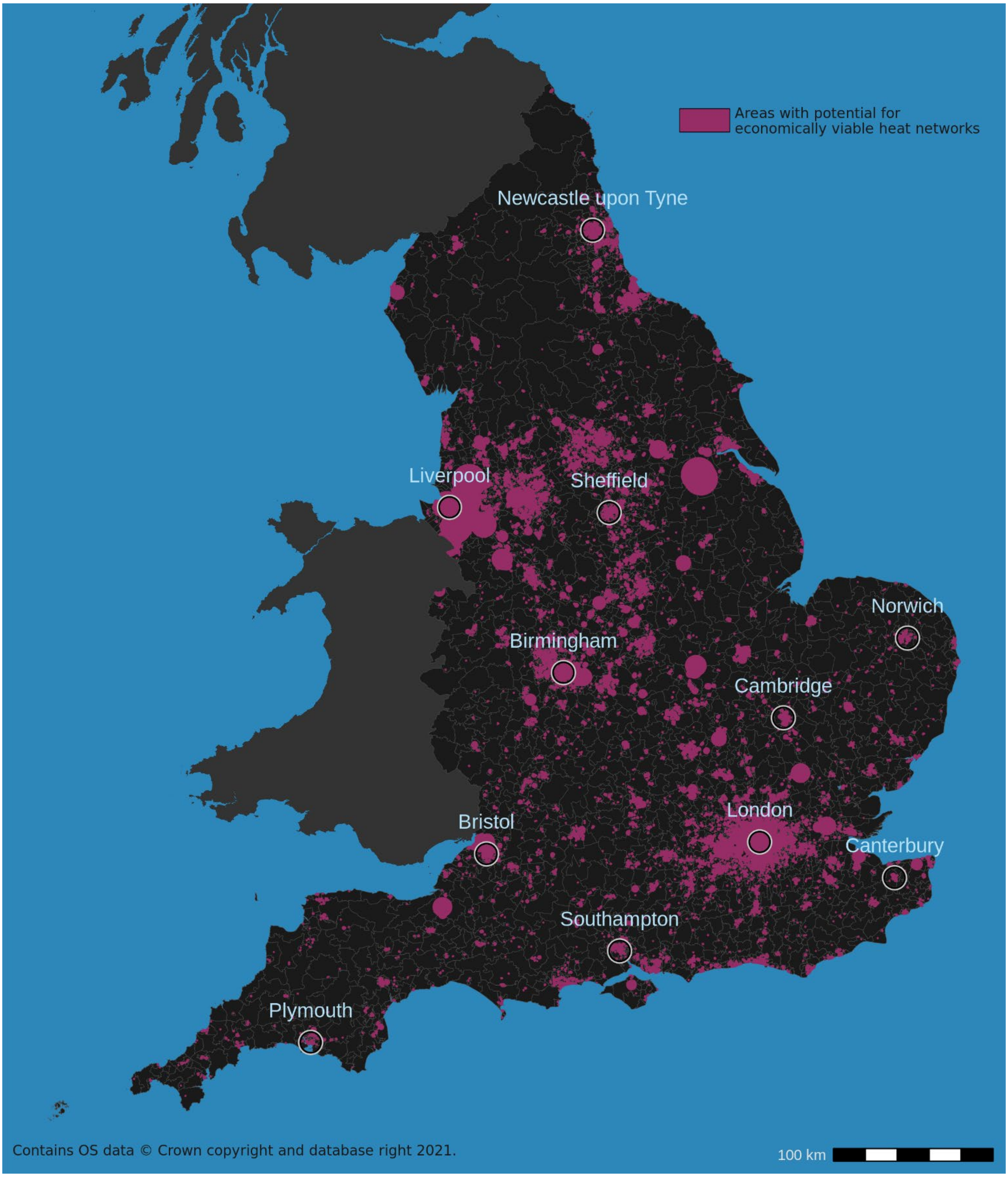


Figure 16: England areas with potential for economically viable heat networks

Northern Ireland

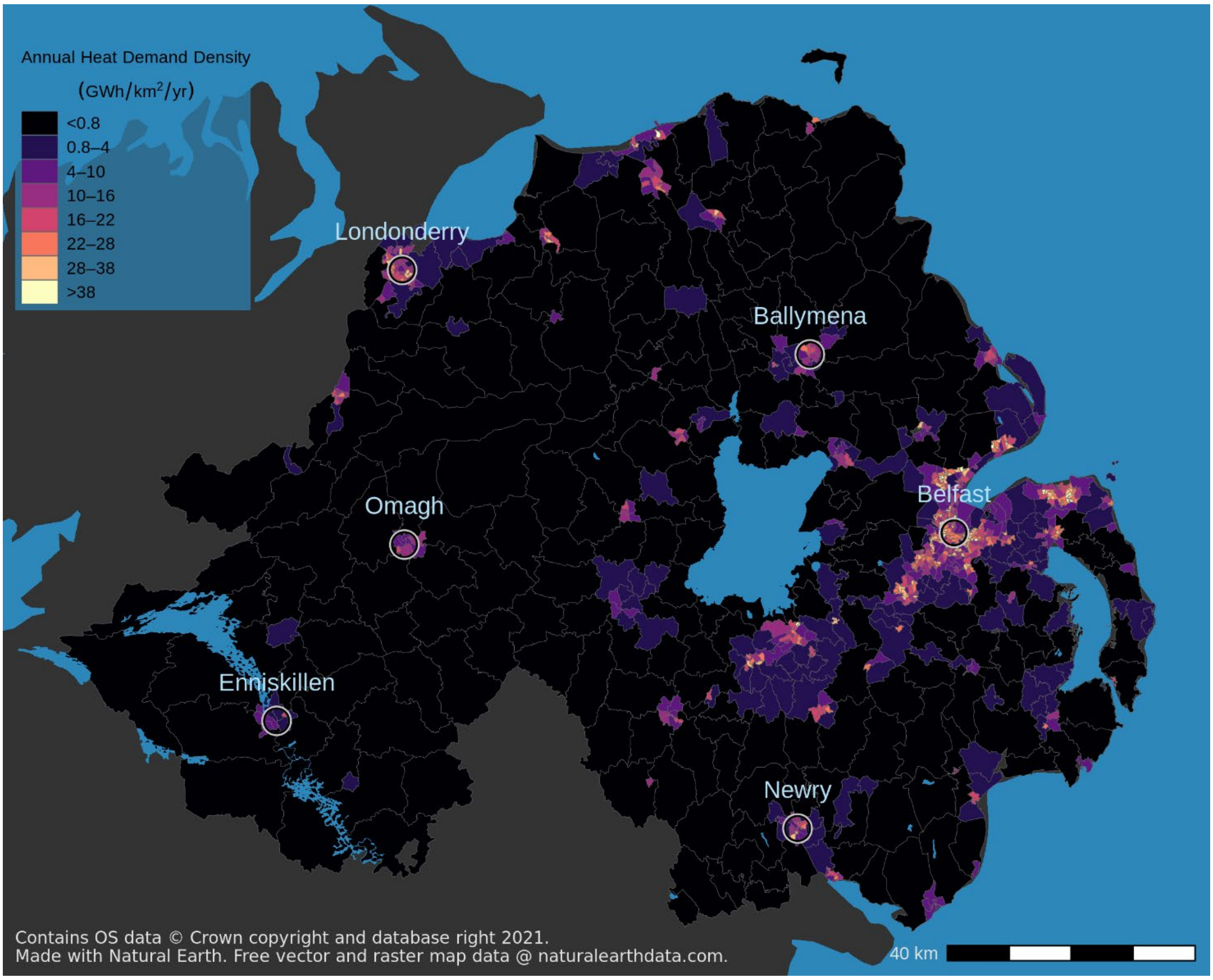


Figure 17: Northern Ireland heat demand density

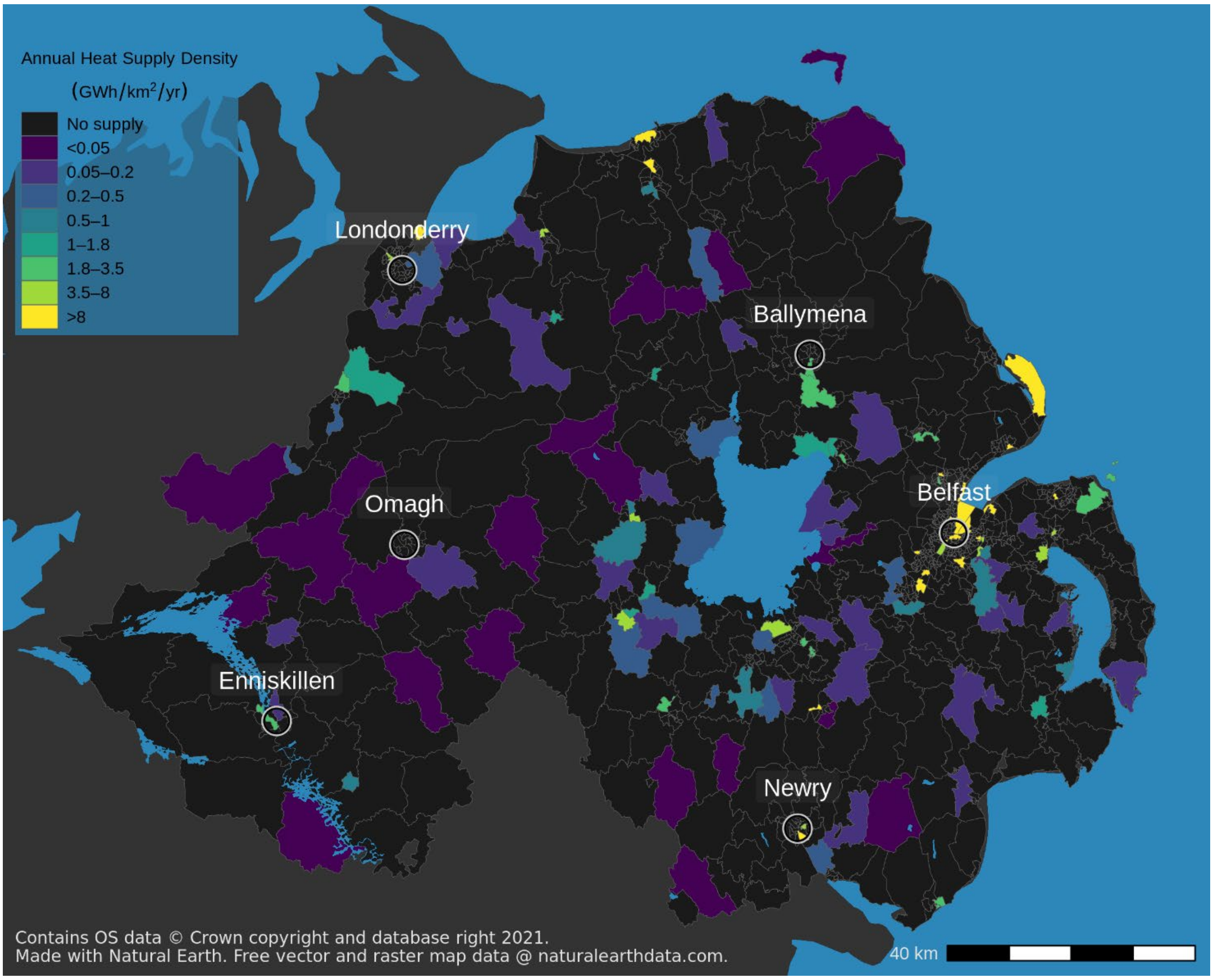


Figure 18: Northern Ireland heat supply density

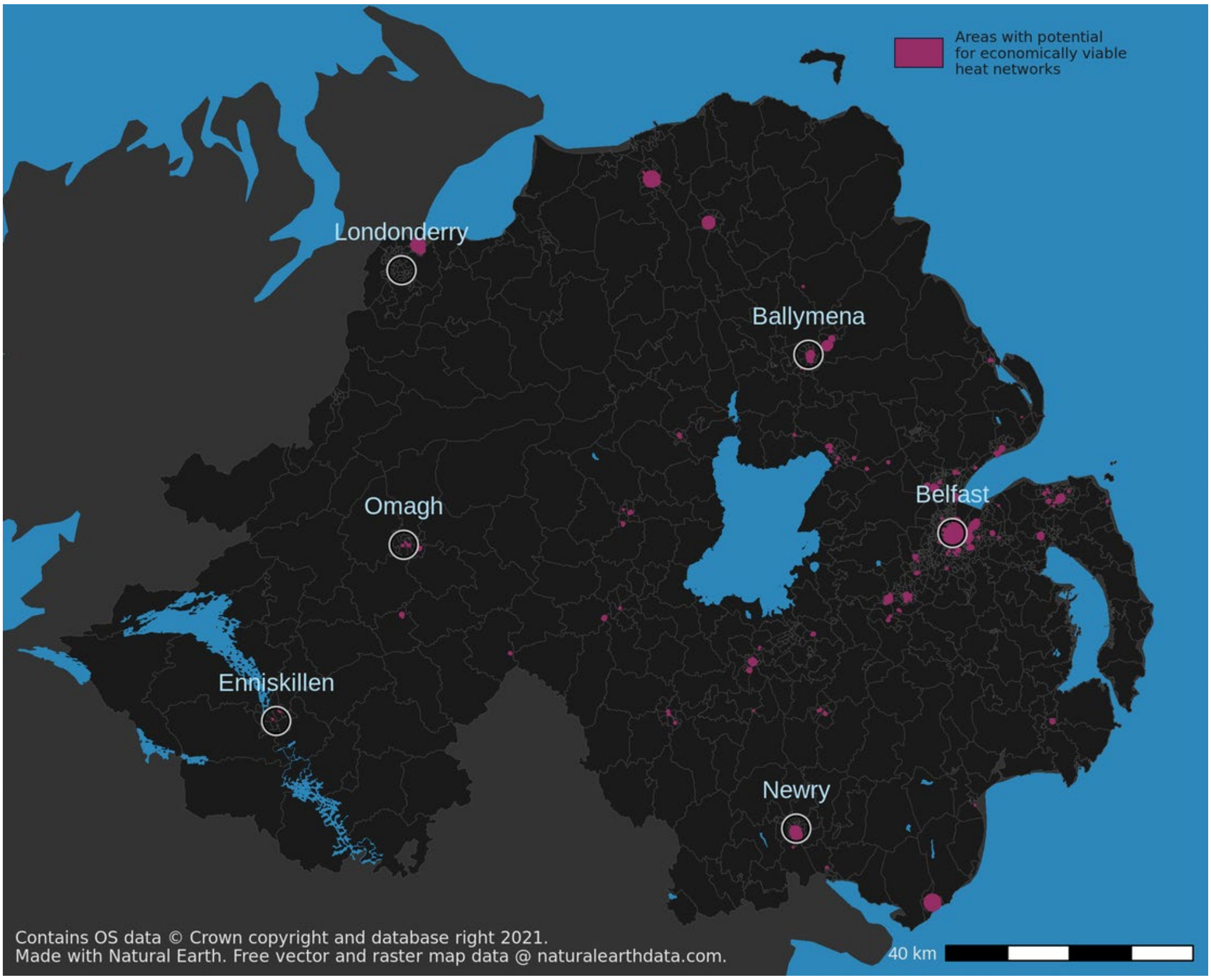


Figure 19: Northern Ireland areas with potential for economically viable heat networks

Scotland

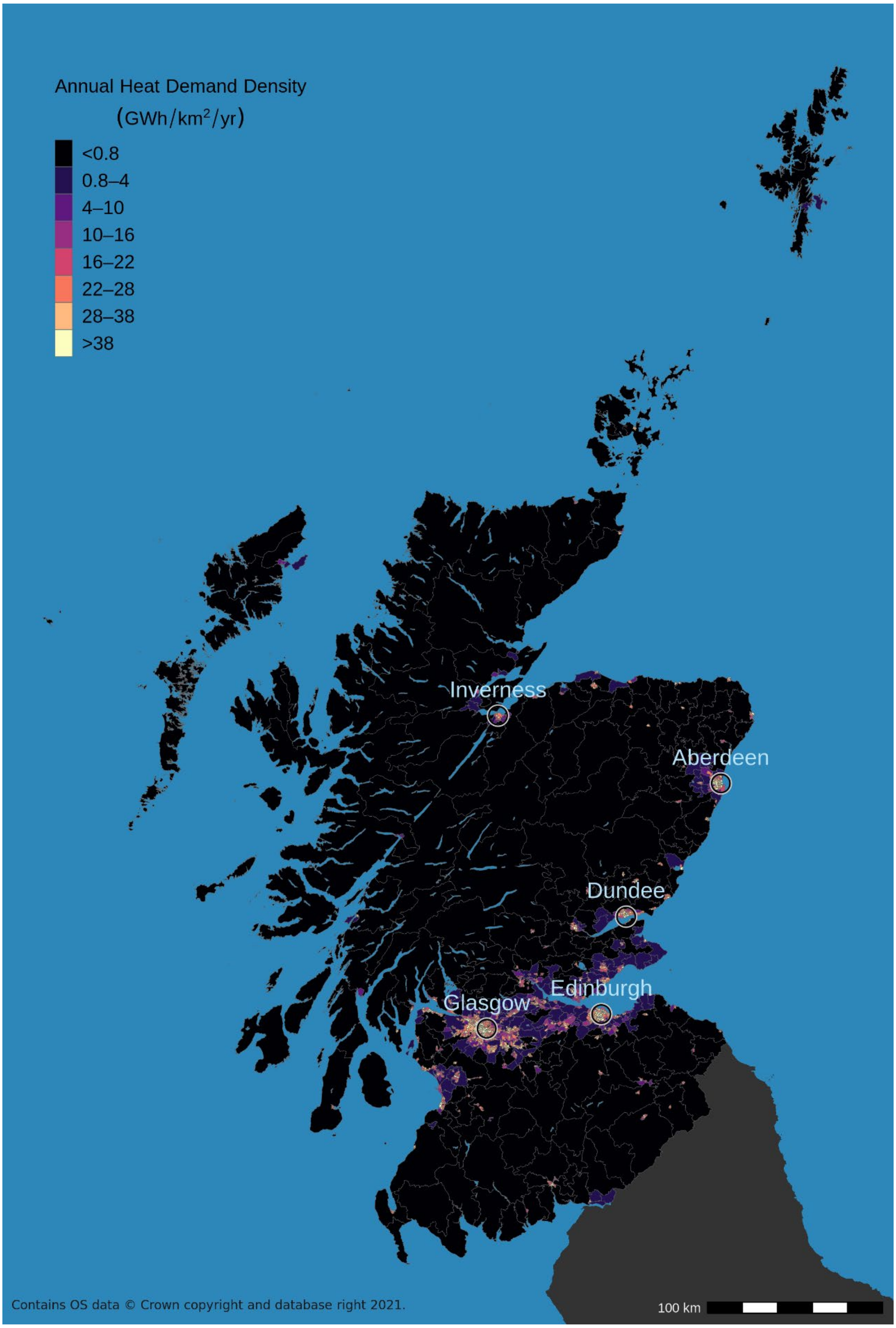


Figure 20: Scotland heat demand density

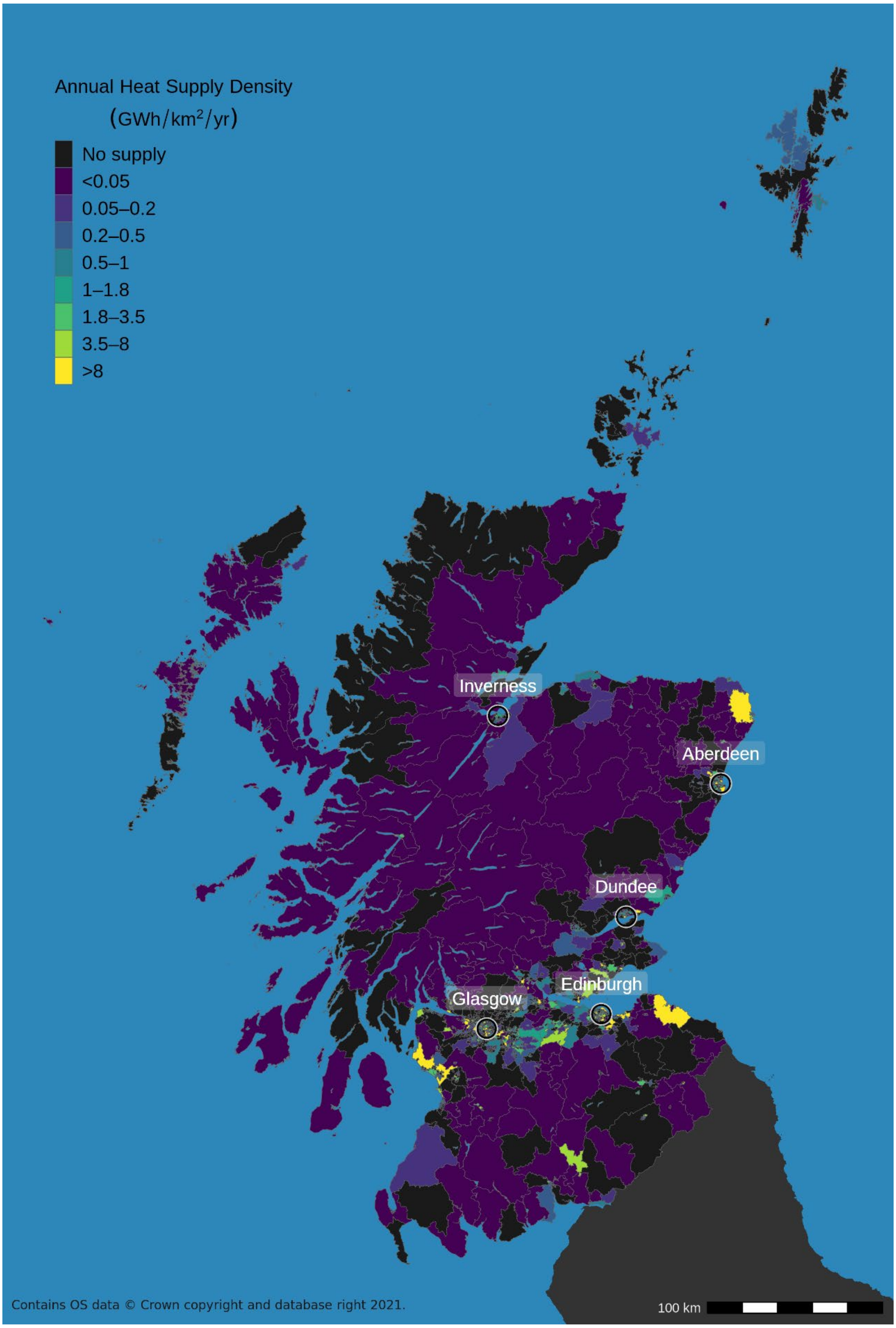


Figure 21: Scotland heat supply density

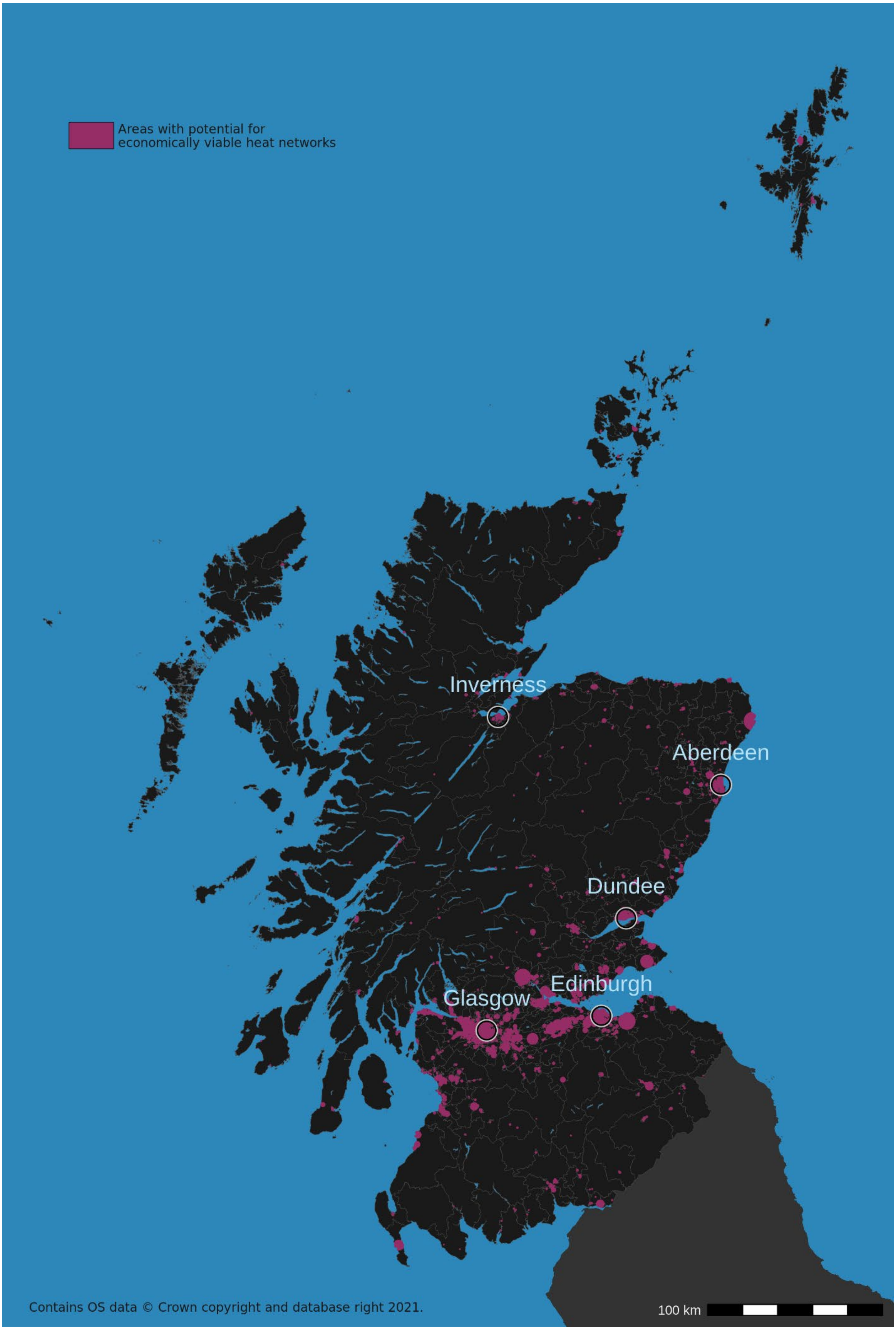


Figure 22: Scotland areas with potential for economically viable heat networks

Wales

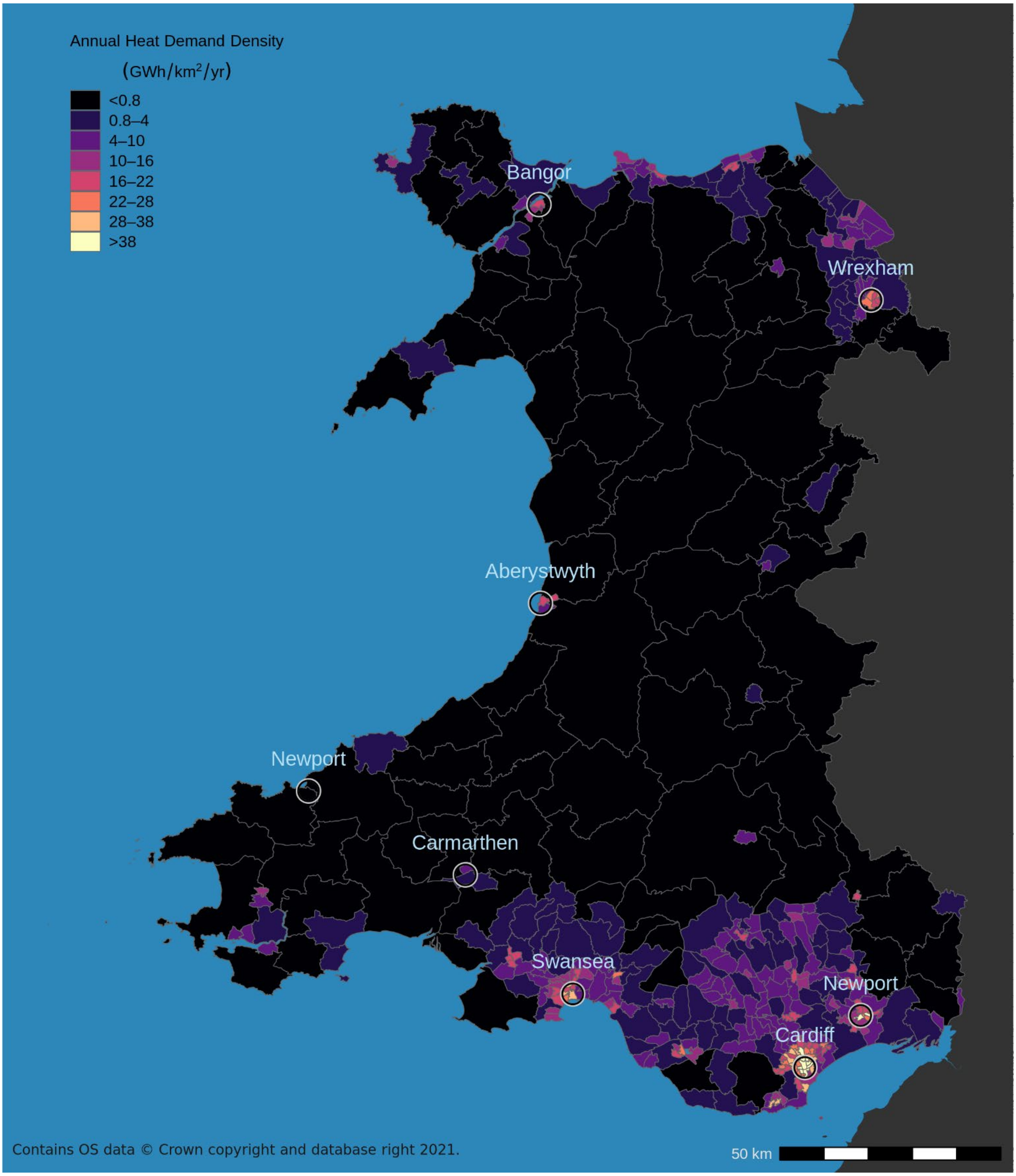


Figure 23: Wales heat demand density

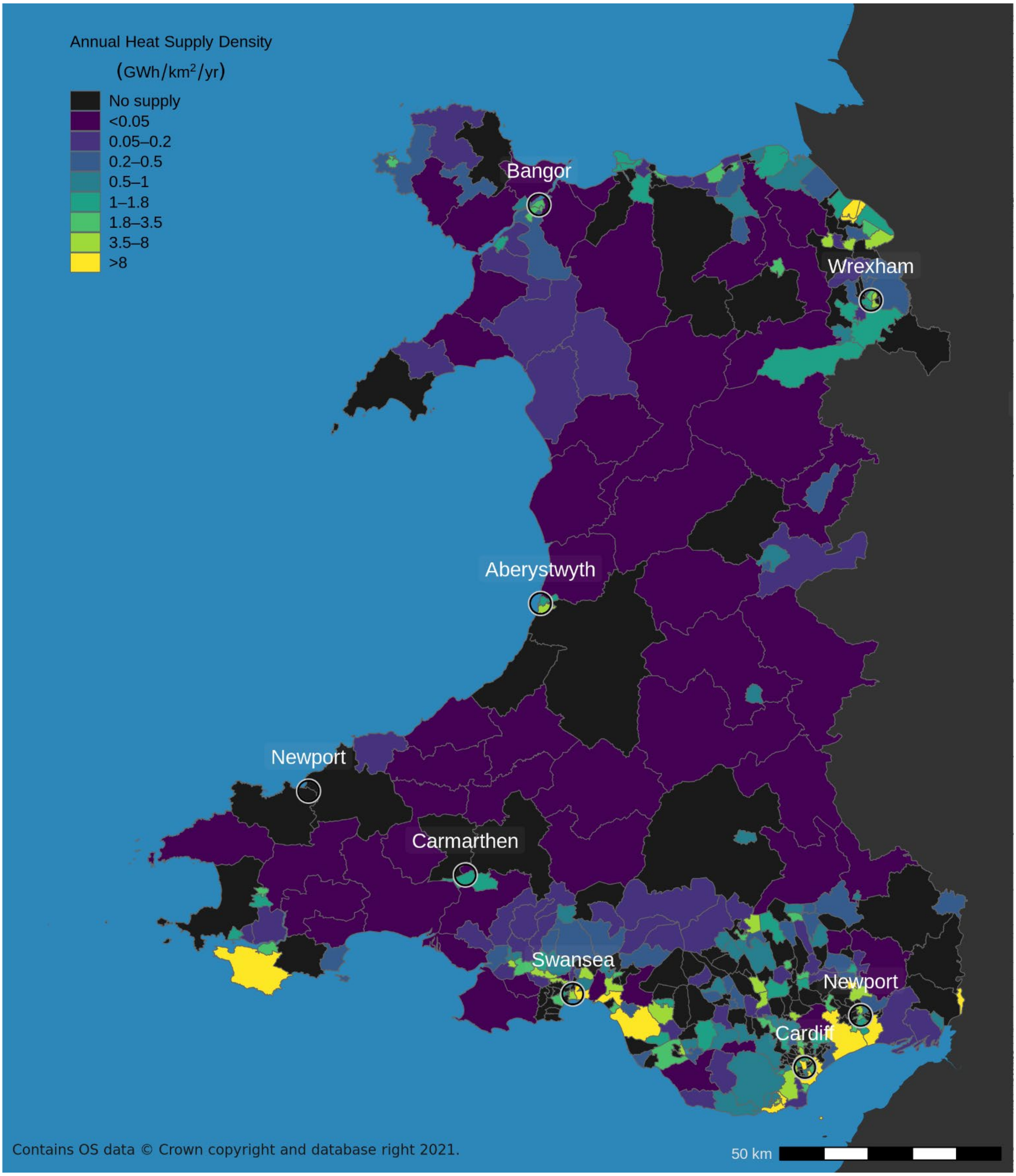


Figure 24: Wales heat supply density

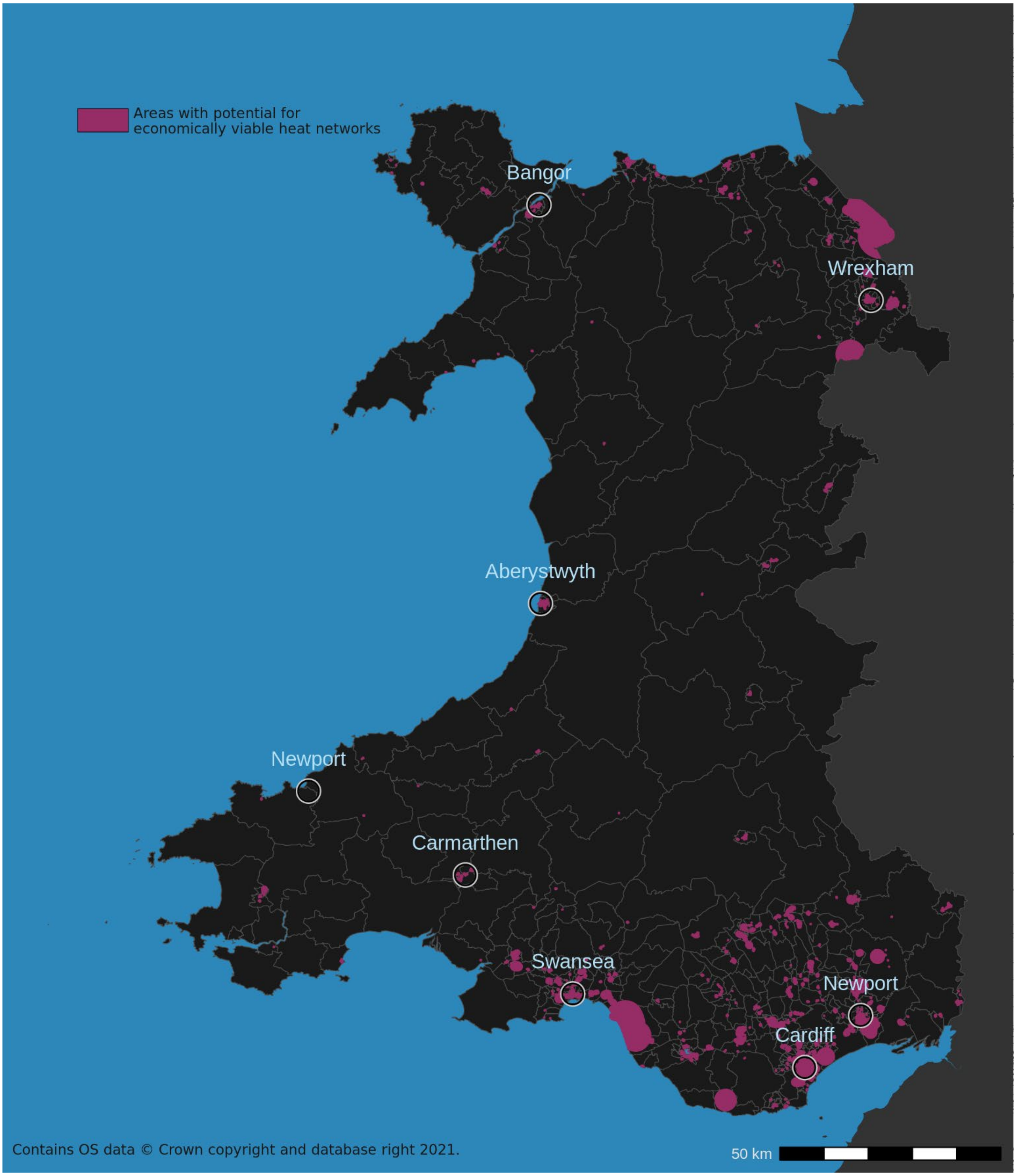


Figure 25: Wales areas with potential for economically viable heat networks

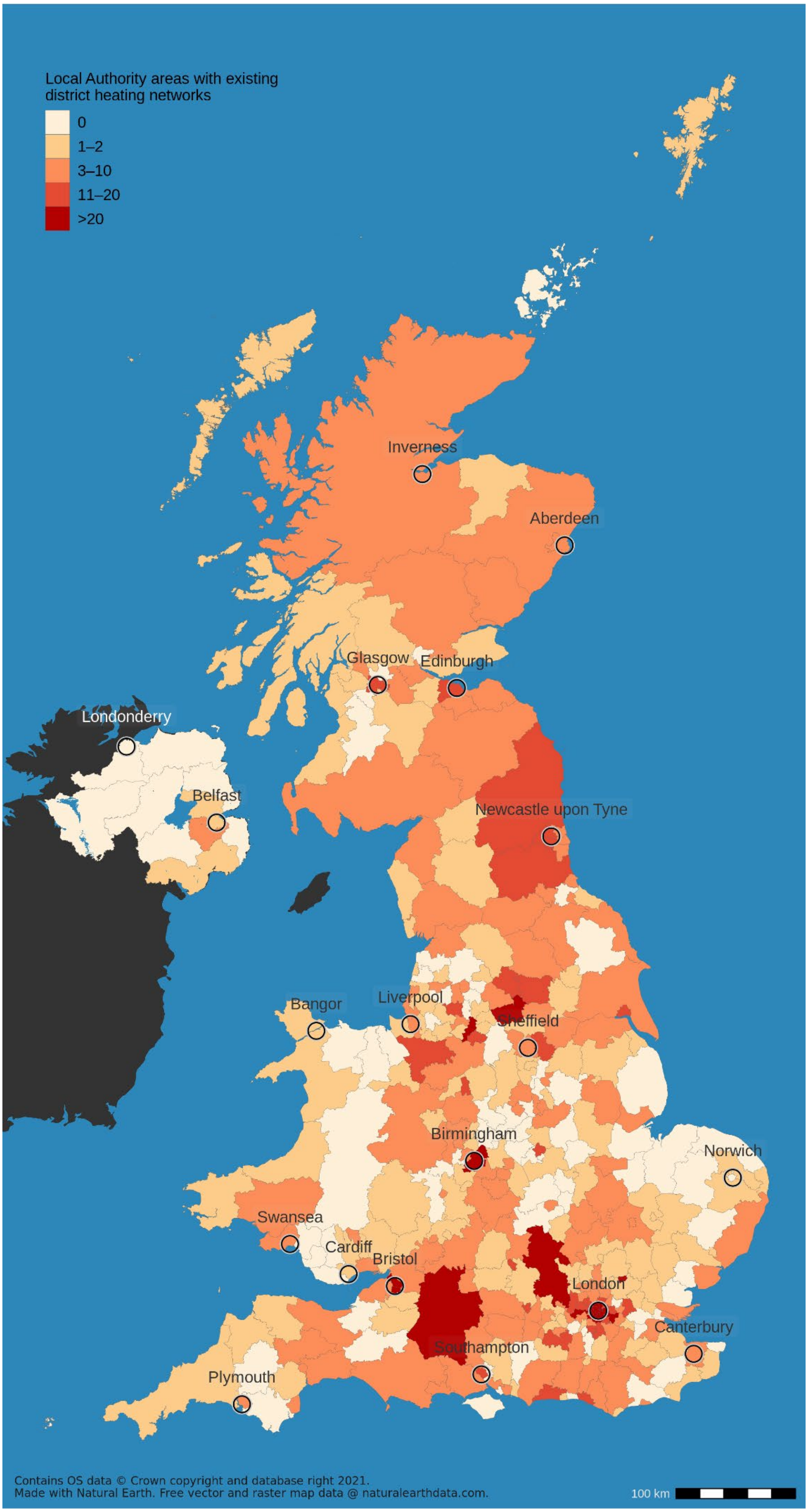


Figure 26: Existing district heat network schemes in the UK

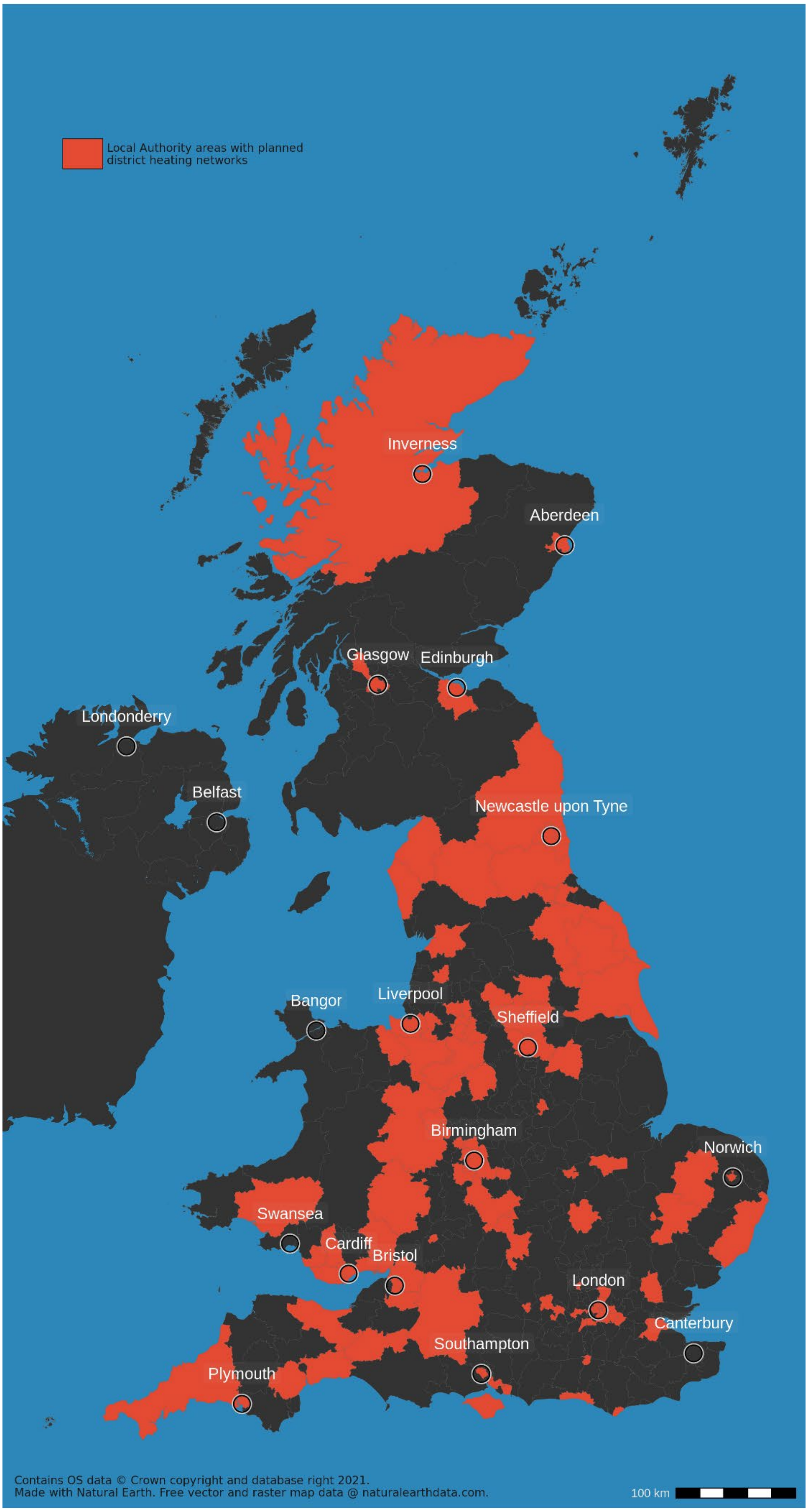


Figure 27: Planned district heat network schemes in the UK

Appendix 3: Spatial Model Methodology

This section outlines four key steps of the spatial model flow. It is summarised in section 2.2 of the main report and as such there is repetition between sections.

Current heating & cooling consumption

Heating and cooling demand in the UK has been determined initially using an energy demand benchmark approach. This is dependent on building floor areas and building typologies. Benchmarked heat demand in England and Wales has then been calibrated against sub-national heating estimates derived from estimates of Lower layer Super Output Area (LSOA) gas consumption data and national consumption of non-gas heating fuel.

The heating and cooling building-level consumption estimates have been estimated for the UK by three similar methodologies for: England and Wales, Scotland, and Northern Ireland. This was based on the availability of data used in the heating/cooling demand methodology, which is listed in Table 23 for each nation.

Table 19: Address and building level data sources

Nation	Address data	Building data	Supplementary data	Calibration data
England and Wales	Ordnance Survey Address Base Premium (OSABP)	Ordnance Survey MasterMap (OSMM)	Valuation Office Agency (VOA)	Energy Consumption in the UK[65] (ECUK) and metered gas consumption data in Lower layer Super Output Areas (LSOA)
Scotland	Scotland Heat Map[66]			
Northern Ireland	Address Base Premium Islands (OSABPI)	OS NI Fusion (OSNIF)	N/A	ECUK

Table 24 gives the data sources of benchmarks which were applied to each of the building typologies in England, Wales and Northern Ireland. Building typologies were derived by joining the Building Energy Efficiency Survey (BEES) sector and sub-sector definitions to the typology

[65] Energy Consumption in the UK https://www.gov.uk/government/statistics/energy-consumption-in-the-uk
[66] Scotland heat demand map and associated data, available at http://heatmap.scotland.gov.uk/

codes in OSABP. In Scotland, heat demand data was provided by the Scotland Heat Map (see footnote on previous page).

Where non-domestic ratings data from the VOA were available for a building, the OSABP floor area was superseded by VOA data as it provides more accurate information. The non-domestic VOA data was processed to exclude non-heated spaces such as storage areas or car parks, which, if included, would give an over-estimation of internal floor area.

The key buildings datasets used for analyses are as follows:

- VOA datasets provided building data for two million non-domestic properties per annum. This data provides a reliable building floor area based on the Royal Institution of Chartered Surveyors (RICS) code of measuring practices and a building typology in the form of an ‘SCAT code’.
- OSABP data contains address information for all properties in GB (OS AddressBase Islands (OSABI) has been used for Northern Ireland coverage) including a ‘classification code’ which can be mapped to a building use type / typology. For some properties, the SCAT code from the VOA dataset is also featured in OSABP.
- OS Mastermap (OSMM) data contains a geographic output of GB (OSNI Fusion has been used for Northern Ireland) buildings which enables estimation of building footprint.
- To estimate the individual non-domestic building demand the baseline data for buildings floor areas and typology are multiplied by BEES benchmarks (by typology).

Table 20: Data sources for heating and cooling benchmarks for England, Wales, and Northern Ireland

Sector	Source
Non-domestic (heating and cooling)	Building Energy Efficiency Survey (BEES)[67] A 2014/2015 report on non-domestic building stock in England and Wales. Survey of energy consumption across different building sectors.
Domestic (heating only)	National Energy Efficiency Data-Framework (NEED)[68] A study that aimed to better understand energy use and energy efficiency in buildings. Matches gas and electricity consumption data with information on installed energy efficiency measures.

Non-domestic heat demand mapping

England and Wales

Individual building demand is calculated by the following steps:

1. Priority is given to the VOA data, which provides a floor area and use type for a property. For some VOA data records, the building has reported multi use typologies for different buildings floors and the associated floor area. This data has been processed to exclude the floor area of rooms or floors which will not require heating. For example, if a multi-purpose building has a car park on the ground floor, the floor area of this car park has been removed from the total area to avoid overestimation. Note this can only be applied where sufficient data is provided. The use types which have been excluded from the heat demand calculations (for example car parks etc) have been reported in the assumptions log.

2. The next step in the process is to match VOA properties on to OSABP data. VOA uses Unique Address Reference Numbers (UARNs) which can be mapped on to UPRNs in OSABP.

3. Where VOA data is unavailable for a building, then the next most appropriate data to estimate the floor area is OSMM, in combination with OSABP to clarify the building typology, using the Classification Code.

4. Additionally, the BEES benchmarks for a given building typology are used to estimate heat demand using building floor area.

[67] https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees
[68] https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework

Benchmarked demand is calibrated against meter point gas consumption data (total gas consumption, rather than non-domestic only. This step is undertaken in tandem with calibration of domestic heat demand):

5. In order to compare with LSOA-level meter point data the building level estimates are mapped to LSOA geographies.

6. To identify whether buildings are on/off the gas grid, the Xoserve off gas grid lookup[69] has been used.

7. ECUK heat demand breakdowns are used to infer the amount of non-gas heating fuels for buildings on the gas grid that are not heated with gas.

8. A calibration factor is calculated for each LSOA based on the metered consumption in that area, corrected for buildings that do not use gas for heating. This factor is applied to all individual heat demands.

9. The model incorporates a lower cut off for the calibration factor of 0.5, and an upper cut off for the calibration factor of 2, to remove instances of a spurious data point affecting the heat demand results of buildings.

Northern Ireland

Due to limited availability of local energy consumption datasets for Northern Ireland, consumption at the LSOA equivalent level is derived from total individual building demand, following steps 1-4 in the methodology section above.

Scotland

The Scotland Heat Map data is used to identify heat demand for individual buildings in Scotland. The Scotland building data is then aggregated on an Intermediate Zone level, which will be used as an equivalent to the LSOA aggregation described for England and Wales.

Benchmarks

The BEES Sector and sub-sector heating benchmarks used for non-domestic heat demand mapping in England, Wales and Northern Ireland (not Scotland) are given in Table 25.

[69] https://www.xoserve.com/media/2687/off-gas-postcodes-v2.xlsx

Table 21: BEES heating benchmarks used in England, Wales and Northern Ireland

BEES Sector	BEES Sub-sector	Space Heating (kwh/m2)	Domestic Hot water (kwh/m2)	Total (kWh/m2)
Community arts leisure	'Theatres, concert halls & cinemas'	159	8	167
Community arts leisure	'Clubs'	117	10	127
Community arts leisure	'Community centres'	117	10	127
Community arts leisure	'Leisure centre (with swimming)'	142	19	161
Community arts leisure	'Leisure centre (without swimming)'	142	19	161
Community arts leisure	'Museums art galleries & libraries'	103	6	109
Community arts leisure	'Places of Worship'	81	1	82
Community arts leisure	'Community arts leisure'	98	5	103
Education	'Nurseries'	110	20	130
Education	'Secondary schools'	92	19	111
Education	'Primary schools'	115	21	136
Education	'Education'	105	18	123
Education	'Higher education – teaching and research'	112	9	121
Education	'Higher education – residential'	99	33	132
Emergency Services	'Law courts'	126	4	130
Emergency Services	'Prisons'	179	32	213

BEES Sector	BEES Sub-sector	Space Heating (kwh/m2)	Domestic Hot water (kwh/m2)	Total (kWh/m2)
Emergency Services	'Police station'	193	28	221
Emergency Services	'Emergency Services'	183	25	208
Emergency Services	'Fire/ambulance stations'	190	14	204
Health	'Health centres'	100	10	110
Health	'Hospitals'	150	50	200
Health	'Nursing homes'	200	70	270
Health	'Health'	140	50	190
Hospitality	'Cafes'	45	23	68
Hospitality	'Hotels'	97	48	145
Hospitality	'Pubs'	120	17	137
Hospitality	'Restaurants'	55	37	92
Hospitality	'Takeaways'	55	37	92
Hospitality	'Hospitality'	97	33	130
Industrial	'Factories'	57	2	59
Industrial	'Large industrial'	57	2	59
Industrial	'Workshops'	96	2	98
Industrial	'Industrial'	81	2	83
Military	'Military accommodation'	103	30	133
Military	'Military offices'	79	6	87
Military	'Military storage'	105	5	110
Military	'Military'	92	7	99
Office	'Offices (private)'	100	10	110
Office	'Offices (private)'	53	11	64
Office	'Offices (private)'	77	10	87
Office	'Offices (reference)'	91	11	102
Office	'Offices'	79	10	89

BEES Sector	BEES Sub-sector	Space Heating (kwh/m2)	Domestic Hot water (kwh/m2)	Total (kWh/m2)
Retail	'Betting offices'	61.00	1.00	62
Retail	'Department stores'	73	3	76
Retail	'Hairdressers & beauty salons'	78	111	189
Retail	'Supermarkets'	156	4	160
Retail	'Large food shops'	156	4	160
Retail	'Large non-food shops'	73	3	76
Retail	'Retail warehouses'	66	0	66
Retail	'Showroom (non-vehicle)'	84	3	87
Retail	'Small non-food shops'	61	1	62
Retail	'Showroom (vehicle)'	84	3	87
Retail	'Retail'	77	3	80
Storage	'Cold stores'	1	7	8
Storage	'Large distribution warehouses'	35	2	37
Storage	'Stores'	28	2	30
Storage	'Warehouses'	48	2	50
Storage	'Storage'	36	2	38

Exclusions and limitations

Non-domestic gas consumption is published on the BEIS website for Great Britain and uses a cut-off (lower bound) of 73 MWh/yr to determine whether meter point data represents non-domestic gas consumption[70]. This method for distinguishing non-domestic gas consumption is likely to exclude gas consumption from small non-domestic buildings. For this reason, non-domestic and domestic LSOA gas consumption estimates have been combined to calibrate benchmarked heat demands. Therefore, sectoral split for heat demand is inherited from benchmarking.

In some areas of the UK, estimates of LSOA level gas consumption is not available. This is either due to data availability (see Northern Ireland section) or data has been suppressed to protect sensitive information. In cases where LSOA gas consumption is not available,

[70] Sub-national consumption statistics: methodology and guidance booklet: https://www.gov.uk/government/publications/regional-energy-data-guidance-note

comparison steps 5-9 (above) are not included, and consumption is estimated solely from benchmarking.

Information on properties not connected to the gas grid was used to indicate what proportion of each LSOAs heat demand is captured under the gas consumption data.

VOA data is regarded as the best quality source of information for floor area in this analysis, as it can provide the detailed size of individual rooms and areas which are not in need of heating (garages, car parking etc.). All VOA records have been processed to identify how much, if any, of the floor area is not in need of heating and this has been subtracted from the total floor area to improve the accuracy of the heat demand estimation. Due to the scale of the analysis, it is likely that some floor areas are not accurate for the buildings they represent.

Domestic heat demand mapping

England and Wales

Domestic energy consumption data are available at national, and sub-national level (gas consumption for Great Britain only) through official statistics. Estimates for households not connected to the gas grid are also available at sub-national level through official statistics (for Great Britain only).

The domestic individual building data was compiled in the same manner as described for the non-domestic data but does not use an equivalent VOA data source for domestic properties. Therefore, OSMM has been used to determine building floor area, which has been matched to OSABP data for building typology (terraced, semi-detached, flat etc) and the National Energy Efficiency Data-framework (NEED) standard benchmarks for domestic building heat demand have been applied.

The NEED benchmarks are provided in headline tables as gas consumption per floor area for an average domestic property, and separately as a total gas consumption per type of domestic building. NEED data is also available through the anonymised NEED dataset which combines building typology, floor area and gas consumption for a sample of four million households in Great Britain.

The following table presents the domestic NEED benchmarks which have been calculated from the NEED database and were used in the NCA model:

Domestic building typology	Heat consumption per floor area (kWh/m2) – starting assumption
Flats	200
Other	175

The methodology for producing domestic heat demand mapping started with mapping individual building level demand, which was undertaken using the following steps:

1. Filter domestic properties from the OSABP data. This data provides building footprint and building typology.

2. Match building floor area from OSMM to the outputs of step 1.

3. Use NEED benchmarks to calculate expected annual heat demand based on building typology and floor area.

The results from the above steps have then been calibrated against sub-national gas meter point data (total gas consumption, rather than domestic only. This step is undertaken in tandem with calibration of domestic heat demand):

4. To compare with LSOA-level meter point data the building level estimates were aggregated to LSOA geographies.

5. The Xoserve off gas grid lookup was used to identify buildings on the gas grid.

6. A calibration factor was calculated for each LSOA based on the metered consumption in that area; this was corrected for buildings that do not use gas for heating. This factor was applied to all individual heat demands.

7. The model incorporates a lower cut-off for the calibration factor of 0.5, and an upper cut off for the calibration factor of 2, to remove instances of spurious data affecting the heat demand results.

Northern Ireland

Due to limited availability of local energy consumption datasets for Northern Ireland, consumption at sub-national level, heating demand was derived from total individual building demand, following steps 1-3 in the methodology section above.

Scotland

Data for Scotland were obtained from the Scotland Heat Map. Process loads associated with distilleries were omitted (for consistency with heat demand mapping in other regions), and the ‘unscaled’ heat demand values in the dataset were used.

Mapping

Maps are produced for England and Wales, Scotland, Northern Ireland, and Great Britain and Northern Ireland. Heat demand, cooling and supply have been aggregated within MSOA (England and Wales), IZ (Scotland) and SOA (Northern Ireland) census geographies in preference to lower-level census geographies, such as LSOA, to display data more clearly at the scale of the mapping areas chosen.

Heating demand and heating supply estimates have been presented as GWh/km2/year; cooling demand estimates have been presented as kWh/km2/year The range of scaled heat values were then placed into eight classes that reflect equal intervals across the whole data range. Because heat values have a very large range and are highly skewed (lower heat values show several orders of magnitude higher frequency than higher values), classification was based around quartile ranges of log-transformed heat that were then recast back to their non-log values.

Heat networks with potential for economic viability have been shown as a combined layer including both location specific and location agnostic sources.

The mapped outputs are presented in Section 3.4 and Appendix 2.

Heat source analysis and mapping

Various heat sources have been analysed through this study. These are classified within three categories:

- **location specific sources** of heat, i.e. existing sources of heat at known locations;
- **water sources** like rivers, marine, lakes and canals and other surface water; and
- **location agnostic sources** of heat, i.e. generation plant that can be installed largely regardless of location.

Details on how these sources are treated in the model are described in this section.

Location specific sources

Data on known current heat sources was processed to enable the mapping of heat sources in the UK. A range of sources have been captured through this study, as shown in Table 26.

Table 22: Location specific heat source summary

Source category	Sources included	Data source
Combined heat and power plant	Existing gas and biogas fired combined heat and power plant (CHP)	CHP Quality Assurance Programme, BEIS
Incinerators	Energy from Waste incinerators (EfW), Advanced Conversion Technology (ACT) EfW incinerators, Biodrying Mechanical & Biological Treatment (BMBT), Landfill Mechanical & Biological Treatment (LFMBT) & Other incineration plants	DEFRA and devolved environment agencies
Thermal Power Stations	Gas, biomass/biogas and nuclear power plants (Coal *omitted*)	Digest UK Energy Statistics, BEIS
High grade waste heat sources	Cement, lime and iron and steel production, crematoria *(Petrochemical plants / refineries omitted)*	Waste Heat Research conducted by Arup for England, Northern Ireland, and Wales and BRE for Scotland.
Low grade waste heat sources	Chemical, cold stores, data centres, food and drink, other mineral industries, paper and pulp, electricity substations, supermarkets, wastewater treatment works, underground railways and active minewater pumping stations.	Waste Heat Research conducted by Arup for England, Northern Ireland, and Wales and BRE for Scotland. Minewater stations from the Coal Authority.

Water sources

Information has been used from the Water Source Heat Map[71] to estimate the availability of heat from sources like rivers, canals, marine, lakes and other surface water in England. For the rest of the UK, only coastal areas have been included in the analysis.

Location agnostic sources

The sources listed in Table 26 are located at existing sites and are therefore specific to a location. In contrast 'location agnostic' sources are technologies which we assume could be

[71] https://www.gov.uk/government/publications/water-source-heat-map

deployed anywhere where there is demand for heating. The following technologies are included in the definition of 'location agnostic' heat sources:

- air source and ground source heat pumps
- biomass boilers and biomass CHP
- gas boilers and gas CHP
- electric boilers
- hydrogen boilers

Geothermal heat sources were not included.

Treatment of heat sources in the model

For each heat source, assumptions are used to determine the temperature at which heat can be captured from the source. If an uplift in temperature is required to meet the assumed network supply temperature of 80°C, the associated heat pump efficiency is calculated.

Assumptions on the availability of sources are made to determine the heat output per annum and peak output. System capital and operational costs are also captured in the model, including any likely tariffs payable to heat suppliers, e.g. incinerator operators, water companies or Distribution Network Operators (DNO).

These assumptions are used to generate Levelised Cost of Generation (LCOG) figures for each source type, which feed into calculations on how far heat can be distributed from a source (see Appendix 3 for further explanation of the calculations).

Heat source maps

Heat source availability has been mapped by aggregating available heat supply to MSOA, IZ and SOA level, which are comparable sizes of census geography between nations in the UK. Values are given in GWh/km^2/year heat available, i.e. no distinction between source temperature is made.

Assessing the economic potential for heat networks

Heat networks that show economic potential are those that are both technically and economically viable throughout their installed life. The assessment of potential applied assumptions around capital, operational and replacement costs to determine which buildings in the UK could be economically served by heat networks.

To calculate the extent of economically viable heat network deployment in the UK, the model has undertaken the following stages (also described in Figure 28).

1. Aggregate individual residential flat heating consumption into building-level consumption where applicable (i.e. where many overlapping demands were shown at the same location, these were aggregated up to become building-level demands);

2. Filter the building level heat demand for those that were deemed to be eligible for supply by a heat network, i.e. any building with consumption greater than 73MWh/yr. This value was chosen to be consistent with the gas consumption threshold used by BEIS to determine whether an address is domestic or non-domestic[72]. Domestic buildings are therefore only included in networks if they form part of a communal block; standalone domestic buildings are not considered viable for heat network connection in this analysis.

3. Calculate the Levelised Cost of Generation (LCOG) for each location specific source (see explanation below), excluding water sources which were analysed separately, then used the calculations to determine high, medium and low (H/M/L) Linear Heat Density (LHD) values. Categorised heat sources into the H/M/L LHD brackets. The LHD gives the minimum heat demand required per metre of distance from the building (kWh/m), in order that the heat revenues generated can pay back the cost of installation of that pipework within a given timeframe.

4. Generate 'buffer radii' around every building to show the distance from which it could be served heat by a network profitably, using the Low LHD value. Where radii of buildings overlap, clusters were created. See Figure 29.

5. Filter out clusters with two or fewer buildings or less than 0.5GWh/yr heat demand.

6. Identify heat sources that were categorised as 'Low LHD' within the vicinity of the generated clusters. Where a heat source could not meet the total demand of the cluster, it was assumed that top-up boilers are used to meet the remainder of the demand. To maximise the heat supplied by low carbon heat sources, any cluster which can only be partially supplied by a heat source underwent an additional step of analysis to determine if the cluster is in the vicinity of an alternative heat source from a higher LHD category. If it was possible to supply more of the cluster's demand with the alternative heat source then that cluster was skipped and added to the 'unallocated' demand.

7. For any demand not met by Low LHD sources, steps 4 to 6 were repeated for Medium LHD: clusters were generated using the Medium LHD radii, then heat from Medium LHD sources is allocated to meet demand. The process was repeated again for High LHD.

8. Once all viable heat sources have had their available heat supply allocated, the model then repeated the analysis for clusters which were close to water sources, regenerating potential clusters using the Medium LHD value.

9. Following the analysis of location specific sources, including water sources, the model moves on to find networks that could be served by a location agnostic heat source. Clusters were generated from remaining demand based on the Low LHD values and these clusters then become heat networks served by location agnostic sources.

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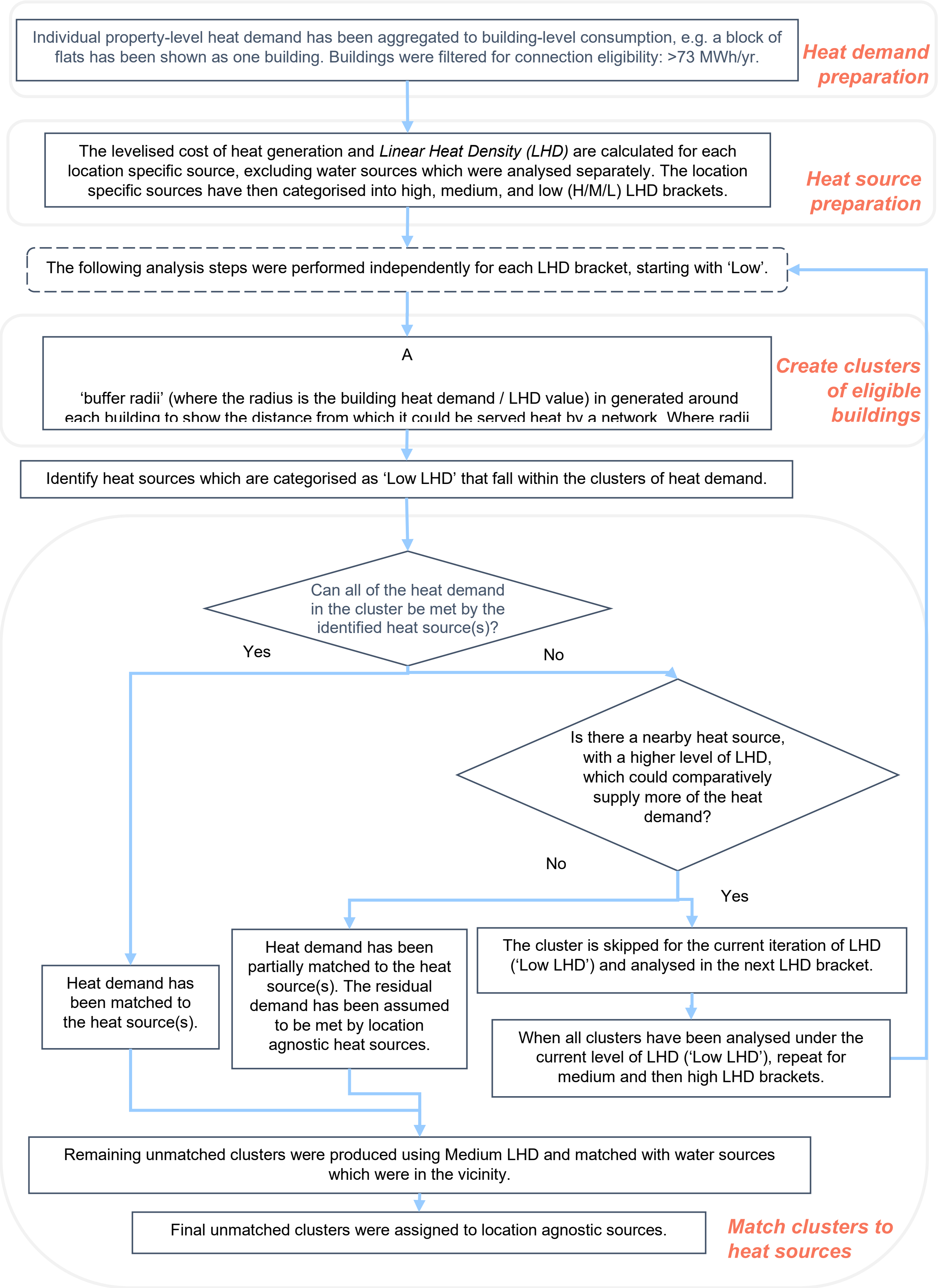
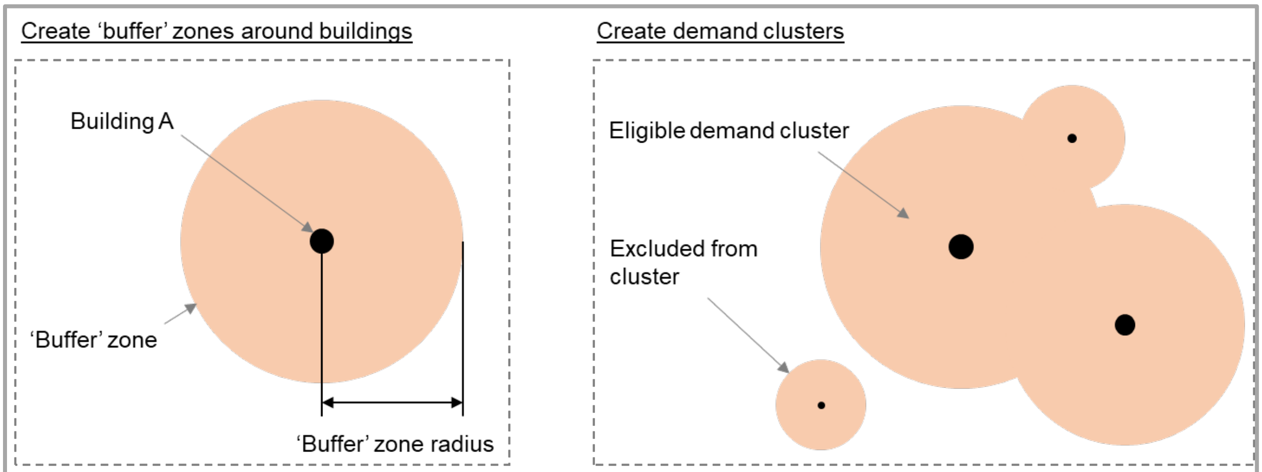
[72] Sub-national consumption statistics: methodology and guidance booklet: https://www.gov.uk/government/publications/regional-energy-data-guidance-note

Figure 28: Flowchart of the Economic Potential for heat networks methodology





$$\text{Radius} = \frac{Building\ heat\ demand\ (\frac{kWh}{annum})}{Linear\ heat\ density\ (\frac{kWh}{annum.m})}$$

Figure 29: Building cluster generation illustration

Levelised cost of generation (LCOG)

For each source type, assumptions were used to determine the following:

- Temperature of heat available at the source and hence whether a heat pump will be required to upgrade it to the assumed network supply temperature (80°C).
- Source-specific heat pump COPs[73] based on assumed seasonal source and supply temperatures and a Carnot COP efficiency approximation.
- Heat output in kWh/yr, kW peak and availability factors (to account for maintenance or other periods where heat may not be available).
- Costs of capture / generation equipment, including tariffs payable to heat suppliers, e.g. incinerator operators, water companies, DNOs.
- Fuel / electricity requirements for heat generation

For all waste heat sources, a 'Levelised cost of capture' (LCOC) figure was calculated, reflecting the capital and operational costs associated with capturing heat from the source over 40 years. LCOC figures only relate to heat capture at the temperature at which it is wasted, i.e. they do not include for any heat pump or other related costs.

Based on the source-specific heat temperature, the model decides whether a heat pump is required and if so, its source-specific COP. A levelised cost of generation (LCOG) was calculated for all sources, based on:

[73] In the assessment, the use of seasonal average temperatures result in COP values being equivalent to Seasonal COP (SCOP) values.

- LCOC (e.g. from waste heat sources);
- costs of heat generating plant (e.g. heat pumps, back-up boilers) and the energy centre itself;
- costs of EC utilities connections;
- replacement costs of equipment above; and,
- operating costs of generating plant, including fuel/electricity/heat costs and allowances for maintenance.

LCOG represents the cost per kWh associated with generating a usable unit of heat at 80°C that can then be used in any modelled network. LCOG values factor in LHD calculations, as described below.

The availability of each heat source was estimated based on the understanding of each technology. The periods when the heat source may not be available was estimated, with any shortfall in heat output assigned to the assumed back-up heat supply. This sum of the heat output from the heat source, heat output from back-up supply and a factor of heat lost through distribution, was used as the total heat available to networks.

It is assumed for the purposes of the model that heat is generated in this manner by a notional ‘Generation Company’, or GenCo.

Linear heat density (LHD)

The LHD calculations assumed that a ‘Pipework Company’, or PipeCo, purchases heat from the GenCo at the Energy Centre boundary and distributes it to buildings. Heat is sold by the PipeCo to a ‘Distribution Company’, or DisCo who owns, operates and manages everything within building envelopes.

The LHD defines the *minimum* heat demand a building must have to support being served by a heat network **per metre distance** from that building (*not* per linear metre of pipework):

$$Linear\ heat\ density\ \left(\frac{kWh}{annum.m}\right) = \frac{Pipework\ non-direct\ factor\ \times Amortised\ pipe\ costs\ (\frac{£}{m.annum})}{Revenue\ per\ unit\ heat\ (\frac{£}{kWh})}$$

Where:

$$Amortised\ pipe\ costs\ (\frac{£}{m.annum}) = \frac{Pipework\ costs\ per\ metre\ (\frac{£}{m})}{PipeCo\ required\ payback\ period\ (annum)}$$

And, to account for the difference between typical expected pipework length vs actual linear distance (‘as the crow flies’):

$$Pipework\ non-direct\ factor = \frac{Pipework\ length\ (m)}{Linear\ distance\ (m)}$$

And:

$$Revenue\ per\ unit\ heat\ \left(\frac{£}{kWh}\right) = PipeCo\ sale\ price\left(\frac{£}{kWh}\right) - \ LCOG\ \left(\frac{£}{kWh}\right)$$

Costs of purchasing/operating equipment within building envelopes, as well as sale of heat to end users, is undertaken by the DisCo and is not modelled explicitly.

The various resulting LHD values for each source type were grouped into three brackets: high, medium and low. The model generates clusters from the low value initially and allocates heat from sources within that bracket to those clusters, before moving on to the medium and high values respectively. As LHD increases, cluster sizes decrease.

Finally, the model tests the sensitivity to the LHD values used by undertaking a sensitivity analysis on two of the key underlying assumptions: pipe cost and the heat margin applied. The resulting three LHD value scenarios are shown in Table 27.

Table 23: Economic potential scenarios - underlying assumptions variances

Scenario	% change pipe costs	Pipe costs £/m	Heat 'margin'(1)	LHD values, kWh / m.yr		
				Low	Medium	High
Low network uptake	+10%	2,200	-10%	3,600	8,200	24,100
Base case (medium uptake)	0%	2,000	0%	2,900	6,700	19,700
High network uptake	-25%	1,500	+30%	1,700	3,900	11,400

(1) Heat 'margin': this is the difference between the cost of heat purchased by the network operator and the value at which it is supplied to a customer. In the sensitivity testing the value of the 'heat margin' in £/kWh has been varied by the % in the table.

Heat demand projection to 2050

Heat demand in the UK has been projected to 2050 using projections derived from the Energy and Emissions Projections (EEP) model suite. This is a set of tools for projecting future energy demand and greenhouse gas emissions for the UK based on economic, demographic and other drivers, taking into account expected impact of current and planned Government policies. Details of this methodology is published by UK Government74. From the EEP, further steps were taken to derive specific heating and cooling demand projections from the overall energy demand projections. This includes calibrating the demand to Energy Consumption in the UK (ECUK)75 and converting the projections which are in terms of fuel input basis to output basis by modelled assumptions on appliance efficiencies and changes in heat demand. In the domestic sector these are modelled using the National Household Model (NHM)76 and in the non-domestic sectors where there is considerably less information, a simplified approach of trending the projections to match the overall EEP energy demand for these sectors is used.

Cost Benefit Analysis of heat networks compared with individual building counterfactuals

The cost benefit analysis (CBA) compares heat network solutions to building-by-building alternatives. The analysis is carried out on the heat demand that is economically viable to be supplied via a heat network, as determined by the Medium economic potential spatial model

[74] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794741/energy-emissions-projections-methodology-overview.pdf
[75] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk
[76] https://data.gov.uk/dataset/957eadbe-43b6-4d8d-b931-8594cb346ecd/national-household-model

scenario. As the CBA is expressed as Net Present Value (NPV), costs and benefits common to both are not included in the analysis such as existing heat networks and the underlying infrastructure.

The CBA undertaken for the purposes of this study is high-level and should not be interpreted as an indication of the UK government's intention for current and future policies. Importantly, the CBA does not capture the benefits of climate change mitigation (except in a very limited way in terms of the social cost of carbon), which would likely outweigh any capital investment costs required. The analysis also does not consider economic impacts such as job creation and increased wealth due to manufacturing and distribution in low carbon technologies. It simply assesses the cost benefit of heat networks compared with individual building solutions in three alternative high level future energy pathways.

The basic premise of the analysis is simple in that it is assumed that the economic potential for heat networks as assessed by the spatial model is fully met by 2050 i.e. that 20% of UK heat demand is met by heat networks by 2050. The change in energy demand to 2050 follows modelling based on the government's energy projections EEP[77]. These projections are based on assumptions of current government policies, future economic growth, fossil fuel prices, electricity generation costs, UK population and other key variables.

It is assumed that the same proportion of future demand could be met by heat networks as the model predicts for current demand.

From the economic potential modelling two types of heat network have been identified, one that relies predominantly on location specific heat sources such as waste heat from industry or thermal power plants, and one that relies predominantly on location agnostic sources such as boilers and heat pumps. Using this classification, the location specific heat sources are the same for the heat networks in all three scenarios and the location agnostic heat network sources mirror the single building solutions.

The low carbon pathways chosen were an electrification pathway where heating moves to electric solutions such as heat pumps, and a hydrogen pathway where natural gas boilers are converted to hydrogen boilers from 2035[78]. In addition, a baseline scenario was modelled where the primary energy source continued to be gas, similar to today.

The three scenarios are:

1. **Continuation of current primary heating fuel (gas):** Location agnostic heat sources for heat networks are gas CHP and gas boilers; any supplementary supply required to cover periods where the primary source is unavailable is provided by gas boilers. Single building solutions in the counterfactual are gas boilers. This is a baseline position

[77] https://www.gov.uk/government/collections/energy-and-emissions-projections (16 May 2019 update)
[78] It is important to note that results cannot be compared between scenarios and each should be considered independently. This is because the approach taken to modelling the individual building solutions in the counterfactuals are different for each scenario and as such are not directly comparable.

representing the current UK energy system. A NPV is calculated comparing the heat network solution against the building level gas boiler solution.

2. **Electrification pathway**: Location agnostic heat sources for heat networks are large heat pumps; any supplementary supply required to cover periods where the primary source is unavailable is provided by electric boilers. Single building solutions in the counterfactual are smaller heat pumps. This is a simplified decarbonisation scenario achieved essentially through electrification of heat through heat pumps only. A NPV is calculated comparing the heat network solution against a single building level heat pump solution.

3. **Hydrogen pathway**: Location agnostic heat sources for heat networks are large natural gas boilers which are gradually replaced by hydrogen boilers from 2035: any supplementary supply required to cover periods where the primary source is unavailable is provided by gas boilers to 2035 and hydrogen boilers thereafter. Single building solutions are smaller gas boilers which are replaced by hydrogen boilers over the same period. The choice of 2035 for the start of the transition is somewhat arbitrary but would roughly coincide with the gas boilers installed in 2020 coming to the end of their technical lifetime.[79] A NPV is calculated comparing the heat network solution against a single building level hydrogen boiler solution.

For each scenario, the following is calculated, based on assumptions detailed in Appendix 5: Model assumptions and the projected UK heat demand to 2050:

- carbon emissions, split out by 'traded' and 'non-traded' sectors as defined by the EU ETS scheme;
- capital costs of necessary equipment (infrastructure costs were assumed part of fuel / electricity prices);
- replacement costs (of generation equipment only);
- operational costs including fuel / electricity, and maintenance costs;
- offset costs from generated energy (i.e. CHP-generated electricity);
- carbon emissions and associated traded / non-traded carbon costs;
- air quality damage costs;
- fuel inputs; and,
- portion of which are renewable.

Capital costs were assumed to be spread equally across the time period, i.e. solutions are rolled out at a constant rate to 2050. For network scenarios, capital costs come from the spatial model with the generation plant costs for 'Location Agnostic' networks deducted from the spatial model figures. The scenario specific costs for generation plant (i.e. boiler, CHP and

[79] This analysis is based on a stylised scenario in which the hydrogen price is set by blue H_2 by 2030. https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base

ASHP costs) were then added back in in the CBA. The same approach is taken for OPEX costs.

The HM Treasury Green Book[80] social time preference rate of 3.5% was used to discount cash flows to present values. Capital costs are assumed to be spent in the same year as the asset becoming operational. For simplicity and to avoid optimism bias, the capital and fixed variable operational prices are assumed to be constant across all technologies at current prices and therefore do not capture any cost reduction that may occur. The residual value of the assets at the end of the assessment period (2020 to 2050) is factored into the analysis (as a benefit) to take account of different technology lifetimes.

The energy costs used are long-run variable costs (LRVC) of energy, which represent the costs of energy supply to society as a whole and which exclude transfers between groups. BEIS has not yet developed LRVCs for hydrogen and therefore as a proxy production costs of hydrogen, which exclude any network and storage costs, has been used. However, as these excluded costs are common to both the heat network and single building solutions, their net value is assumed to be zero.

The LRVC and the air quality damage factors and carbon prices have been taken from the IAG's 2020 toolkit (IAG 2018)81 with the exception of hydrogen[82] and emission impact of electricity displaced by gas CHP where values have been taken from bespoke natural gas CHP analysis.[83],[84]

The baseline is a business as usual (BAU) scenario, where gas is continued as the primary heating fuel, whilst the electrification and hydrogen scenarios represent scenarios with a higher degree of decarbonisation; inputs such as fuel prices and carbon prices have been set to reflect this.

Table 24: CBA scenario parameters

Parameters	Gas (baseline)	Electrification scenario	Hydrogen scenario
Electricity prices	Central LRVC	High LRVC	High LRVC
Gas prices	Central LRVC	High LRVC	High LRVC
Hydrogen prices	N/A	N/A	Bespoke
Carbon prices	Central	High	Bespoke

80 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf

81 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360044/2014_Background_Documentation_to_DECC_HMT_Supplementary_Appraisal_Guidance.pdf (section 5)

82 Scenario based assumptions from https://www.gov.uk/government/publications/hydrogen-supply-chain-evidence-base

83 https://www.gov.uk/government/publications/bespoke-natural-gas-chp-analysis

84 This estimate is from 2014 and does not capture the recent trend of renewable electricity on the grid.

The CBA has not been modelled from the investor point of view in any great detail as this assessment is at the national level and there would be a large variation in cost and benefits at specific site level. The financial NPV is therefore derived as the social NPV with the following changes in the input parameters:

- A higher discount rate of 7.5% is used;
- Use of retail fuel prices instead of LRVC [85]; and
- With no environmental and air quality impact costs considered.

No retail fuel prices for hydrogen has been developed by BEIS but this is approximated from the hydrogen production cost using:

hydrogen retail price = (hydrogen production cost) * (gas retail price)/(gas wholesale price)

for the retail prices in the domestic and service sectors.

An annual fuel saving is calculated for each of the scenarios, the average net amount of fuel used in the heat networks against the single building solutions. In the case of the baseline, the fuel used to generate electricity in the CHP have not been off-set against the fuel used to generate the equivalent electricity on the grid (fossil fuel, nuclear, renewable or through interconnectors etc).

The renewable share of fuel is calculated for the heat network in each of the scenarios. The renewables included here are the aerothermal, geothermal hydrothermal heat sources for the heat pumps only. The renewable proportion of electricity generation that powers the heat pumps has not been considered.

[85] Tables 4-8 in https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

Appendix 4: Alternative Network Potential modelling methodology

Methodology: LSOA-level network potential

An alternative method of assessing the potential for heat networks in the UK was also investigated as part of this study and is described in this appendix.

This methodology assesses the amount of heat demand in the UK at Lower layer Super Output Area level that could be served by heat networks (as supplied by location specific / agnostic sources). It uses fewer economic constraints than in the economic potential model assessment described in Appendix 3, and is more focussed on the technical potential for meeting demand through known sources of heat.

Areas of demand which can be supplied by the various heat sources were identified by:

1. Filtering the building level heat demand for those with consumption greater than 73MWh/yr. The filtered (i.e. heat network eligible) demand was aggregated to LSOA level.

2. Iterating through the location-specific heat sources to exhaust all available heat supply to eligible nearby demand. This is the demand:supply matching step. Available supply is allocated in priority of highest neighbouring LSOA demand to lowest neighbouring LSOA demand until all available supply had been allocated. Demand of LSOAs that are adjacent to heat source LSOAs (first order neighbours) is met prior to demand of LSOAs once removed (second order neighbours), and so on.

3. After allocating all the heat from the location-specific heat sources, the algorithm then assessed water sources, allocating eligible demand near to known water sources to networks fed by water source heat pumps.

4. The remaining, eligible heat demand is assumed to be met by location agnostic heat sources. Some economic constraints based on LHD were used in this step, to prevent the model allocating all remaining heat to location agnostic sources.

The heat sources have been categorised based on scale of the demand:supply matching step. Heat sources whose supply exceeded the demand of at least one of its neighbouring LSOAs are considered to be ‘large’, with the opposite considered to be ‘small’. Large heat sources are capable of meeting the demand of large district heat demands, whereas small heat sources are capable of serving local build level demand.

In some cases, the same LSOA could be supplied by both a large heat source or a small heat source and the model needs to decide which source to prioritise.

Experimentation was carried out to identify the optimal order of priority for allocating ‘large’ and ‘small’ heat sources. A limitation of this methodology was that priority of heat sources was applied through size rather than economic considerations (which were used in the economic potential model).

Two scenarios were modelled in the alternative methodology:

- **LSOA-Level Potential Scenario A**: Eligible demand that could be met by more than one source is allocated to large sources
- **LSOA-Level Potential Scenario B**: Eligible demand that could be met by more than one source is allocated to small sources

Results for both scenarios are presented in Table 29.

Table 25: Potential for heat networks by technology, based on LSOA-level demand

	Scenario A	Scenario B
Total TWh/yr	UK total	UK total
CHP Plant	8.3	8.3
Incinerators	1.1	1.1
Thermal Power Stations	0.2	0.2
High Grade Waste Heat Sources	0.4	0.4
Low Grade Waste Heat Sources	24.3	24.3
Water Source Heat Pumps	2.7	2.7
Location Agnostic Sources	46.5	49.9
Back-up Boilers	10.8	10.8
Total	**94.3**	**97.6**
As % of total heat demand	**19%**	**20%**

As can be seen from results, the two methods of heat allocation yield very similar results. The model expects ‘Location Agnostic’ heat sources like ASHPs and GSHPs to contribute the most heat. These technologies were often used in conjunction with other sources in the same network. Significant contributions are also made by Low Grade Waste Heat Sources which, in comparison to High Grade Waste Heat Sources, tend to be closer to demands for heat. Back up boilers (gas, electric or hydrogen) exist in every network as a means of meeting demand in the event of the alternative supply being unavailable, hence their contribution is also high.

It can be seen from results that the outputs from the alternative methodology are comparable to the medium uptake scenario of the preferred economic potential methodology, as described in Sections 2 and 3 of this report. This is despite the lower economic constraints and due to the difference in means of heat network propagation between both methods. Due to the greater number and precision of inputs employed in the building-level assessment, it was chosen not to report this alternative method in the main part of the report.

Appendix 5: Model assumptions

The following assumptions have been adopted in the heat demand mapping:

Number	Description of Assumption
1.	Measurements have been generalised from studies in England and Wales and applied in Northern Ireland. These include heating and cooling demand benchmarks and average building heights (by type of building).
2.	The average storey height for buildings in the UK has been assumed as 3.45m. This has been used to calculate the number of storeys per building from the OS building height data.
3.	Heating demand benchmarks were taken from BEES, as the sum of space heating and domestic hot water consumption.
4.	Cooling seasonal efficiency was assumed as 2.2.
5.	Residential properties in the UK have been assumed to not require cooling in this analysis.
6.	In areas where no gas consumption data is available (ie. The LSOA is off the gas grid or has been suppressed for disclosure reasons), building heat demand in that LSOA is based on benchmarking.
7.	Estimates for heat generation from consumption of non-gas heating fuels for building on the gas grid has been assumed to be uniform over the UK.

In the assessment of the Economic Potential for heat networks, the following assumptions have been adopted:

Number	Description of Assumption
1.	Clusters must have more than 2 buildings, and a combined demand of greater than 0.5GWh to be considered a 'heat network' in the analysis.
2.	A building must have at least 73MWh/yr of heat demand to be considered for connecting to a heat network.

In the Cost Benefit Analysis, the following assumption have been adopted:

Number	Description of Assumption
1.	It is assumed that the economic potential for heat networks as assessed by the spatial model (Table 10) is fully met by 2050 i.e. that 20% of UK heat demand is met by heat networks by 2050.
2.	The change in energy demand to 2050 follows modelling based on the government's energy projections (EEP[86]).

In the alternative methodology for heat network potential as described in Appendix 4, the following additional assumptions were adopted:

Number	Description of Assumption
1.	For the modelling of building clusters to assign WSHP and location agnostic heat sources, the 'low' LHD value was used, to reduce the constraint of economics

[86] https://www.gov.uk/government/collections/energy-and-emissions-projections (16 May 2019 update)

Appendix 6: Data sources

Name and description of data source	Date of data	Domestic / non-domestic	Geographic coverage	Source organisation / programme
LSOA gas consumption	2018	Both	GB	BEIS
LSOA estimates of properties not connected to the gas network	2018	Domestic	GB	BEIS
ECUK fuel consumed for heating	2019	Both	UK	BEIS
ONS Local Authority District to Region dataset	2020	Both	England and Wales	Office for National Statistics
Scotland Heat Map (SHM)	2020	Both	Scotland	Scottish Government
Non-domestic Ratings List	2017	Non-domestic	UK	Valuations Office Agency
OS Mastermap data - Identify buildings in GB	2020	Both	England and Wales	Ordnance Survey
OSNI Fusion – Identify buildings in NI	2020	Both	NI	Ordnance Survey
AddressBase Premium Mapping of domestic and non-domestic properties in GB	2020	Both	GB	Ordnance Survey
AddressBase Premium Islands Mapping of domestic and non-domestic properties in NI	2020	Both	NI	Ordnance Survey
Building Energy Efficiency Survey	2014	Non-domestic	England and Wales	BEIS

Name and description of data source	Date of data	Domestic / non-domestic	Geographic coverage	Source organisation / programme
(BEES) - benchmarks for heating and cooling in non-domestic buildings				
National Energy Efficiency Data-Framework - benchmarks for heating demand in residential properties	2013	Domestic	GB	BEIS
Water source heat map	2015	N/A	UK	BEIS
Waste heat research – England, Wales, and Northern Ireland	2020	N/A	England, Wales and NI	Arup, on behalf of BEIS
Waste heat research - Scotland	2020	N/A	Scotland	BRE, on behalf of Scottish Government
Incineration sites - England	2016	N/A	England	DEFRA
Incineration sites - Scotland	2016	N/A	Scotland	Scottish Environment Protection Agency
Incineration sites - Northern Ireland	2016	N/A	NI	Department for Agriculture, Environment and Rural Affairs
Incineration sites - Wales	2016	N/A	Wales	Natural Resources Wales
Mine water treatment sites	2020	N/A	GB	Coal Authority
Thermal Power stations	2020	N/A	UK	BEIS

Name and description of data source	Date of data	Domestic / non-domestic	Geographic coverage	Source organisation / programme
CHPQA	2020	N/A	UK	BEIS
Various national statistics, including DUKES and ECUK	2020	N/A	UK	UK Government

Appendix 7: Interpretation of analysis for England, Northern Ireland, Scotland, and Wales

This Appendix provides an overview of how the analysis used in this report differs by nation in the UK. The analysis aims to provide a consistent assessment of the potential for heat networks across the UK, however, due to data availability, there are some inconsistencies in the analysis which are explained below.

The main areas where there is scope for inconsistency between nations in the UK are:

- Identification of sources of low carbon and waste heat supply, which were commissioned through separate waste heat research studies.
- Estimation of heating and cooling demand, through the NCA spatial modelling.

Identification of sources of low carbon and waste heat supply

Bespoke research has been conducted for the National Comprehensive Assessment to identify sources of low carbon and waste heat in the UK, by BEIS and Scottish Government. The research builds on an existing UK wide evidence base for low carbon and waste heat, which includes CHP, Incinerators, Thermal Power Stations and Mine water pumping stations; and has specialised on certain sectors of industry for England, Northern Ireland and Wales, and Scotland separately. The following industrial sectors were investigated separately for the nations below:

England, Northern Ireland, and Wales

Cement, lime and iron and steel production, crematoria, chemical, cold stores, data centres, food and drink, other mineral industries, paper and pulp, electricity substations, supermarkets, wastewater treatment works and underground railways.

Scotland

Distilleries, breweries, bakeries, paper and pulp, laundry, supermarkets, data centres, electricity substations, wastewater treatment works and landfill.

Modelling of heating and cooling demand

Default demand methodology used for England and Wales

The methodology used to estimate heating and cooling demand in England and Wales has been considered as the default methodology for estimating demand in this report due to it being the most utilised approach. The methodology has been used to estimate heating and cooling demand in England and Wales, as well as parts of the methodology being used to estimate demands in Northern Ireland and Scotland.

The default demand methodology is described in section 2.2 and limitations have been discussed in Section 2.3.

The following tables provide a summary of how the methodology differs by nation relative to the default methodology and the potential impact these variations could have on the results.

Methodology variation in Northern Ireland

<table>
<tr><th>Description of methodology variation</th><th>Risk/Impact of variation on results</th></tr>
<tr><td>Heating and cooling demand have been benchmarked using a similar process to that used for England and Wales, i.e. with use of BEES and NEED benchmark values. The BEES and NEED studies are based on samples from England and Wales, and Great Britain respectively, therefore it has been assumed benchmarks are generalisable for application in Northern Ireland. This method has been used to impute heating and cooling demand in Northern Ireland due to lack of corresponding studies in Northern Ireland, and to maintain as consistent approach with England and Wales as possible.</td><td>The risk of generalising benchmarks for application in Northern Ireland is that heat demand in different building types could be significantly different in Northern Ireland compared with England and Wales, and Great Britain. This could impact on the location and scale of heat networks deemed to be economically viable in Northern Ireland.</td></tr>
<tr><td>OSNIF data provides footprints for individual buildings in Northern Ireland, however, it does not currently provide information for building heights. Building heights in Northern Ireland have therefore been estimated based on analysis from the NCA model for England and Wales and are an average of building heights observed in England and Wales. Building height is used to derive the number of storeys in a building that would require heating/cooling and hence influence the total floor area to multiply by the typology benchmark demand in kWh/m2.</td><td>The risks associated with generalising building height for application in Northern Ireland are:
– That the average building height in England and Wales and Northern Ireland are different.
– That there is material variation of building height by typology in Northern Ireland which is not accounted for in the method used.
Both risks could have resulted in incorrect heat demand assessments that could have influenced the size and location of heat networks deemed to be economically viable.</td></tr>
<tr><td>In Northern Ireland as a whole, the dependency on gas is not at the same level as Great Britain. Therefore, gas consumption in Northern Ireland is not a good measure of heating demand at the national or local level. Consequently, in Northern Ireland, the step for calibrating benchmarked heat demand to gas consumption has been omitted.</td><td>In the England and Wales analysis undertaken for the NCA, it was found that benchmarked heat demand was higher than heat demand derived from national consumption of fuels (including gas). As a result, the calibration step for England and Wales reduced heat demand compared with the benchmarked assessment. As this step was not undertaken for Northern Ireland it is possible that the heat demand used is slightly inflated.</td></tr>
</table>

Methodology variation in Scotland

Description of methodology variation	Risk/Impact of variation on results
Building level heating demand in Scotland has been based on the underlying data from the Scotland Heat Map. The Scotland Heat Map uses a variety of data sources to estimate demand for heat. Whilst following, in principle, a floor area benchmarking model for the majority of non-domestic buildings, it utilises CIBSE TM46[87] energy benchmarks that include both space heating and hot water demand. In general these represent a larger demand per unit area than the benchmarks applied in the rest of the UK. For the majority of domestic properties, heat demand is obtained from Energy Performance Certificates (EPCs) or the Energy Saving Trust's Home Analytics dataset (which uses EPCs as a basis for modelling). Heat demand from these two sources includes both space heating and hot water. More details of the data sources and methodology can be found in the Scotland Heat Map User Guide[88].	The results of the economic potential analysis show that there is a high potential for heat networks in Scotland compared with regions of England, Wales, and Northern Ireland. It is expected that if approaches for modelling heat demand were aligned, there would be a smaller difference in potential for heat networks between Scotland and the other nations/regions in the UK.
The Scotland Heat Map does not contain data for cooling demand, therefore, to estimate cooling demand, cooling benchmarks have been applied to Scottish buildings via the method used for England and Wales. This method uses building floor areas to which are applied a cooling benchmark. However, there have been some differences in the process for validating building floor areas in the Scotland Heat Map compared with NCA modelling in other nations. Therefore, there is scope for some inconsistency in estimates of building cooling demand in Scotland, and the rest of the UK.	It has been identified that in a small number of cases floor areas for buildings in Scotland have been omitted from the Scotland Heat Map data. Therefore, these buildings have not contributed to the total cooling demand in Scotland.

[87] CIBSE TM46: https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7evAAC

[88] The Scotland Heat Map User Guide (2.0 user guide) is available at: https://www.gov.scot/publications/scotland-heat-map-documents/

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