Community Heat Development Unit

Review of Existing Heat Networks

February 2024

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1. Background

Within the UK there are over 14,000 heat networks providing heating and hot water to approximately 480,000 customers[1]. Heat networks can be split into two categories:

- 85% of heat networks in the UK are **communal**, where a multi-household building has heating and hot water provided by a single heat source e.g. a block of flats.
- 15% of heat networks in the UK are **district**, where multiple, separate households or heat users receive some or all of their heat from a network e.g. a row of terraces.

Heat networks in the UK are typically powered by either gas boilers or gas combined heat and power (CHP)[2]. Information in the UK is limited, however government data estimate that 65% of heat networks are owned and managed by private companies[3] and 80% of connected buildings are residential properties[4].

The aim of the Community Heat Development Unit (CHDU) project is to establish a model for low carbon, community led heat networks which is replicable across the UK. This document presents a review of relevant existing and planned heat networks in the UK and overseas to inform the initial concept design.

2. Scope

This document offers a review of existing heat networks mostly in the UK with a particular focus on heat networks which:

- are heated using low carbon heat sources,
- heat domestic housing and are retrofitted to existing buildings,
- are operational,

[1] Energy Security Bill factsheet: Heat networks regulation and zoning (updated 20 March 2023) - GOV.UK
[2] https://www.theade.co.uk/assets/docs/resources/Heat%20Networks%20in%20the%20UK_v5%20web%20single%20pages.pdf
[3] 2022 Heat Network Consumer and Operator Survey - GOV.UK
[4] Energy Trends: March 2018, special feature article - Experimental statistics on heat networks - GOV.UK

- are on a community scale (less focus on very large scale networks connecting 1000s of properties).

There are numerous community-led heat network projects which are currently in development but not yet constructed. Where available, the project feasibility studies have been reviewed to identify any learnings for the CHDU project.

The emphasis has been on reviewing heat networks which are located in the UK, however a few low carbon heat networks outside of the UK are referenced where domestic examples are limited.

3. Review Process

Three steps have been followed in the process of reviewing existing heat networks and heat network development projects:

1. Review root sources including heat network funding databases, heat network developer case studies, national heat network maps. A full list of the root sources reviewed are presented in Appendix A.
2. Screen projects identified in root sources and search for more specific information on project websites, news articles and academic publications.
3. Contact relevant projects for more detailed information where required, including documented feasibility studies.

The Sharenergy team also travelled to Rocks Green, Shropshire, to visit the housing association owned biomass heat network, and Bishop's Castle to better understand the context of the proposed air source heat pump (ASHP) powered network.

4. Relevant Operational Heat Networks

A desk based review of UK heat networks identified ~40 operational heat networks which use a low carbon primary heat source to heat multiple buildings, and which may offer some useful learning to the CHDU project. The most relevant projects are summarised below, categorised by the type of primary heat source. Examples of operational heat networks from outside the UK are also referenced where there is limited domestic experience. A short definition of each heat source is provided in Appendix B.

4.1. Ground Source Heat Pumps (GSHPs)

4.1.1. Central Plant

There are a number of small operational heat networks in the UK using a centralised GSHP as a primary heat source within a community scale project.

Comberton Village College

Comberton Village College[5] successfully replaced 16 individual gas boilers with 11 heat interface units connected to a low temperature heat network. GSHPs with a total capacity of 1MW_{th} raise the network flow temperature to 65°C (55°C return) which is high enough to be compatible with 70% of the existing radiators within the college, requiring only 30% of radiators to be upgraded. 140kWp of rooftop PV panels are used to provide some of the power requirements of the GSHPs. The design assumed a coefficient of performance (CoP) of 2.7 with carbon emissions expected to drop to 30% of the original gas heating system.

Swaffham Prior

At Swaffham Prior in Cambridgeshire, a centralised heat network has been installed with a 1.6MW closed loop GSHP supported by 130 boreholes, bolstered with a 500kW ASHP and 200m^3 thermal store to manage peak demand[6] (figure 1). Four electric boilers provide back-up heat; gas boilers were discounted due to the prohibitive cost of connecting to the gas main. A 2018 feasibility study recommended an open loop GSHP but a hydro-thermogeological assessment identified the underlying “green-sands" geology to be unsuitable[7]. Using ASHPs to provide the full heat load was rejected at the feasibility study stage due to the high capital costs of the proposed heat pump and the corresponding low RHI tariff compared to GSHPs.

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[5] https://www.cibsejournal.com/case-studies/case-study-comberton-village-college-heat-network

[6] https://www.cambridgeshire.gov.uk/residents/climate-change-energy-and-environment/climate-change-action/low-carbon-energy/community-heating/swaffham-prior-heat-network/about-swaffham-priors-heat-network/how-the-heat-network-works

[7] Bouygues Energies and Services and Infinitas Design (2018), *Swaffham Prior Heat Network, Techno-Economic Feasibility Study*, Works Package 2.

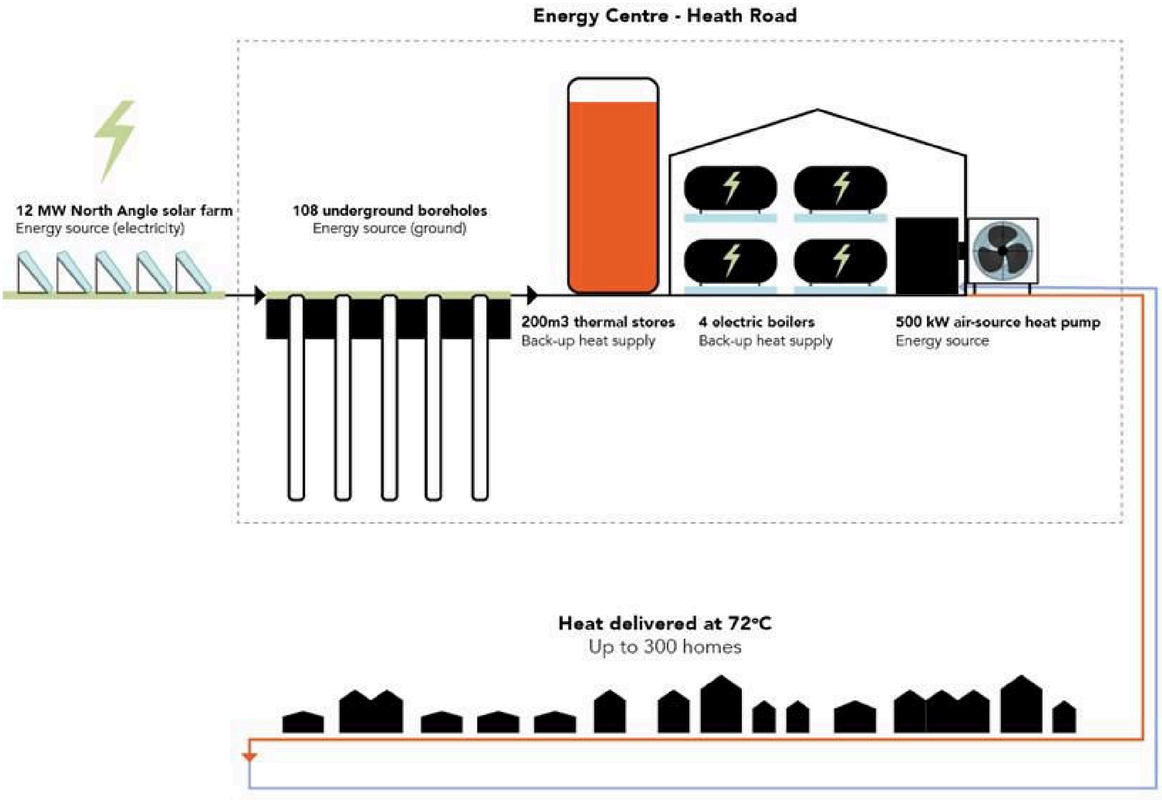

Figure 1: Swaffham Prior heat network

The business case for Swaffham Prior assumes at least 160 of the 330 properties will sign up to the network, representing an annual thermal demand of ~2.5GWh. There are no large anchor loads in Swaffham Prior, excluding a pub and small school, all connected buildings are domestic properties. The financial feasibility of Swaffham Prior is enabled by strategic investment from Cambridge County Council alongside significant funding from the Heat Networks Investment Project (HNIP). A HNIP grant of £2.8 million covering 50% of the construction costs was requested, which improved the predicted 60 year IRR from 3.83% to 5.03%[8].

The commercial structure of the project is outlined in figure 2. The heat network pipework is owned by a council owned Special Purpose Vehicle (SPV) which satisfies the requirements of bodies receiving HNIP funding. This Pipe Company owns the network pipework, but not the energy centre, and generates income through trench rental to broadband providers and a standing charge for transmission of heat around the network.

[8] Swaffham Prior Community Heat Project – Investment Case

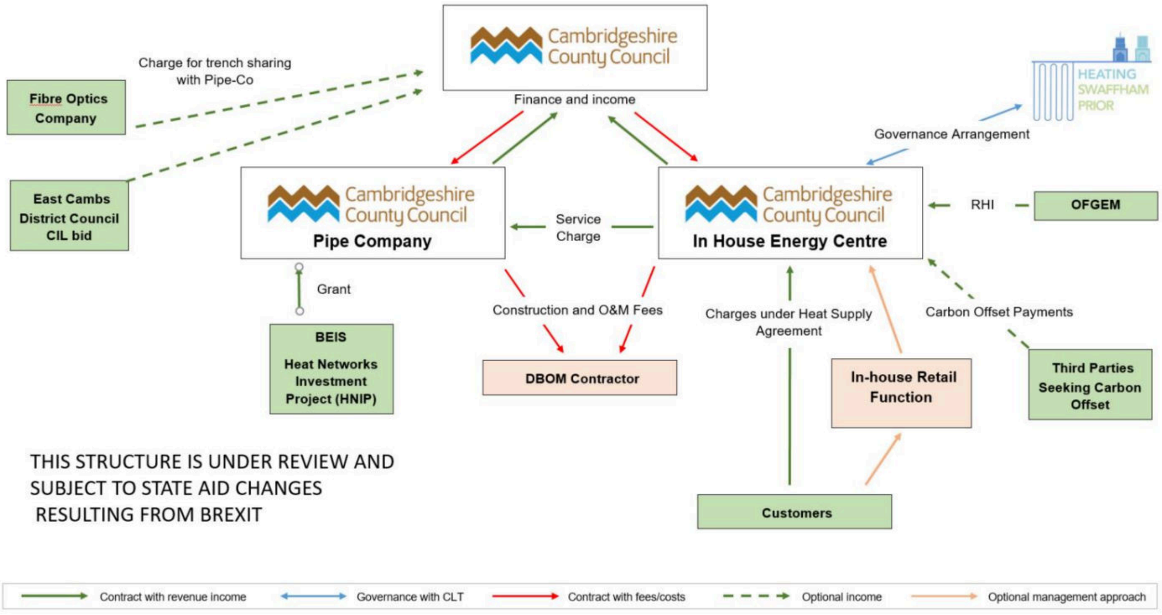

Figure 2: Proposed commercial structure of project

The energy centre and heat generation is owned by the council with income provided by a standing charge (£313 - £471 depending on house size) and metered usage (9.86p/kWh). Electricity is provided at £0.05/kWh from the 12MW North Angle solar farm (equivalent to the grid wholesale price in 2021) via a private wire. Electricity generated at North Angle solar farm is expected to provide 95% of the scheme's energy requirements. In total, 52% of the project's revenue is expected from heat sales, 34% is from carbon credits and Climate Change Levy and 14% from Renewable Heat Incentive (RHI) payments.

Flagship Homes

Flagship Homes[9] have developed four small heat network projects using centralised, closed loop GSHPs retrofitted to properties at housing association sites in Norfolk and Suffolk resulting in 70% savings in users' energy bills. There are a mix of housing archetypes across the three sites including flats (in two storey semi-detached houses), bungalows and detached houses built between the 1970s and 1990s, with EPC ratings of C or D. The heat networks mostly replace electric storage heaters, requiring the installation of wet heating systems in individual homes and metered heat interface units (HIUs).

The heat networks are modular and connect 20-30 homes to a central plant room with pairs of GSHPs varying between 46kW and 90kW each, and 2m3

[9] Landmark renewable heating scheme cuts costs for Flagship residents - Finn Geotherm

storage tanks. The central plant includes domestic scale plumbing infrastructure (e.g. standard hot water cylinders) allowing maintenance to be completed by existing contractors. The first heat network in Watton, South Norfolk, was installed in 2017 with the latest project in Felixstowe installing 6 phases (each of ~20 homes) in 2021. The projects are funded in part by the non-domestic RHI, providing quarterly payments over 20 years.

Similar to Swaffham Prior, multiple feasibility studies of heat network projects in smaller, rural communities have identified GSHPs as being the most viable means of providing heat to a network, compared to other low carbon technologies. These projects are discussed in section 5.

4.1.2. Ambient Shared Loop

Stithians - Kensa Heat the Streets

The Kensa Heat the Streets[10] project in Stithians, Cornwall, is the only operational ambient shared loop network in the UK that was identified during this review (excluding projects which connect a couple of households to a single borehole). In 2023 Kensa installed ~100m deep borehole arrays (42 boreholes) and network pipework underneath the Stithians streets to which individual households connect, extracting heat using GSHPs. Access to the network is charged using a monthly standing charge of £25[11] with users powering their choice of GSHP from their domestic electricity supplier. The relatively low standing charge is partly achieved by Kensa's ambient shared loop being designed to be entirely passive, without ongoing operational costs.

The trial scheme in Stithians is covering the £3,500 heat pump fee and installation costs, which would normally be payable by the individual household. Estimated monthly costs for Stithian residents is £130 vs £141 for individual oil heating, a saving of £11 per month, however, this is dependent on market electricity prices since the GSHPs are powered by the user's domestic electricity supplies.

4.2. Water Source Heat Pumps (WSHPs)

For the purposes of this review, projects using water source heat pumps as their primary heat source are split into four sub-categories:

- Mine water: water is pumped from flooded, subsurface mine workings

[10] https://heatthestreets.co.uk/category/stithians/
[11] The Cornish village getting its heat from beneath the street

- Fresh water bodies: water is pumped from surface rivers or lakes
- Sewage: heat is extracted from waste sewage water
- Marine: heat is extracted from sea water

4.2.1. Mine water

There are a large number of abandoned mine workings across the UK[12] many of which are flooded. The temperature of water within flooded mine workings is typically higher than surface water sources and experiences less seasonal variation.

A review of the performance of mine water heating and cooling systems produced by the University of Strathclyde in 2021[13], summarised a number of operational and decommissioned projects in the UK and abroad. Mine water heating schemes in the UK fall into three categories:

- Decommissioned communal or small heat networks
- Operational heating schemes (a single heat user)
- Operational heat networks (multiple heat users)

Decommissioned Small Heat Networks

Mine water heat has been utilised by a number of housing associations in Scotland as a means for heating communal heat networks. Shettleston housing association developed an open loop scheme to heat a 16 unit social housing complex with a 65kW heat pump. Although operational for 20 years, the ongoing maintenance burden of cleaning ochre and particulates from equipment, and lack of suitably skilled contractors, led to the scheme being decommissioned.

Similarly an 18 unit social housing block in Lumphinnans was heated using a 65kW heat pump to extract heat from 12°C-14.5°C mine water in a 172.5m borehole. Oxygenation of the return flow in the reinjection borehole resulted in ochre precipitation, eventually clogging the open loop system, which caused the scheme to be decommissioned.

A private mine water heating scheme was developed at Llwyn Lanc Uchaf farm in Crynant, Wales, using a 35kW heat pump with separate abstraction and reinjection boreholes to heat farm buildings. Similarly to the Scottish schemes, ochre build-up ultimately rendered the system too expensive to operate.

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[12] Interactive Map Viewer | Coal Authority
[13] A review of the performance of minewater heating and cooling systems

Operational Heating Schemes

There are a number of operational heating schemes in the UK which demonstrate feasibility of mine water to provide heat, although these schemes are small-scale and cannot be viewed as heat networks.

A small standing column system is operational at Markham, near Caerphilly,[14] using a 20kW_{th} heat pump to heat an office complex. This system has avoided oxygenation and hence clogging since the water passes through the heat pump and back into the borehole (at a depth 15m lower than abstraction) without atmospheric contact. The actual operational CoP of the system was calculated as 1.9 while operating at a flow/return temperature of 52°C/45°C and is limited by the electricity demand of pumping water from a depth of 170m. A study in 2015[15] suggested that a CoP of 2.7 could be achieved pumping from a depth of 120m and a CoP of 3.95 at a depth of 15m below the surface.

Similarly an open loop scheme at the National Coal Mining Museum at Caphouse heats an exhibition building using a 10kW_{th} heat pump. A higher CoP of 3.5-4 is achieved but this is largely due to mine water pumping costs being ignored due to the heat pump using treated mine water which has already been extracted from the mine workings.

Dawdon mine water treatment scheme in County Durham pumps water from the local mine for treatment to avoid contamination of aquifers which supply an estimated 30,000 people with drinking water. The scheme extracts heat from the 20°C untreated mine water using a 12kW WSHP to heat the offices and buildings which comprise the treatment scheme. Rooftop solar reduces electricity costs. The scheme is aiming to expand to use the entire 150L/s flow of untreated mine water to heat a network of 1500 new house at Seaham Garden Village using a 6MW WSHP[16], demonstrating the heating potential of mine water in the UK.

[14] Water from abandoned mines as a heat source: practical experiences of open- and closed-loop strategies, United Kingdom
[15] https://irep.ntu.ac.uk/id/eprint/26742/1/PubSub4063_Al-Habaibeh.pdf
[16] Seaham Garden Village - Coal Authority

Operational Heat Networks

One operational district heating network was identified in the UK which uses mine water as a heat source. The Gateshead District Energy Scheme[17], predominantly heated by 4MW of gas CHP, had a £15.6m extension[18] to use a 6MW water source heat pump to extract heat from mine water in a coal seam 150m below ground level, via a pair of boreholes. Mine water is reinjected into a seam closer to ground level via a single borehole and a fourth borehole balances water pressures between the two seams, figure 3. The network provides heat to 350 social housing customers and public buildings with planned expansions to cover another 270 homes[19].

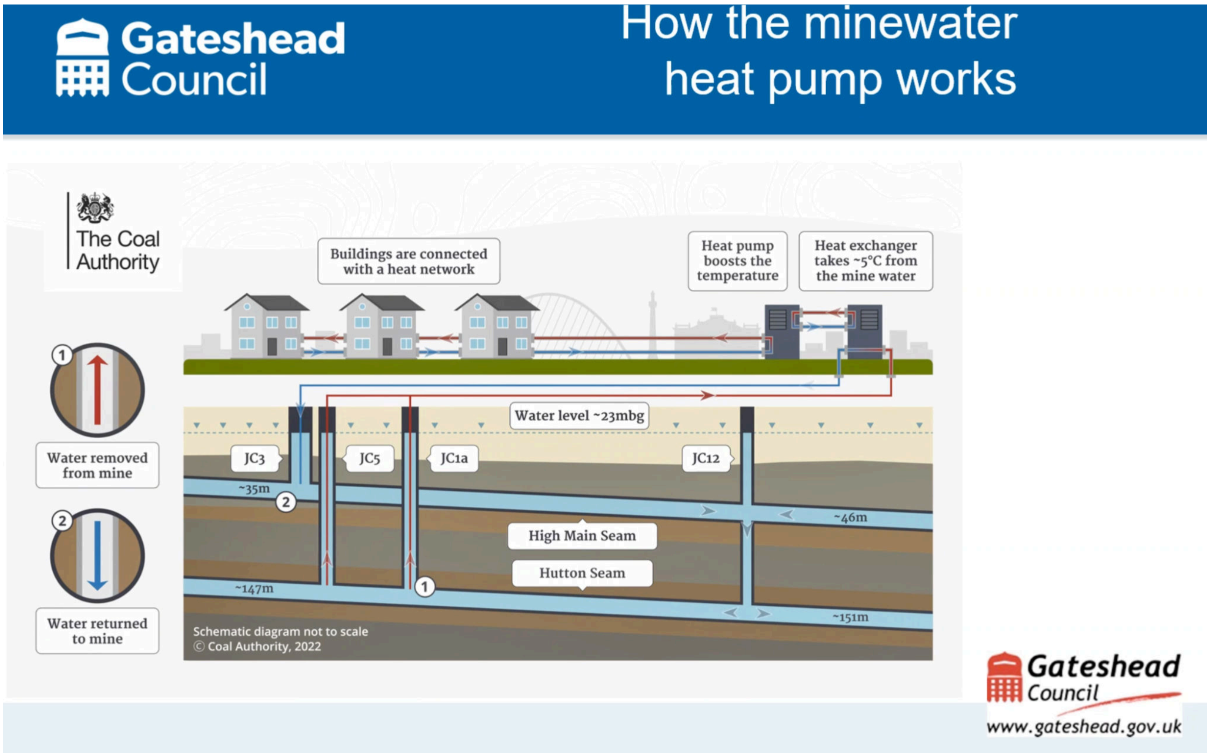

Figure 3: Gateshead District Heating Scheme, mine water heat system

4MW of solar is being installed to provide electricity to the heat pumps and supply electricity directly to customers (in additional to that generated by CHP) via a private wire network[20]. This private wire network was installed during the first phases of the heat network project (CHP only) with electricity sales being critical to financial viability of the whole system. Centrica installed and now

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[17] Gateshead's District Energy Network, including mine water heating, to deliver carbon reductions
[18] Heat networks project pipeline: July - September (Q3) 2023
[19] Mine water energy scheme at Gateshead - Coal Authority
[20] Gateshead District Energy Scheme

manages 3MW of battery storage within the private wire grid to help provide peak power to users and frequency response to the national grid.

4.2.2. Rivers

In 2015 DECC published a water source heatmap layer identifying the available heat capacity of water sources in England and proximity to urban locations with notable heat demand[21]. A key conclusion is that smaller urban areas in England with lower annual heat demands (<500GWh combined) located on larger rivers can have their entire heat demand satisfied by the river alone (see heat map in Appendix C). There are a few examples of heat networks in the UK being powered by river base WSHP and more examples of networks in development e.g. Exeter City Centre, Queen's Quay Glasgow and Mersey Heat in Liverpool.

Viking Heat Network

Perhaps the most relevant operational heat network which uses a river based WSHP in the UK is the Viking heat network located on the south bank of the River Tyne at the outskirts of Jarrow. With £4.6m of funding from the European Regional Development Fund, the network was developed by South Tyneside Council to heat three residential tower blocks (which already have communal heat networks installed) and multiple public buildings including a leisure centre[22]. The project is expected to receive £100k of annual RHI payments[23].

Figure 4: 700kW water source heat pump used in the Viking Heat Network

[21] Water source heat map layer
[22] https://www.southtyneside.gov.uk/article/3772/Overview
[23] https://publications.southtyneside.gov.uk/updates/2023-2024/q1/

The network is heated using a 700kW WSHP, figure 4, extracting heat from the 12°C river water in the Tyne. Water is pumped around the network at a flow temperature of 75°C-80°C ensuring compatibility with existing heat systems. Power is provided by 1MW of solar and gas CHP, which also provides additional heat, with 650kWh of battery storage. Figure 5 illustrates how the weekly heat demand throughout the year is supplied by the WSHP (blue), gas CHP (green) and gas backup boilers (red).

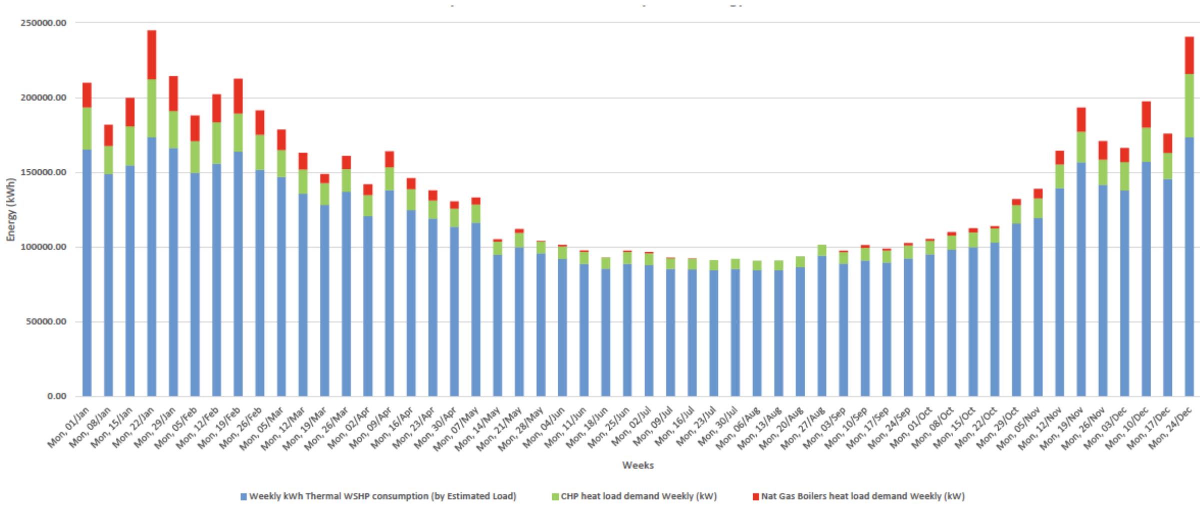

Figure 5: Weekly heat supply split by technology[24]

A private wire follows the route of the heat network connecting the solar farm and gas CHP to council buildings to make use of any excess electricity that's generated.

The core financial model expects that the payback period of the WSHP based heat network and private wire scheme will be 45 years (after the grant) if just supplying the initial 10 council owned buildings. This is predicted to offer a £94k cost saving over the business as usual scheme buying gas and electricity from the grid for heat and power respectively. Connection of a hospital site to the network and agreement to supply heat at 7.75p/kWh and electricity at 8.2p/kWh is expected to generate an additional £307k of annual revenue, reducing the payback period of the council's investment to 15 years (after the grant).

The initial route proposal for the network is presented in figure 6, with the energy centre highlighted in red and connected buildings highlighted in blue.

[24] G. Hosford/C. Liddle (2019), Viking Energy Network, Jarrow (VENJ), Mechanical and Electrical Services, Stage 3 - Modelling and Concept.

The length of the spine of the initial network is illustrated in orange and is ~3.4km long.

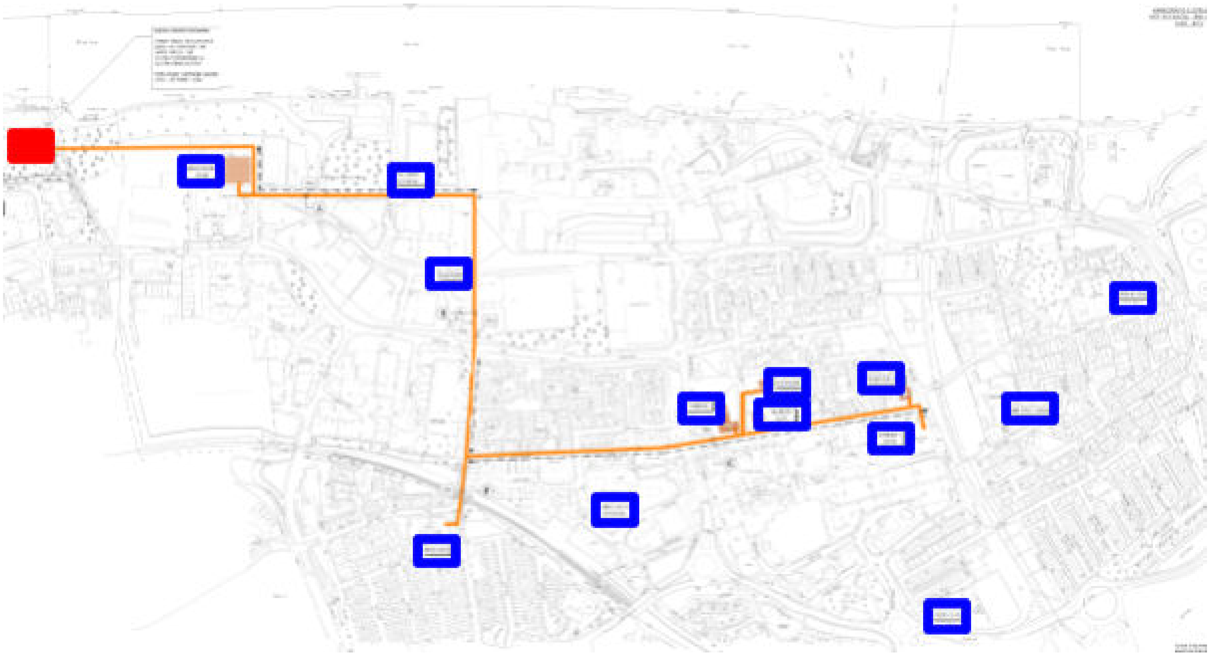

Figure 6: Preliminary route of heat network pipework and private wire

Bristol City Centre and Glasgow Queen's Quay

Vattenfall/Bristol City Leap[25] are developing a Bristol city centre network mostly focusing on connecting new, larger developments initially to finance the upfront CAPEX. Heat is being extracted from Bristol Harbourside using a 3MW WSHP, the largest in England. The Queen's Quay[26] development in Clydebank, Glasgow, has installed a 2.65MW WSHP heat pump providing heat to a network of old (75°C/60°C flow/return) and new buildings (70°C/45°C flow/return). The network is expected to operate with a CoP of 3.1.

Fruit Farms

Although not heat networks, there are a couple of examples of fruit farms using heat network scale WSHPs to extract heat from rivers to heat greenhouses. The Hunt Hall Partnership have installed an 8.8MW WSHP on the river Loddon and Clock House Farm have installed a 10.6MW WSHP on the river Medway. Both projects use very large heat pumps compared to those currently installed in UK heat networks, illustrating the potential scale achievable by this heat source.

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[25] https://www.bristolcityleap.co.uk/heat-networks/
[26] https://www.cibsejournal.com/case-studies/a-new-era-for-heat-queens-quay-heat-pump/

Figure 7: Clock House Farm pumping infrastructure (bottom left) and energy centre (top right) adjacent to 6.5 hectares of heated poly tunnels

Mannheim

In Germany, a 28MW WSHP has been installed on the Rhine supplying ~3,500 households with heat as one of five “living lab” projects in the country focused on energy transition[27]. The WSHP has been connected into an existing heat network which delivers heat to customers at around 85°C to help reduce the fraction of heat generated through coal CHP. There are plans to connect renewable electricity generation to the heat pump. The heat pump can extract up to 700l/s of water from the Rhine[28] at a temperature of 20°C in summer and 5°C in winter, and reduces the temperature between 2°C and 5°C before discharging it back into the river.

4.2.3. Sewage

There are a few examples of operational heat networks in Scotland which extract heat from sewage water.

Borders College, Galashiels

A small scale heat network at the Borders College in Galashiels has been operating since 2015[29]. Two 400kW centralised WSHPs transfer heat directly from untreated wastewater in the town sewer, heating a network connecting 3

[27] https://www.siemens-energy.com/global/en/home/stories/mvv-mannheim.html#:~:text=At%20the%20 Mannheim%20site%2C%20the,up%20to%2099%20%C2%B0C
[28] River Heat Pump in Mannheim Supplies Climate-Friendly Heat - energiewendebauen.de
[29] Borders College - Scotland

buildings of mixed archetype (Victorian, 1960s and new build). The system is owned and operated by SHARC Energy Systems (SPV) who sell heat to the Borders College saving them £10,000 per year compared to the previously installed gas boilers. Sewage temperatures range between 7°C-8°C in winter and 13°C-16°C in summer. The system provides 1.8GWh[30] of annual heat operating at a flow temperature of 50°C-60°C and runs efficiently with a reported SCoP of >4. The configuration of the system is illustrated in figure 8.

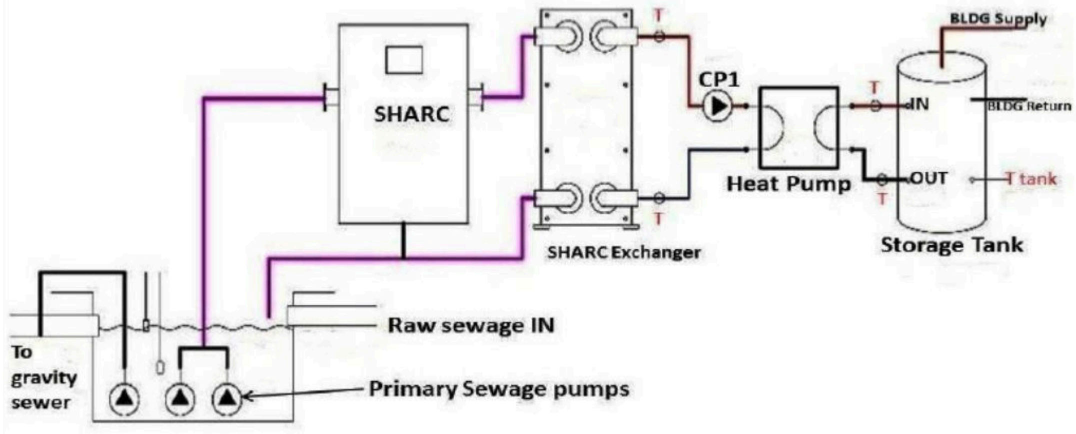

Figure 8: Configuration of Borders College sewage heat pump

Stirling Heat Network

A £6m heat network developed in Stirling has an energy centre located at a Scottish Water waste treatment plant housing two 330kW WSHPs[31]. The WSHPs are powered using electricity from an existing gas CHP engine which also provides heat to the network and wastewater treatment processes, figure 9. Heat is sold to Stirling Council who operate the network, providing heat to a mixture of public buildings and private businesses via a low temperature heat network (60°C/40°C flow/return). Heat users receive a 10% cost saving over compared to using their conventional gas boilers[32]. The project benefitted from £2m of investment from the Scottish Government Low Carbon Infrastructure Transition Programme and Non-Domestic Renewable Heat Incentive.

[30] Borders College and SHARC
[31] CHP case study - Stirling Energy Centre
[32] Written question and answer: s6w-05904 | Scottish Parliament Website

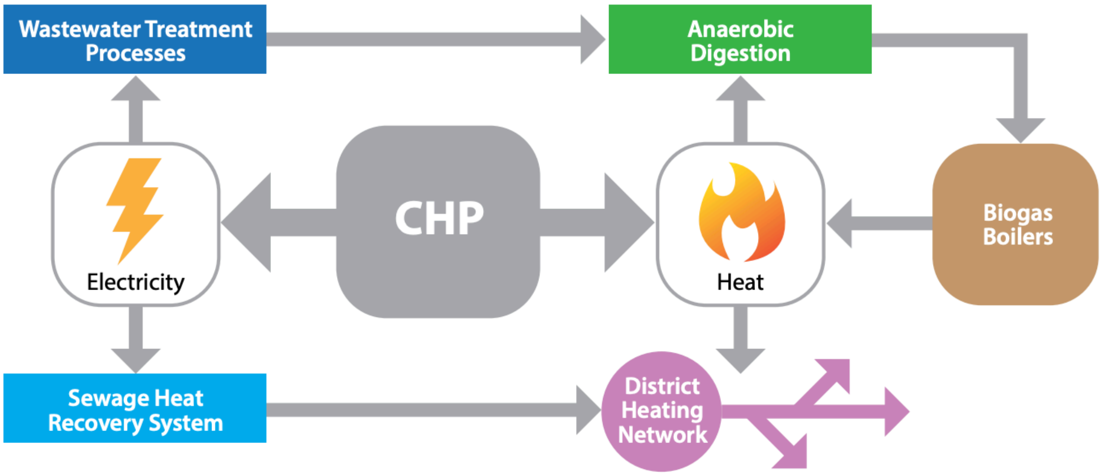

Figure 9: Configuration of heat sources in Stirling heat network

4.2.4. Marine

There are no examples of operational heat networks within the UK which extract heat from marine environments. A review of heating projects identified a single example of a heat network scale heat user in the UK: Plas Newydd House, a National Trust property in Anglesey. In 2014, the National Trust spent £600,000 installing a 300kW WSHP at the property to replace the existing oil boilers[33]. The system operates at a CoP of 3.0-3.2 and provides a saving of £30,000 per annum once RHI payments are included. Gas boilers provide backup heating and increase heat in the system during times of peak demand.

[33] https://cmscoms.com/wp-content/uploads/2016/02/NT-Heat-Pump-PlasNewydd_v2.pdf

Figure 10: Plas Newydd House, sea water heat exchanger and pump house[34]

Drammen, Norway

Marine based WSHPs have been installed in large district heating networks outside of the UK. In Drammen, Norway, a 13.2MW WSHP has been installed in an existing district heating network, drawing heat from the adjacent fjord. The network is a very large centralised network providing heat to >60,000 properties and is owned and operated by the municipality and a private energy company. The WSHP extracts 4°C of heat from 8°C water using an ammonia coolant and operates the network at 90°C flow and 60°C return temperature allowing old and new buildings to connect to the network[35]. The seasonal CoP measured over 7 years is reported as 3.05[36] with the potential to increase by adding cooling demand to the network. 8MW of biomass and 30MW of backup gas boilers also provide heat to the network. Including the WSHP within the network has resulted in significant cost savings (~£2 million per year).

Another example of a heat network using marine based WSHPs outside the UK is a 60MW heat pump in Esbjerg which is powered using electricity generated by

[34] https://www.kimpton.co.uk/marine-source-heat-pump-plas-newydd/
[35] https://www.bbc.co.uk/news/business-31506073
[36] Heat Networks Investment Project

offshore wind turbines[37], this is of a considerably larger scale than the focus of the CHDU project.

4.3. Air Source Heat Pumps (ASHPs)

There are limited examples of large scale ASHPs being used in operational heat networks within the UK. All of the projects identified predominantly supply heat to communally heated housing association blocks of flats, which have a relatively high thermal density. Note that Swaffham Prior uses a hybrid solution where ASHPs bolster the closed loop GSHP system, discussed in Section 4.1.1.

Bunhill, Islington

The only example of an operational centralised district heat network in the UK, which uses ASHPs as the primary heat source, is the Bunhill heat network extension in Islington, London. ASHPs are used to extract heat from a Transport for London tube air vent to heat the Phase 2 extension to the existing Bunhill gas CHP heat network.

Figure 11: Bunhill Energy Centre housing the ASHP, tube vent and store

[37] https://www.man-es.com/discover/esbjerg-heat-pump

The energy centre, figure 11, houses a 150m^3 thermal store and the 500kW ASHP[38] which receives electricity from two gas CHP units with a combined output of 700kW. Electricity is also sold to the grid.

The network extension supplies 550 existing buildings with high densities of heat demand, including: council and housing association owned blocks of flats, two leisure centres and a primary school. The domestic properties were previously connected to communal heat networks heated using gas boilers, which remain in-situ to provide backup heating.

NG Homes, Glasgow

ASHPs have successfully been installed by NG Homes to heat communally heated blocks of flats in Glasgow. At Balgrayhill, electric overnight storage heaters were replaced with wet heating systems heated by shared ASHPs located on the tower block roofs[39]. Individual homes were connected using individual HIUs which allowed heat usage to be metered and users to adjust temperatures within their properties. Residents' electricity costs have reduced by 60-70%.

On the Carron Estate,[40] seven tower blocks had their heating system upgraded from a mixture of electric storage and electric wet systems to a heat network heated using ASHPs. The ground mounted ASHPs are partially powered by solar PV installed on three of the tower block roofs, connected by private wires (figure 12).

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[38] https://colloide.com/app/uploads/2023/04/Colloide-and-Danfoss-Bunhill-2-Case-Study.pdf

[39] https://www.gov.scot/publications/capital-projects-supported-through-the-low-carbon-infrastructure-transition-programme/

[40] https://www.gov.scot/publications/social-housing-net-zero-heat-fund-q1-2022/pages/2

Figure 12: Roof mounted ASHPs at Balgrayhill and solar PV on the Carron Estate

Similarly, the Hebburn Renewable Energy scheme in Gateshead installed a heat network connecting a number of high rise flats and a large public leisure centre/library complex. The network is predominantly heated by two 450kW centralised ASHPs which are powered by on-site gas CHP and solar PV. A mine water scheme was considered but borehole investigations indicated stability issues.

Vestervig

There are a few examples of ASHPs being incorporated into existing district heating systems in Denmark. Danish district heating provider Vestervig Fjernvarme installed a 1.2MW ASHP to enable reduced usage of the 4.6MW wood-chip boiler which heats the network, allowing it to be shut off during summer. The heat pump has a seasonal coefficient of performance (SCoP) of 3.2 and heats a large 2,000m^3 insulated storage tank while it's windy and electricity is cheap[41]. The energy centre including the storage tank, ASHP and biomass boiler housing is shown in figure 13.

[41] Danish District Heating Provider Phases Out Fossil Fuels with CO 2 Heat Pump

Figure 13: Vestervig Fjernvarme ASHP and biomass energy centre

4.4. Biomass

Biomass is the predominant heat source used in low-carbon heat networks in the UK with a large number of networks being developed in the early 2000s and 2010s.

Rocks Green

Example schemes include Rocks Green, a housing association estate built in 2008 with 91 homes connected to a biomass district heating network. Heat is provided by 2 x 150kW wood chip boilers backed up by 2 x 200kW oil boilers. The relatively low thermal demand of the properties, use of underfloor heating and installation of HIUs which do not require domestic hot water tanks, allows the network to operate efficiently at low flow and return temperatures of 60°C and 45°C. This translates to relatively low heating and hot water costs with one resident reporting paying ~£600 annually for a 2 bed house.

Ignis Wick

FES Group Ltd operates a larger biomass heat network in Portree, Skye[42] covering 200 domestic properties (mostly council owned), a distillery, a council building and district hospital. The 3.5MW biomass boiler generates steam which is sold directly to the distillery for use in the distillation process. The average

[42] Ignis Wick Energy Centre and District Heating Scheme | FES Group Ltd

cost of heating and hot water per household was reported as £500 per year in 2022[43].

Community Owned Networks

The only community owned heat networks in the UK are biomass. This review identified three community owned and operated heat networks of a similar scale which use biomass as a primary heat source: Springbok Wood and District Heating, Douglas Community Ecoheat and Woolhope Woodheat.

Springbok Sustainable Wood Heat Co-op[44], a community owned organisation, owns and runs a small district heating system which sells heat primarily to Care Ashore, who own a large Victorian care home, and residents living in a mix of residential blocks, small houses, maisonettes and bungalows, figure 14. Two 199kw Herz biomass boilers heat the system which is split across three heat mains: one to the care home fed by a single boiler, two to the remaining properties fed by the second boiler. Backup is provided by pairs of oil boilers and 5000l storage tanks. Initial CAPEX of the project was funded by £425,000 raised through two community share offers. A key driver for the project was that the properties were off the gas grid, and it created a local market for wood chip, promoting and incentivising active management of local woodlands.

[43] https://www.johnogroat-journal.co.uk/news/hundreds-feel-the-benefits-of-wick-district-heating-scheme-269066/
[44] https://www.springbokwoodheat.co.uk/the-springbok-district-heating-system/

Figure 14: Extent of Springbok heat network

Douglas St Bride's Community Group installed 75kW and 100kW biomass boilers to heat a small network, replacing oil boilers in three buildings. A trading subsidiary, Douglas Community Ecoheat[45], sells heat on a not for profit basis to the community centre, local bowling club and church. The two boilers feed a 5000l thermal store which then connects to the separate heating systems of the three properties via heat exchangers. This system differs from a normal district heating system in that each building is connected to the energy centre by a unique hot water main, with heat usage monitored centrally rather than at a metre at each property.

The Woolhope Woodheat project in Herefordshire is a Community Co-operative who installed a biomass boiler at Canon Frome Court, heating a communal heat network of 20 flats within the Georgian Manor. The heat network saves 20% on users' heating bills compared to the previously installed individual gas and oil boilers. 3 LPG boilers provide back-up heat and help the system meet peak demand.

[45] https://www.stbridescentre.co.uk/files/Ecoheat-Board.pdf

4.5. Solar Thermal

There are multiple examples of solar thermal contributing to heat networks in Europe[46], including examples of community owned, centralised heat networks in Germany. These networks mostly use biomass as a primary heat source with solar thermal typically meeting 10% and 20% of the annual heat demand, mostly during the summer months. Use of solar thermal in the summer also allows for boilers to be switched off for extended periods, extending their life.

Mengsberg, Germany

An example of a community owned network utilising solar thermal in Germany is the village of Mengsberg, in Hesse[47]. The €6 million centralised network is heated by a 2,950m^2 solar thermal array meeting ~20% of the heat demand combined with a 1.1MW wood chip boiler (~80% of annual demand), 1.6MW biogas boiler (1%-2% of annual demand) and a 300,000L thermal store. The combined heat sources supply 150 households with hot water at 85°C meeting the annual heat demand of 4GWh.

Figure 15: Mengsberg solar thermal array and biomass energy centre

[46] https://task68.iea-shc.org/Data/Sites/1/publications/Solar-District-Heating-Info-Package-of-IEA-SHC-Task-68.pdf
[47] https://task44.ieabioenergy.com/wp-content/uploads/sites/12/2023/10/Task-44-Best-Practice_Mengsberg_Germany.pdf

5. Feasibility Studies - Community Led

A review of publicly available information has indicated that there are limited examples of community led, operational, low carbon heat networks, however there have been multiple feasibility studies commissioned. These studies have generally been commissioned by community groups who have a desire to decarbonise their heating systems and have often been financed using RCEF[48] funding. This section discusses the conclusions from feasibility studies published by 12 community led heat network projects.

5.1. Primary Heat Sources

Of the 13 community heat network projects reviewed, most projects identified a district heating network as being more financially viable than individual ASHPs. 9 projects identified ground source heat pumps as the most viable means of providing low carbon heat to the heat network, 2 projects recommended centralised ASHPs and 1 project recommended a WSHP.

11 of these projects recommended a centralised heat network, where hot water is heated to a usable temperature at an energy centre and piped to individual users. 1 project recommended a decentralised, ambient loop network with individual heat pumps installed at each user.

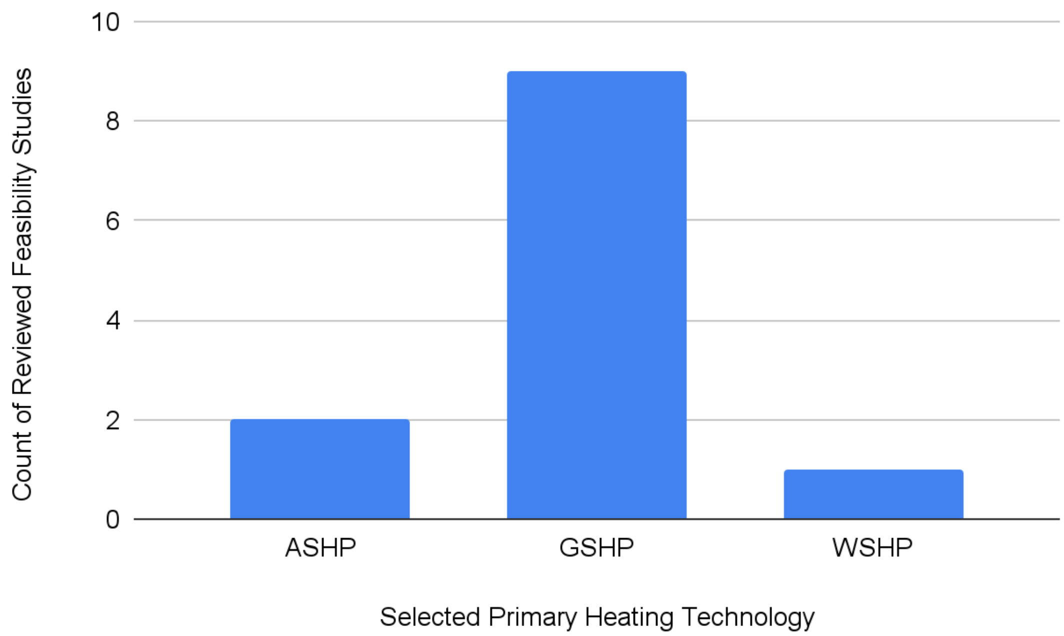

Figure 16: Primary heating technologies recommended in reviewed feasibility studies

[48] https://www.gov.uk/guidance/rural-community-energy-fund

5.1.1. Ground Source Heat Pumps

The types of GSHP recommended in the heat network feasibility studies are illustrated in figure 17.

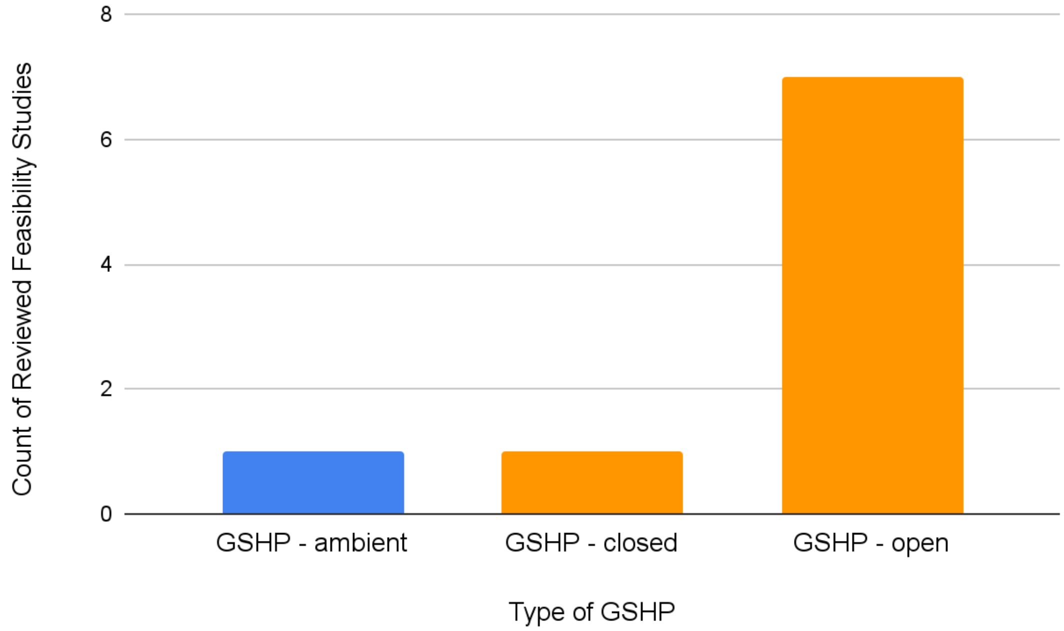

Figure 17: Types of GSHPs recommended in reviewed feasibility studies

Open Loop GSHP

This is the most common type of GSHP recommended due to the typically lower capital costs of accessing the heat source compared to closed loop systems. Seven projects, located at Bildeston[49], Brightwell-cum-Sotwell[50], Kings Langley[51], Shenstone[52], Shoreham[53], Stonnall and Upper Heyford[54], were recommended this heat source in a centrally heated network.

Of these, the most financially viable was Bildeston, predicting a 40 year IRR of 10.3%, heating 536 properties including a mix of domestic housing and some larger anchor loads. King's Langley is a much larger network of 1136 buildings seemingly dominated by domestic housing and is less viable, predicting a 40 year IRR of 4.7%

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[49] Heating Bildeston Feasibility Study
[50] Brightwell-cum-Sotwell Executive Summary
[51] Kings Langley Feasibility Study
[52] Shenstone and Stonnall Feasibility Study
[53] Brighton & Hove Energy Services Co-Operative (2022), *Rural Community Energy Fund, Stage 1 - Feasibility Report*.
[54] Heat Upper Heyford Feasibility Study

A heat network at Shenstone is marginally viable predicting a 30 year IRR of 0.9% with an open loop GSHP despite making use of existing water treatment pumping infrastructure and its borehole. The IRR value increases to 2.4% with the installation of a 1.9MW solar PV array to power the heat pump. Similarly, a feasibility study at Shoreham predicts a marginal 25 year IRR of 2.0%, even with an unexpectedly high uptake of 80% of households making up the core of the village.

Brightwell-cum-Stowell, Upper Heyford and Stonnall predict negative or very low 30 year IRR values. This is in part due to them not including local renewables generation in the final financial calculations.

Closed Loop GSHP

One project at Cranleigh[55] recommended a closed loop GSHP to centrally heat a network. Closed loop GSHPs involve more groundworks than open loop (more boreholes which may also need to be deeper) to meet a given heat demand however are potentially more replicable since they do not require the presence of a local aquifer (not present at Cranleigh). The study suggested a 6.78% IRR after 30 years assuming ~2% of the village signed up (65 households and 16 council owned buildings).

Ambient Loop GSHP

One project recommended an ambient network coupled with network owned individual heat pumps. The feasibility at Greener Great Coxwell[56] was focused on a small village of 110 houses with amongst the lowest annual heat demand of the studies reviewed (2.4GWh). This low heat demand and lack of anchor loads, meant that a centralised GSHP heat network offered no payback over a 40 year period. The marginal financial viability of the proposed ambient network design (40 year IRR of 2.17%) is dependent on individual heat pumps (owned by the network) being powered by on-site wind electricity generation, connecting to heat pumps attached to individual homes using a private wire network. The study suggested the private wire connection was feasible provided the connection was only to the heat pumps, with domestic electricity demand provided through the national grid.

[55] Cranleigh Low Carbon Heat Network Feasibility Study
[56] Greener Great Coxwell Low Carbon Heat Project, RCEF Stage 1 - Phase 2 Report

5.1.2. Air Source Heat Pumps

Heat networks heated by centralised ASHPs were not often considered within the reviewed feasibility studies despite individual ASHPs being a common counterfactual. Two projects, led by Sharenergy, involved feasibility studies at Bishop's Castle[57] and Brassington[58] and identified centralised ASHPs as the preferred option; closed loop and ambient shared loop GSHPs were discounted given the high capital costs of ground works, limited options for incorporating thermal storage at individual properties and difficulty reducing users' electricity costs through local renewable generation (i.e. private wire). While feasibility of the Brassington network is marginal given its small scale and lack of larger non-domestic users, the network at Bishop's Castle is predicted to have a 30 year IRR of 5.3%.

ASHPs are recommended as secondary heat sources in a couple of feasibility studies. The Kings Langley study suggests using a small number of ASHPs (2x500kW units) to bolster the 5MW open loop GSHPs during the colder months, due to limited water flow from the aquifer. Other projects proposing to use open loop GSHPs at Brightwell-cum-Sotwell, Shenston and Stonnall also suggest including centralised ASHPs in the network for similar reasons.

5.1.3. Water Source Heat Pumps

A single community led feasibility study was reviewed which recommended a river based WSHP (RSHP) as a heat source within a centralised heat network. The study, commissioned by Grantchester Parish Council[59] recommends a 1.41MW WSHP which extracts heat from water from the river Cam to supply the village with heat via a 70°C/45°C flow/return temperature network. A sustainable abstraction rate of 75 L/s was calculated assuming a temperature drop of 3°C, allowing the 1.41MW WSHP to meet 93.1% of the village's annual heat demand. An additional 1MW ASHP was recommended to supply the remaining 6.9% of the annual heat demand and ensure the 2.37MW peak demand could be met. The layout of the village and its proximity to the river Cam is illustrated in figure 18.

[57] Bishop's Castle Heat Network Feasibility Study
[58] Brassington Heat Network Feasibility Study
[59] Scene Connect Ltd (November, 2022), *Grantchester Parish Council, Low Carbon Heat Network - Feasibility Study.*

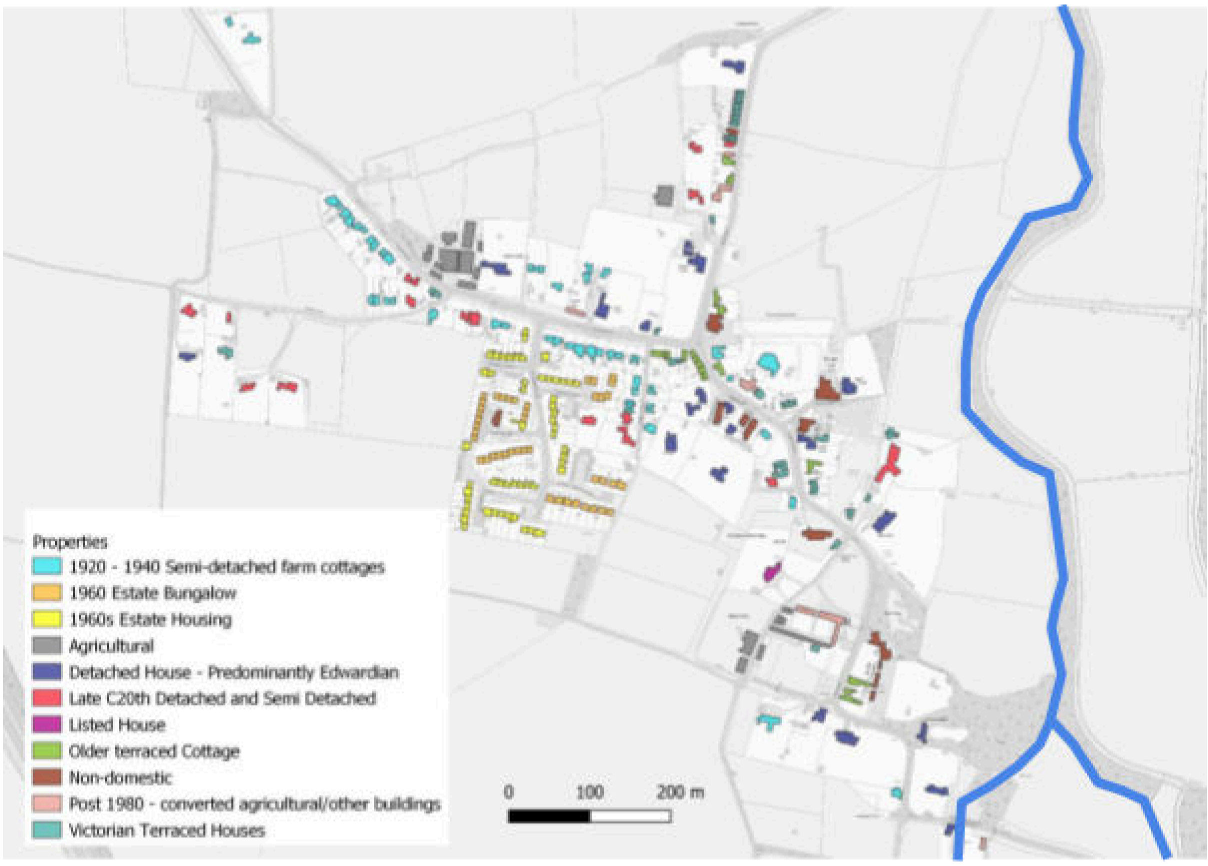

Figure 18: Grantchester building archetypes (river Cam in blue)

There is a wide variety of building archetypes across the 272 properties in Grantchester with ~38% of properties being 1920-1940s terraced or semi-detached houses and 36% being 1960s housing estate bungalows or houses. The study assumes an uptake of almost 100% of the village requiring installation of wet heating systems in the 30% of the village's properties which currently use electric storage heaters, estimated to cost £300,000 - £400,000. Note that these properties are principally owned by South Cambridgeshire District Council. There aren't any large anchor loads within the village with the 12 non-domestic buildings requiring only ~6% of the total 4515MWh annual heat demand.

The study predicts a 40 year IRR of 6.36% including a 50% grant from the GHNF and excluding the cost of wet heating system upgrades. This rate of return is reasonable compared to other community scale feasibility studies especially since on-site renewable electricity generation is not included in the financial model and the village does not have any large anchor loads.

The report provides a useful comparison of the RSHP against other primary heating technologies, reproduced in figure 19. The increased OPEX of the ASHP compared to a closed-loop GSHP or RSHP, reduces the feasibility of heating the network mostly with an ASHP. The increased CAPEX of the closed-loop GSHP (due to borehole drilling) makes a RSHP more financially viable as a primary heat source. Interestingly, as a secondary heating technology, the increased CAPEX of a closed-loop GSHP outweighs the increased OPEX of an ASHP.

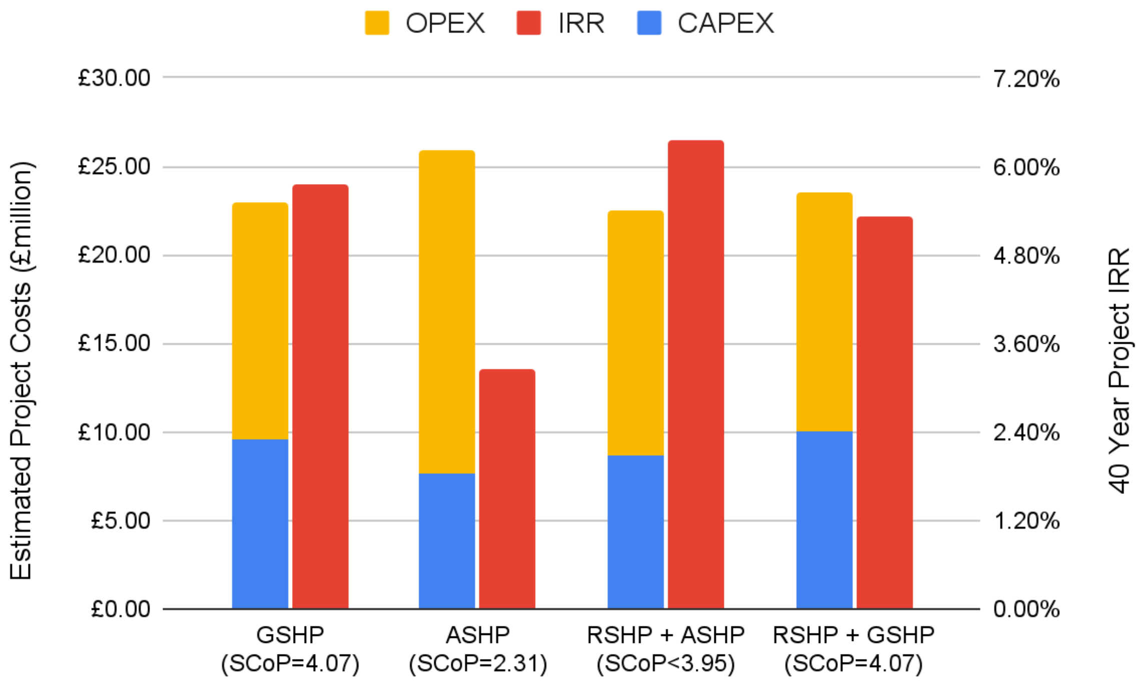

Figure 19: Initial CAPEX, 40 years of OPEX and predicted IRR for different heating technologies in a centralised heat network at Grantchester

5.2. Secondary Heat Sources and Thermal Storage

All centralised feasibility studies with low carbon heat sources indicated that thermal storage (centralised, insulated hot water tanks) and additional heat sources would be required for the networks to meet the peak heat demand. Electric boilers are most commonly recommended to provide back-up heat.

The Great Coxwell network, which focused on an ambient loop, suggested a detailed review of a large wet sand battery developed in Finland, which could be heated by on-site electricity and used to raise the temperature of the ambient loop. The study suggested that the SCoP of the heat pumps could be increased to 5.9 using this technology, but such an approach is not commonplace and wasn't modelled in detail.

5.3. Thermal Demand and Building Archetypes

Most of the reviewed heat network feasibility studies were in rural locations and hence focused on connecting individual residential buildings to heat networks, often lacking connections to large anchor loads. The three feasibility studies which estimated the highest IRR values, Bildeston (10.31% 40 year), Bishop's Castle (5.3% 30 year) and Cranleigh (6.78% 30 year), were the only studied heat networks which obviously included large non-domestic users. At Bildeston, ~30% of the 7.55GWh annual heat demand is for public and private buildings including a primary school and joinery business. At Bishop's Castle, up to 70% of the 4.67GWh annual heat demand is for non-residential buildings including a leisure centre and community college. And in Cranleigh, ~50% of the 2.15GWh annual heat demand is for public buildings including the village hospital and leisure centre. This suggests that financial viability is improved by connecting large anchor loads into a domestic heat network.

All feasibility studies reviewed include broad ranges of housing archetypes within their networks so it's difficult to report comparisons on the relative benefits of connecting to different housing archetypes. In general the studies were completed in rural locations with housing ranging from >100 years to ~10 years old and in relatively low density. The studies recommended centralised heat networks over individual ASHP counterfactuals, with flow temperatures in the region of 65°C-75°C, and generally avoided modelling improvements to domestic heating systems and insulation.

5.4. On-site Electricity Generation

All reviewed feasibility studies which used a heat pump as the heat source indicated that financial viability of the schemes would be improved with the use of on-site renewable energy generation. This is beneficial both by reducing the unit price of electricity consumed by the heat pumps and also to generate an income through sales of excess electricity through the grid. Since most schemes were centralised, connection of the solar PV and/or wind turbine would be to the heat pumps housed in an energy centre. The viability of the Great Coxwell scheme, which proposed installing a shared ground loop, relied on connecting renewable electricity generation to the heat pump in each property using a private wire grid.

A few feasibility studies make direct reference to the improvements in financial performance achieved by including renewable generation. The Cranleigh project predicts that 200kW of solar PV saves £24k per annum which is equivalent to 15% of expected OPEX. The report on Shenstone calculated that 1.9MW of PV on nearby industrial estate roofs improves the IRR from 0.9% to 1.1%, and adding 0.5MW of wind increases this to 2.4%.

The Bishop's Castle project is novel in that it plans to sell excess electricity generated by solar PV and wind directly to a large consumer, prior to selling electricity to the grid, at a price which is mutually beneficial. This highlights the potential dual benefit of including large anchor loads in a network since they could be a large heat and electricity customer. The operational Gateshead and Viking heat networks have a similar configuration where excess electricity generated by solar PV and gas CHP is sold to users via a private wire connection.

5.5. Finances

All the feasibility studies conclude that financial viability of the proposed networks depends on accessing grant funding, with the more recent studies referencing the Green Heat Network Fund (GHNF).

The approach for selling heat to users was fairly consistent across the feasibility studies with users charged a standing charge of ~£400/annum and a unit price of £0.10/kWh. The main anomaly was in the Shoreham feasibility study, authored by BHESCo, which considered a £90/year standing charge. The study suggests that the standing charge should not be levied since it would not have a material impact on the project finances and the expense of pursuing unpaid standing charges was unfeasible.

As expected, CAPEX costs across the reviewed projects are dependent on the number of connected properties, figure 20. Ignoring the very small heat networks, the main outlier is the Shenstone heat network connecting 730 buildings, which appears to have a disproportionately high CAPEX estimate. Compared to the trendline, the Shenstone heat network requires approximately £5m more CAPEX than expected. This is in part due to the proposed £3m investment in a 1.9MW solar farm and 0.5MW wind turbine, which isn't included in many of the other predicted CAPEX values. Also, comparison against the Kings Langley project (1136 connected buildings) indicates that the heat demand per building at Shenstone is approximately one third of that at Kings Langley but the expected heat network lengths are comparable (~24km). The study at Shenstone identified that the national railway line would need to be crossed either through construction of a bridge (estimated at £400,000) or by routing the network over a greater distance to access an existing underpass, with both solutions resulting in pipework costs of >£1k per building, compared to Kings Langley.

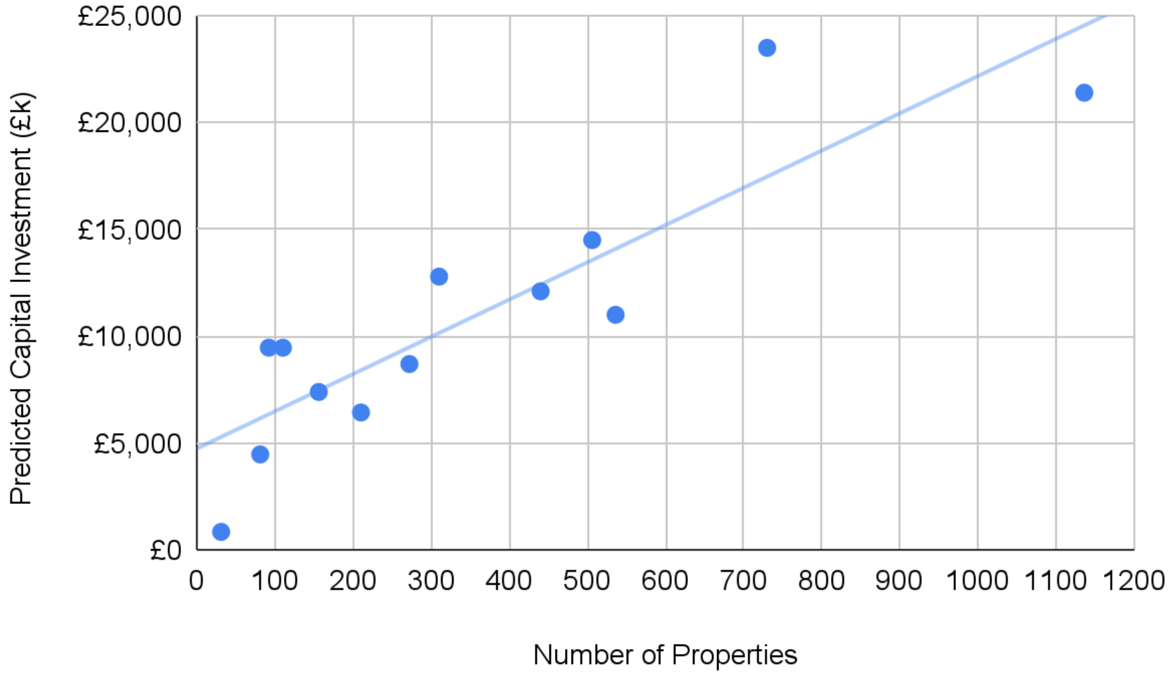

Figure 20: Predicted capital investment vs number of properties in network

Predicted returns on investment are generally low for the reviewed feasibility studies with 30 year IRR values ranging between -4.1% and 6.78% and averaging ~2% including GHNF grant funding. There is not an obvious trend between CAPEX, IRR and thermal demand across the reviewed feasibility studies, presumably due to the large differences in heat network configurations between the proposed locations.

5.6. Carbon Savings

Where reported, feasibility studies consistently reported predicted carbon savings of 90% when heated by a network compared to individual oil or gas heating.

6. Funding of Reviewed Heat Networks

6.1. CAPEX Funding

All UK based operational low carbon heat networks reviewed in this document receive grant funding from central government, with most projects being the recipients of significant payments to offset the initial CAPEX required to install the network.

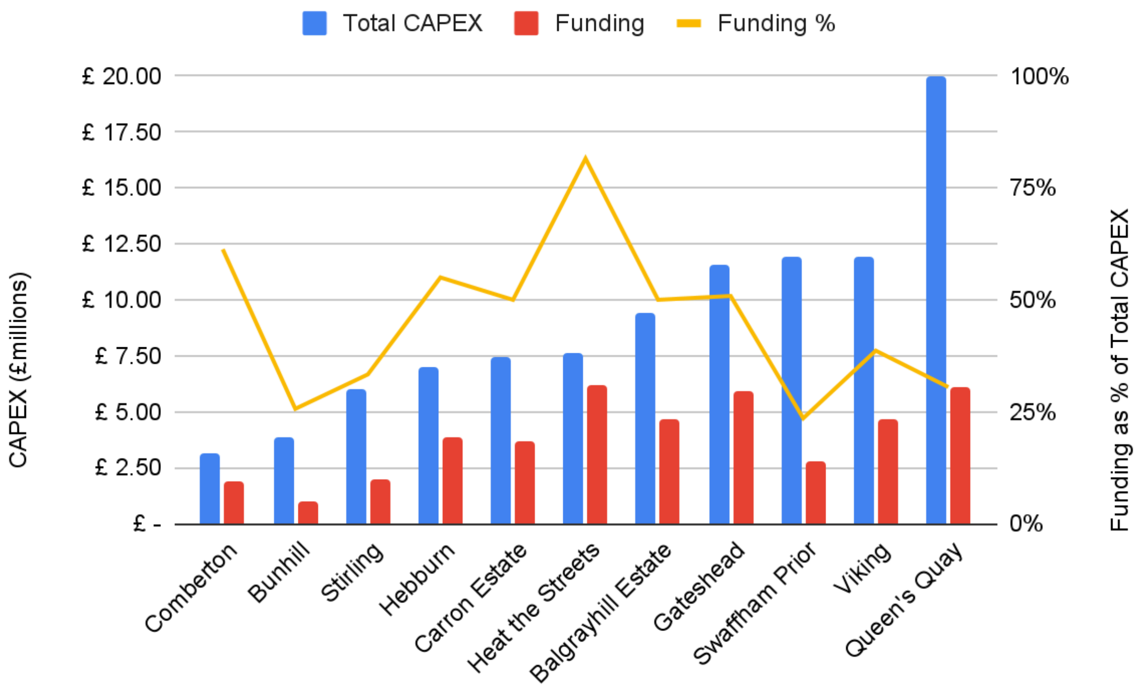

Figure 21: Project CAPEX compared against grant funding

Figure 21 presents the total CAPEX of the reviewed operational projects compared with the funding received from UK government or EU grants. Note that the reported funding values do not include usage dependent payments such as the RHI scheme, or carbon offset payments. The operational low carbon heat network projects presented in figure 21 had between 25% and 75% of their CAPEX funded by government or EU grants with an average funding proportion of 50%.

The distribution of CAPEX funding received from different funding bodies is presented in figure 22.

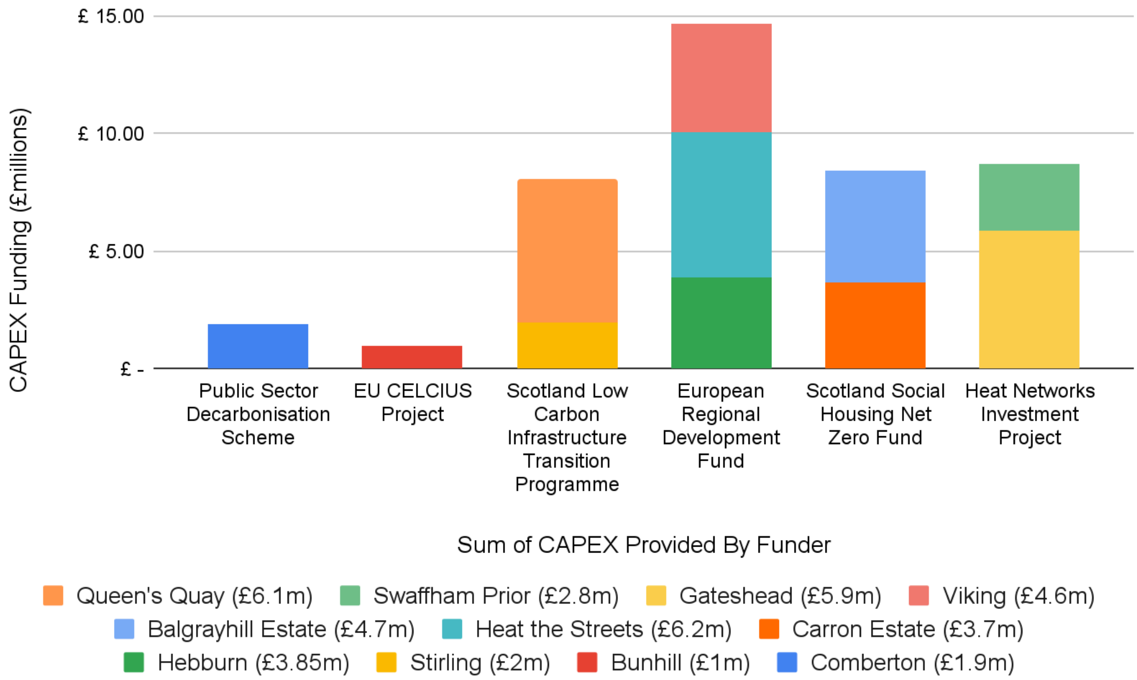

Figure 22: Summary of funds received by reviewed projects

Note that the funding for the Heat the Streets project is understood to cover developments at four locations in addition to the Stithians ambient loop network described in this report.

The source of the remaining CAPEX funding of the projects presented in figures 21 and 22 is illustrated in figure 23. The reviewed projects were predominantly funded by local authorities with projects involving social housing being paid for by the housing association. The Stithians project was the only reviewed project which received CAPEX grant funding and private investment.

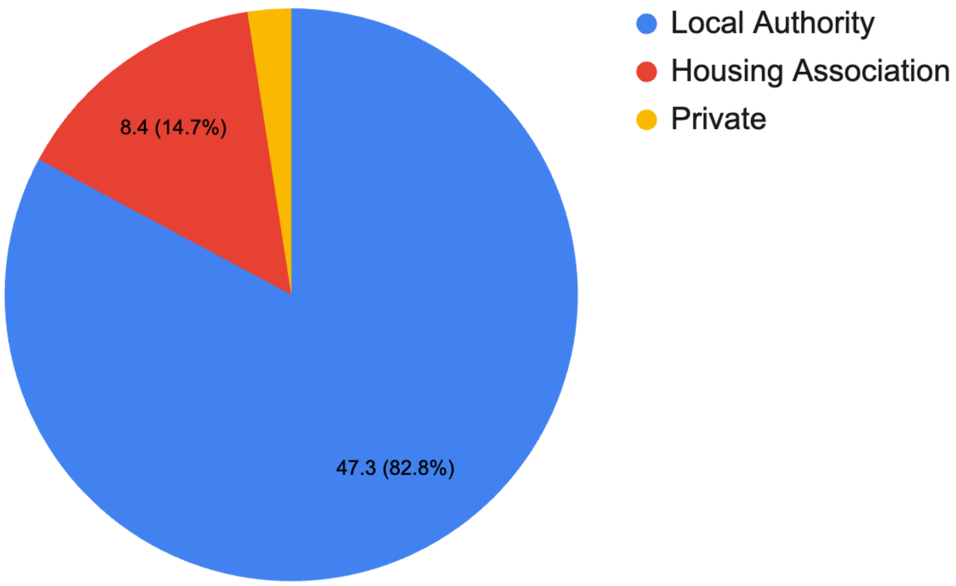

Figure 23: Source of remaining CAPEX funds in £million

6.2. Other Funding

Schemes which were operational before early 2022 also received income from non-domestic Renewable Heat Incentive payments. Example projects include: Flagship homes GSHP schemes (centralised and ambient), Borders College SHARC sewage WSHP, Springbok Woodheat.

6.3. Future Funding

Many of the funds accessed by the operational heat networks reviewed in this report are no longer available:

- HNIP closed to full applicants in October 2021[60],
- non-domestic RHI closed to new applications in March 2021[61],
- ERDF is no longer accessible to UK applicants following Brexit[62].

The UK Government's Public Sector Decarbonisation Scheme re-opens in 2025/2026 however it can only be accessed by public bodies (bodies which have less than 50% of their funding from commercial activities). Also, the funds can only be used to finance heat projects involving buildings which the applicant owns or has a long-term lease arrangement which includes maintenance rights[63].

[60] Triple Point Heat Networks: HNIP Application Guidance
[61] Non-Domestic Renewable Heat Incentive (RHI) | Ofgem
[62] 2014 to 2020 European Regional Development Fund Operational Programme - GOV.UK
[63] Phase 3c Public Sector Decarbonisation Scheme | Salix Finance

The reviewed feasibility studies generally rely on receiving financial support from the GHNF which offers support up to 50% of the construction and commercialisation costs of low carbon heat networks. The key GHNF criteria to satisfy when sizing the heat networks is that the total annual heat demand must be >=2GWh, or at least 100 dwellings in rural locations off the gas-grid if a 2GWh heat demand cannot be achieved[64]. Projects must demonstrate a 40 year social IRR[65] of 3.5% or greater and there are other criteria limiting heat sale prices and carbon emissions. Non-heating/cooling costs (e.g. renewable electricity generators) can also be funded by the grant provided that the savings they provide to the heat network project are greater than their costs.

Since the focus of the CHDU project is on heat network development in England and Wales, funding from the Scottish Government's Low Carbon Infrastructure Transition Programme[66] is not of interest.

7. UK Planned Heat Networks

The UK Government publishes details of government supported heat network projects currently in development or planned for future development. These projects are published in the Heat Networks Planning Database(HNPD) and Project Pipeline summary documents[67].

A review of the HNPD (including project records from 2021-2024) indicates that the ASHPs are the predominant heating technology in low carbon heat networks with at least 100 customer connections. Figure 24 illustrates the number of projects in the HNPD which are primarily heated by low carbon heat sources, split by technology. The figure also compares the average number of connected properties per network.

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[64] GREEN HEAT NETWORK FUND - Scheme Overview - GOV.UK
[65] Social IRR is the scheme IRR, excluding grant, plus the IRR of the social carbon cost savings (compared to a standard counterfactual) plus the IRR of the social air quality impact cost savings (compared to a standard counterfactual).
[66] Low Carbon Infrastructure Transition Programme - Renewable and low carbon energy - gov.scot
[67] https://www.gov.uk/government/publications/heat-networks-pipelines

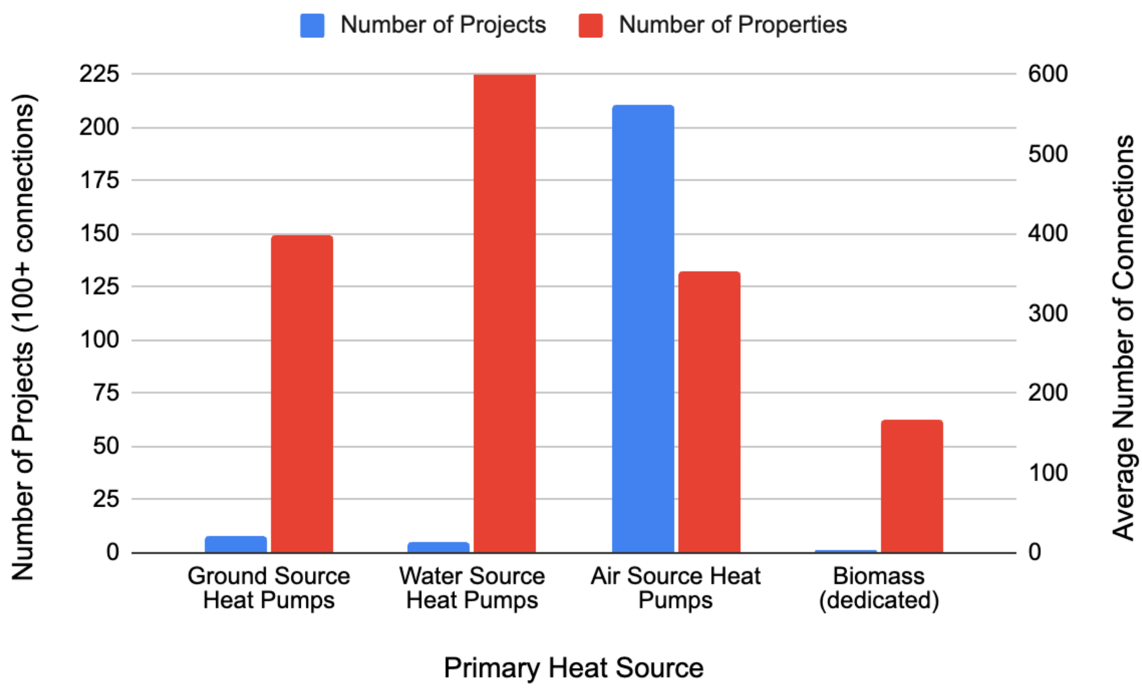

Figure 24: Numbers of connections for larger low-carbon heat networks (100+ customer connections)

Figure 24 suggests that water source heat pumps are being selected as the heat source for larger heat networks compared to other heating technologies. This is somewhat skewed by a couple of very large planned developments including the 15,000 home Seaham Garden Village and 4,304 property Granton Water development in Edinburgh.

The split of communal vs district low carbon heat networks in the database is roughly equal although the network descriptions suggest that most heat networks involve blocks of flats. A comparison of the average number of connected buildings within a heat network against the average number of customer connections per building is presented in figure 25[68]. Comparison of the presented ASHP and GSHP networks suggests that, on average, ASHPs are planned to heat more or larger communally heated buildings whereas GSHPs are planned to heat more dispersed buildings. This may be an artefact of the small number of GSHP networks (8) compared to ASHP networks (211) skewing the comparison, and heat networks mostly being developing in urban areas where there may be less space for drilling boreholes.

[68] For projects with available data.

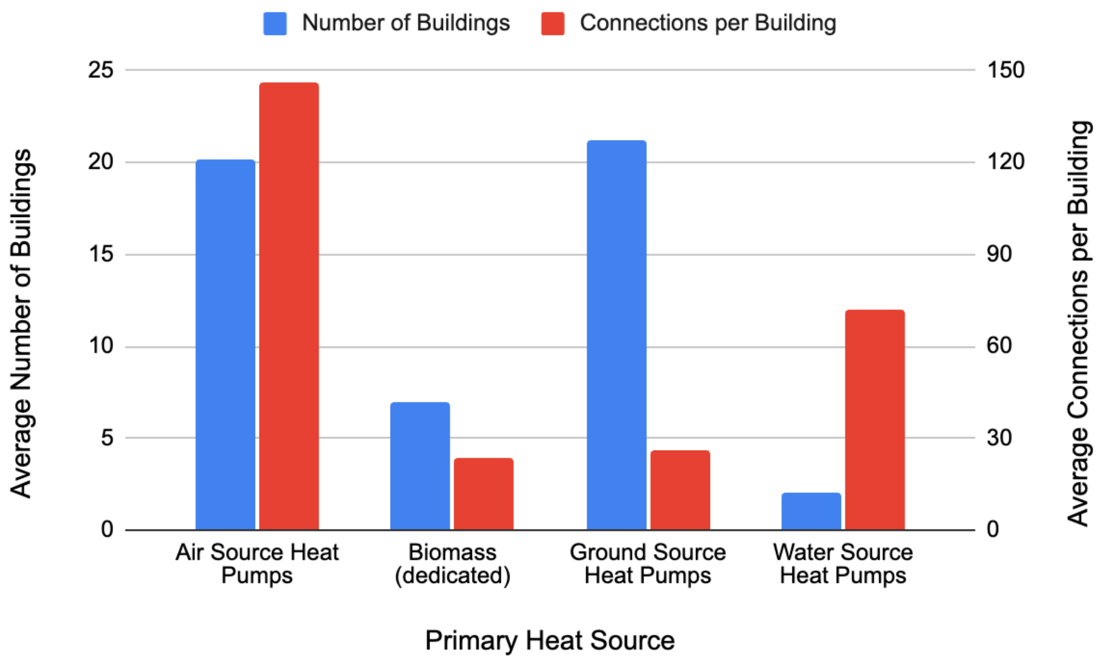

Figure 25: Summary of customers and buildings connected to networks

Further details of planned heat network projects are available in the Heat Network Pipeline summary[69] and are mostly different to those identified in the HNPD. Figure 26 compares the number of projects recorded in the pipeline document vs the average IRR. Note that in total, 16 projects plan to use ASHPs and 18 projects plan to use GSHPs however only projects which have reported IRR values are included in the figure. Heat networks using ASHPs as their primary heat source predict the highest average IRR with sewage source heat pumps (SSHP), ambient loops and biomass predicting next highest IRR values.

69 https://assets.publishing.service.gov.uk/media/659bb736c23a10000d8d0c31/2023-q3-july-september-heat-networks-project-pipeline-summary.xlsx

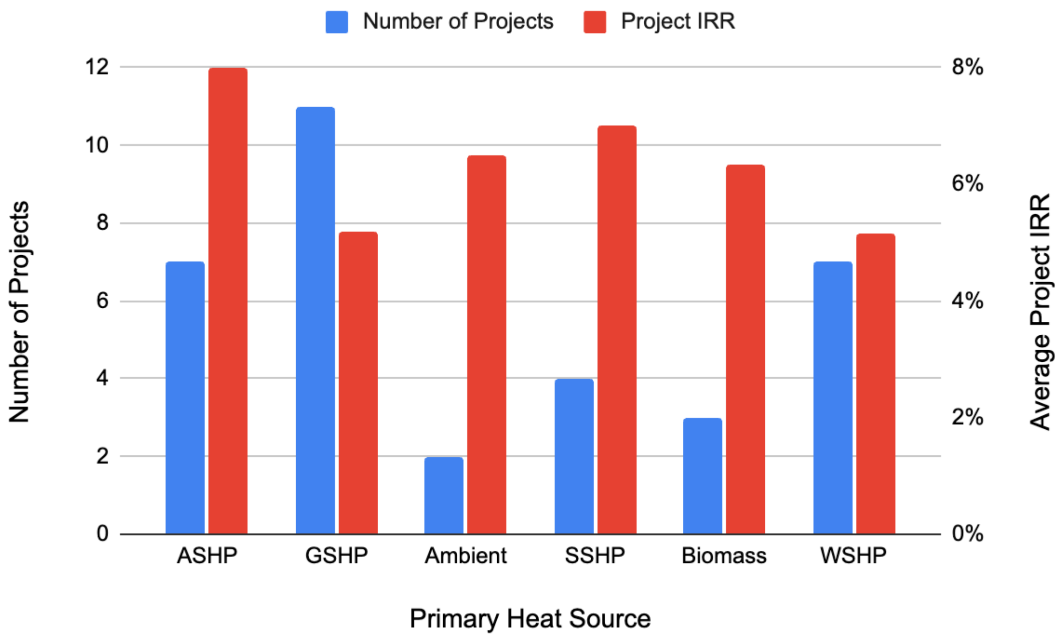

Figure 26: Number of projects in pipeline summary vs average project IRR[70]

Figure 27 compares the average annual thermal demand of the projects reported in the Heat Network Pipeline summary compared against the predicted average project IRR.

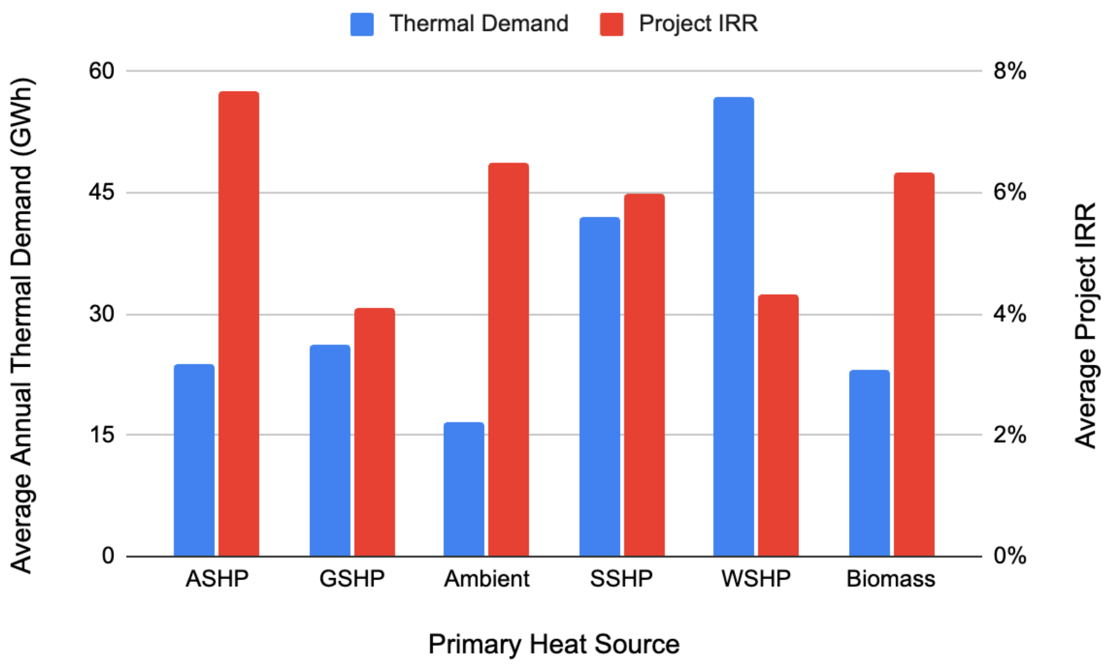

Figure 27: Average annual thermal demand vs average project IRR

[70] SSHP = Sewage Source Heat Pump

Based on the data in Figure 27, ASHP heated networks are expected to be more financially viable than GSHP networks for a similar thermal demand. Similarly to the projects reported in the HNPD, networks heated by WSHP have the highest average thermal demand compared to networks heated by other heating technologies.

8. Summary

There are examples of planned and operational heat networks using low carbon heat sources across the UK and internationally including connections to residential buildings with existing heating systems. A summary of the reviewed projects is provided below.

Network Ownership

The majority of low carbon heat networks summarised in this review are owned in part or full by local authorities or housing associations. This is notably different from the distribution of UK heat network ownership including all heat sources, which is dominated by the private sector.

Heat Network Funding

All UK based operational low carbon heat networks reviewed in this document receive grant funding from central government, with most projects being the recipients of significant payments to offset the initial CAPEX required to install the network or non-domestic RHI payments.

All of the funding schemes in England and Wales which existing operational heat networks have made use of have closed or are inaccessible for projects outside of the EU. The recently opened GHNF is the only known fund which future heat network developments within the scope of the CHDU project could apply to, assuming they are configured to meet the specific application criteria.

Heat Users

In the UK, the operational low carbon heat networks generally connect to large heat users, including council offices, public buildings such as leisure centres and communally heated blocks of flats. In Europe, the examples of low carbon heat networks are generally large residential networks which were initially developed to be heated by fossil fuel CHP and are transitioning to lower carbon energy sources either by incrementally introducing large WSHPs or moving to 5th generation ambient loop networks.

Local Electricity Generation

Local electricity generation is often used to power heat pumps via private wire installations, inferring that investment in local generation is financially beneficial over the project lifetime compared to using electricity from the grid. All reviewed feasibility studies of community scale heat networks which used heat pumps concluded on-site renewable generation would be financially beneficial to the projects.

Secondary and Peak Demand Heat Source

All heat network projects include thermal storage to help balance demand and generation. Back-up heat and peak demand is primarily provided by fossil fuel powered heat sources with gas CHP being used at locations where there is also a requirement to generate electricity for local consumption. A number of feasibility studies suggest using ASHPs to help meet the peak demand of networks heated by open loop GSHPs or RSHPs due to water flow rate limitations.

In Denmark, there are examples of ASHPs being added to existing biomass-fueled networks with very large thermal storage tanks[71]. The ASHPs are run when electricity is cheap (i.e. it's windy) playing an important role in balancing the grid, and store hot water for later use in the network.

The Bunhill project in Islington demonstrates that maintaining the original fossil fuel heat supply in existing communally heated buildings can provide heating resilience and reduce the scale or requirement for centralised backup boilers.

Water Source Heat Pumps

There are examples of mine water heating schemes in the UK and abroad although most UK schemes are fairly small. While the recently commissioned Gateshead mine water heat network appears to be a positive example of mine water heating, many of the UK schemes (communal heat networks or a few buildings) reported water quality issues resulting in non-viable maintenance requirements, ultimately leading to schemes being decommissioned. A published review of the performance of mine water heating schemes[72] deemed them to be

[71] https://www.fenagy.dk/en/cases
[72] A review of the performance of minewater heating and cooling systems

too risky for small / medium sized projects due to the unknowns associated with groundwater systems, borehole drilling and water quality. This site specific variability reduces the replicability of a mine water heat scheme. Schemes at mine water treatment sites are perhaps more viable, but there are a limited number of treatment sites in the UK.

There are a couple of examples of Scottish heat networks which use heat from sewage water, both at a treatment centre (Stirling) and using a sewer main (Galashiels). More examples are available internationally[73].

River sourced WSHPs may be a good option for the CHDU project. The SCoP of river source heat pumps is higher than ASHPs given the average river water temperatures in winter are higher than air temperatures and the heat transfer coefficient of water is greater than air. The pumping requirements of a river source heat pump can be lower than open loop mine water or aquifer GSHPs, which extract water from deeper in the ground. There are a number of examples of recently developed WSHP heat networks and network scale heating schemes in the UK and abroad demonstrating feasibility while operating networks at relatively high flow temperatures of 70-85°C. Also, there are a number of UK heat network projects in development which make use of river source heat pumps e.g Exeter City Centre, Queens Quay on the River Clyde and the Mersey Heat project.

Ground Source Heat Pumps

Most of the existing operational heat networks in the UK which use GSHPs are small in size serving relatively low thermal demands. Flagship Homes have completed multiple closed loop GSHP installations to improve the heating and hot water systems of their tenants. The modular installations, heating 20-30 homes, potentially offer a replicable solution.

Within the reviewed feasibility studies, GSHPs are generally recommended due to the SCoP being higher than ASHPs during winter, when the load is highest. Also, it is rare that there is a water body that might provide an alternative viable heat source at the feasibility study locations. Open loop systems are favoured over closed loop systems since a given heat demand can potentially be supplied by fewer boreholes, requiring less CAPEX. However, closed loop systems require less maintenance and fewer environmental permits.

[73] https://wastewaterheat.online/case-studies

Many of the reviewed projects have referred to encountering unexpected ground conditions while drilling boreholes for GSHPs or mine water WSHPs. For example, the Swaffham Prior project originally intended to use an open loop GSHP extracting water from a subsurface aquifer, however ground investigations indicated that the required abstraction rates could not be achieved from the Greensand aquifer underlying the site. This resulted in a more costly closed loop GSHP system being installed. This suggests that variable ground conditions between sites present a risk to the replicability of a model which relies on specific ground conditions.

The only example identified in this review of an operational ambient heat network in the UK which connects to domestic buildings is the Kensa "Heat the Streets" project in Stithians, Cornwall. This system offers users a higher SCoP value than an ASHP for a standing charge but exposes users to fluctuations in electricity prices unless they have access to a novel electricity supply arrangement. Internationally, the main use case for ambient networks appears to be where there is heating and cooling demand in a 5th generation heat network, however this is a relatively new concept with the first adopter projects being in-development.

Air Source Heat Pumps

There are a few examples of ASHP powered heat networks in the UK: Bunhill in Islington, Hebburn Estate in Gateshead and the Carron Estate in Glasgow. These networks primarily heat multiple pre-existing communally heated buildings in highly urbanised areas. In Denmark, large scale ASHPs are being installed in Denmark coupled with large thermal storage tanks to reduce the use of biomass in existing heat networks.

A feasibility study at Bishop's Castle recommended an ASHP as a primary heat source when coupled with a wind turbine and solar PV installation. Multiple studies recommended bolstering open loop GSHPs with ASHPs to meet peak winter demands.

Biomass

Biomass is the most common low carbon heating technology used in heat networks internationally with 29.8% of Denmark's heat networks being heated by biomass fueled CHP[74]. In the UK, there are multiple examples of community owned heating projects using biomass to heat small district and communal networks, particularly while RHI payments were available.

Note that the DESNZ heat network zoning regulations[75] make reference to upcoming tightening of environmental permitting requirements which may affect the use of solid biomass as a heat source due to the fine particulates produced through combustion.

Planned Heat Networks in the UK

A review of the HNPD and heat network pipeline publications was conducted to understand the configurations of UK Government supported heat network projects currently in development or planned for future development. The main observations are that:

- ASHPs are the primary heating technology being selected for planned centralised heat networks.
- Most planned district heat networks include connections to communally heated blocks of flats.
- Heat networks heated by ASHPs are expected to achieve the highest project IRR values after grant funding, compared to other heating technologies.
- WSHPs may be the chosen technology to heat very large networks.
- GSHPs may be chosen instead of ASHPs for networks with more dispersed buildings.

[74] https://www.sciencedirect.com/science/article/pii/S1364032122000466#bib94
[75] https://www.gov.uk/government/consultations/proposals-for-heat-network-zoning-2023

Appendix A. Information Sources

This appendix presents the core list of information sources used to identify existing low-carbon heat network projects within the UK.

Name	Link	Description
Heat Networks dataset	Heat Networks dataset - data.gov.uk	This data is furnished to the Energy officials within the Department of Business, Energy and Industrial Strategy to provide evidence and to allow analysis for policy development. The data only captures information for England.
Heat Networks Planning Database	BEIS: Heat Networks Planning Database - data.gov.uk	The Heat Networks Planning Database (HNPD) provides a picture of both district and communal heat network deployment across the UK.
Heat Network Locations (Existing and Planned) - Scotland	Heat Network Locations (Existing and Planned) - Scotland - data.gov.uk	The Scotland Heat Map provides the locations of existing and planned heat networks. Both communal and district heat networks are included.
London Heat Map	London Heat Map - data.gov.uk	The London Heat Map is a tool designed to help you identify areas of high heat demand, explore opportunities for new and expanding district heat networks and to draw potential heat networks and assess their financial feasibility.
Feed in Tariff commissioned installations statistics	Feed in Tariff commissioned installations statistics - data.gov.uk	Cumulative count and installed capacity of all installations deployed via the Feed-in Tariff scheme. Statistics are shown for GB, broken down by technology, size band and data source.
Feed-in Tariff Installation Report 30 September 2023	Feed-in Tariff Installation Report 30 September 2023 | Ofgem	This quarterly report gives a breakdown of accredited installations under the Feed-in Tariff (FIT) scheme from 1 April 2010 to 30 September 2023. Data shown in the report is based on the number of installations that have completed accreditation in the above period only.
Evaluation of the Heat Networks Delivery Unit (HNDU)	Evaluation of the Heat Networks Delivery Unit (HNDU) - GOV.UK	Research into how and to what extent HNDU activity assisted local authorities in their development of heat networks.
Heat network template financial model	Heat network template financial model - GOV.UK	For use by financial modellers to input values from a techno-economic model, and evaluate key financial aspects of a prospective heat network opportunity.
Heat Network Optimisation	Heat Network Optimisation Guide	DESNZ guidance on heat network optimisation, aimed at technical engineers and heat network operators,

Guide		focusing on residential and mixed-use heat networks.
HNIP Case Studies	Heat Network Case Study Brochure	DESNZ brochure of case studies of HNIP funded projects in England/Wales (though they all appear to be in England).
DESNZ Case Studies	Heat Networks Investment Project	Another DESNZ brochure but different to the one above.
Sizing up the benefits: thermal storage in heat networks	Sizing up the benefits: thermal storage in heat networks - CIBSE Journal	Using data to inform decisions on trade-off between size of thermal store vs capacity of top-off boiler (CIBSE journal article outlining research paper, to be published late 2023).
Fairheat Previous Projects	Projects: client case studies | Fairheat	Consultancy who provide quality assurance of heat networks.
Heat Network Planning Database	https://assets.publishing.service.gov.uk/media/654923abbdb7ef00124af91e/hnpd-october-2023.csv	DESNZ database tracking the progress of communal and district heat networks from inception through planning, construction, operation and decommissioning.
Heat Network Pipeline Database	Heat Network Pipeline Database	Seems to contain different projects to what's listed in the planning database.
Map of heat networks planning database	Heat Networks Planning Database | DESNZ & Barbour ABI	DESNZ map of heat network projects at various stages of planning / operation.
HNDU minewater projects	Development of Heat Networks in the UK	Includes a list of minewater projects being considered. Multiple projects at feasibility study stage.
Heat Trust map	Heat Trust Registered Sites Map	Heat Trust is all about protecting heat network consumers. We're an independent, non-profit consumer champion for heat networks in Great Britain (England, Wales and Scotland). We launched in 2015 with a clear ambition to place consumers at the heart of a rapidly expanding, but unregulated, heat network market.
Gov Mine Water Heat Projects	Mine water heat - GOV.UK	Government website listing operational mine water heat projects.
Regen Community Heat Guide	Community-led heat projects: an introduction	Regen guide prepared for DECC providing information on options for communities to develop heat projects.

Association for Decentralised Energy district heating map	ADE District Heating Map	Map showing Universities, Hospitals and Residential/Commercial district heating installations in the UK.
Vital Energi	Our Work | Case Studies	Vital Energi's website has a number of case studies and can filter by project type etc.
Highlands and Islands Enterprises	Heat Networks	Highlands and Islands council document on heat networks
Scotland Heat Network Support Unit Case Studies	Case Studies - Heat Network Support Unit	The Heat Network Support Unit (HNSU) aims to support the growth of heat networks by working with the public sector to address key challenges and build capacity through advice, expertise and financial support. Includes map data of heat networks in Scotland and heat demand by location.
Rural Community Energy Fund (RCEF)	Rural Community Energy Fund (RCEF) Resource Bank	Database of RCEF projects.
Non Dom RHI case studies	Monitoring of Non-Domestic Renewable Heat Incentive Ground-Source and Water-Source Heat Pumps - Case Studies - GOV	Report on 28 case studies from the Non-Domestic RHI funded projects.
Scottish Heat Network Fund Quarterly Report	Heat network projects: quarterly reports – July 2023 - gov.scot	Quarterly report of the scottish heat network fund. Includes projects involved in the fund.
Scene (past projects)	Our Projects — Scene	Community energy consultants who have worked on a number of feasibility studies.
Greater South Net Zero Hub	Greater South East Net Zero Hub	Case studies on Net Zero Hub website.
South West Net Zero Hub	South West Net Zero Hub	Case studies on Net Zero Hub website.
North East and York Net Zero Hub	What is the Net Zero Hub?	Case studies on Net Zero Hub website.
North West Net Zero Hub	https://www.localenergynw.org/	Case studies on Net Zero Hub website.
Midlands Net Zero Hub	Midlands Net Zero Hub	Case studies on Net Zero Hub website.

Net Zero Hub Minewater Paper	Mine Energy White Paper	Paper defining state and steps to investigate / enable mine water to be used as a heat source.
OnGen news	https://ongen.co.uk/?s=heat+network	News articles related to heat networks.
TownRock Energy past projects	Projects | TownRock Energy	Geothermal energy consultants
Clyde Mission Energy Masterplan	Appendix A: Stakeholder projects - Clyde Mission: energy masterplan - gov.scot	Plan for low carbon heat and energy infrastructure on the Clyde.
Scotland Green Heat	THINK GREEN HEAT | Power Technology	References to heat network case studies.
Minewater Project Review (Worldwide)	Geothermal heat recovery from abandoned mines: a systematic review of projects implemented worldwide and a methodology for screening new projects	Review of minewater projects across the world and methodology for screening new projects.
Sustainable Energy Projects	https://www.sustainable-energy.co.uk/projects/	Past projects developed by the Sustainable Energy consultancy. Mostly biomass.
Rendesco Projects	Explore Rendesco's Clean Energy Projects In The UK	Past projects developed by Rendesco (ground source heat pumps, but mostly individual users or new build blocks of flats).
Heat Network Procurement Pipeline 2023 q1	Heat Network Procurement Pipeline: 2023 Q1	May contain references to operational projects.
Heat Network Procurement Pipeline 2023 q2	Heat Network Procurement Pipeline: 2023 Q2	May contain references to operational projects.

Appendix B. Heat Source Descriptions

B.1. Ground Source Heat Pumps

Ground source heat pumps (GSHPs) are either installed as a closed loop or open loop system. Closed loop systems flow a coolant around sealed pipework which absorbs sub-surface heat. This tends to require drilling more boreholes, to greater depths than an open loop system. Open loop systems ingest water from subsurface aquifers making direct use of the available heat but requires more consideration of the water quality and environment and is more dependent on the hydrogeology of a location.

B.1.1. Central Plant

Open or closed loops feed coolant to a centralised heat pump which transfers heat to the network pipework. Individual properties have a heat interface unit (HIU) which transfers heat from the network into the properties hot water and space heating system. Pumping hot water around the network requires better insulated pipe than ambient networks to reduce heat losses, however centralised heating can offer efficiency improvements especially if electricity is generated on-site.

B.1.2. Ambient

Open or closed loops where fluid at an ambient temperature is pumped or flows passively through a network of pipes. Individual properties have heat pumps which transfer and upgrade heat into the property's hot water and space heating system. Pumping lower temperature water around the network means lower heat losses, however individual heat pumps at each property are less able to make use of on-site electricity generation.

B.2. Water Source Heat Pumps

There is some crossover in terminology between water source heat pumps (WSHPs) and ground source heat pumps given that open loop ground source heat pumps extract heat from subsurface aquifers. Within the context of this document, WSHPs refer to heat pumps which extract water from water bodies above ground.

B.2.1. Mine water

An open loop mine water system is similar to an aquifer source open loop ground water heat pump, however mine water is extracted from boreholes into the mine which is then passed through the WSHP heat exchanger. There are examples of standing column arrangements where mine water is returned to the extraction borehole at a greater depth or to a separate borehole. Heat may also be extracted from the mine water in a closed loop system.

B.2.2. Rivers

Water is extracted from the river using a pump and passed through the WSHP heat exchanger. Water is returned to the river downstream of the extraction point. There are Environment Agency limits on the allowable temperature differential.

B.2.3. Sewage

Heat is extracted from sewage water either via a heat exchanger directly embedded in a sewer system or at a sewage treatment works. WSHPs are available which can directly intake sewage prior to it being treated.

B.2.4. Marine

Open or closed loop systems where heat is extracted from sea water.

B.3. Air Source Heat Pumps

Air is a reliable source of energy that can be extracted using air source heat pumps (ASHP). This could take the form of individual heat pumps serving individual buildings or, for operating a larger network scale, using an array of Dry Air Coolers (DAC) serving centralised heat pumps in a heat network. As with water source heat pumps, sourcing energy from the air will see lower efficiencies as air temperatures drop. In practice, this results in higher electrical consumption for a given heating capacity and heating flow temperature.

B.4. Biomass

If a good local source of sustainable biomass is available, then this can be a low carbon solution, as the carbon released in the burning process is absorbed on a short cycle through forestry re-growth. Thinning of forests and re-planting can both allow for increased carbon absorption to replace the carbon burnt. However, there are issues with biomass, including possible reductions in air quality, higher maintenance costs, the need to carefully manage the quality of fuel and the need for fuel deliveries.

Note that DESNZ are suggesting that relying on solid biomass combustion as a heat source may become less viable in future with tightening environmental permitting requirements:

> *"Finally, solid biomass combustion produces fine particulate matter, which is the pollutant of greatest harm to human health. These impacts are controlled through environmental permitting regulations, which will continue to be tightened in the future to prevent health impacts. As such, heat network operators that are considering solid biomass combustion as a heat source should closely consider the potential effect of tightened environmental permitting requirements as these develop."* - DESNZ[76]

[76] https://www.gov.uk/government/consultations/proposals-for-heat-network-zoning-2023

Appendix C. Water Source Heat Map

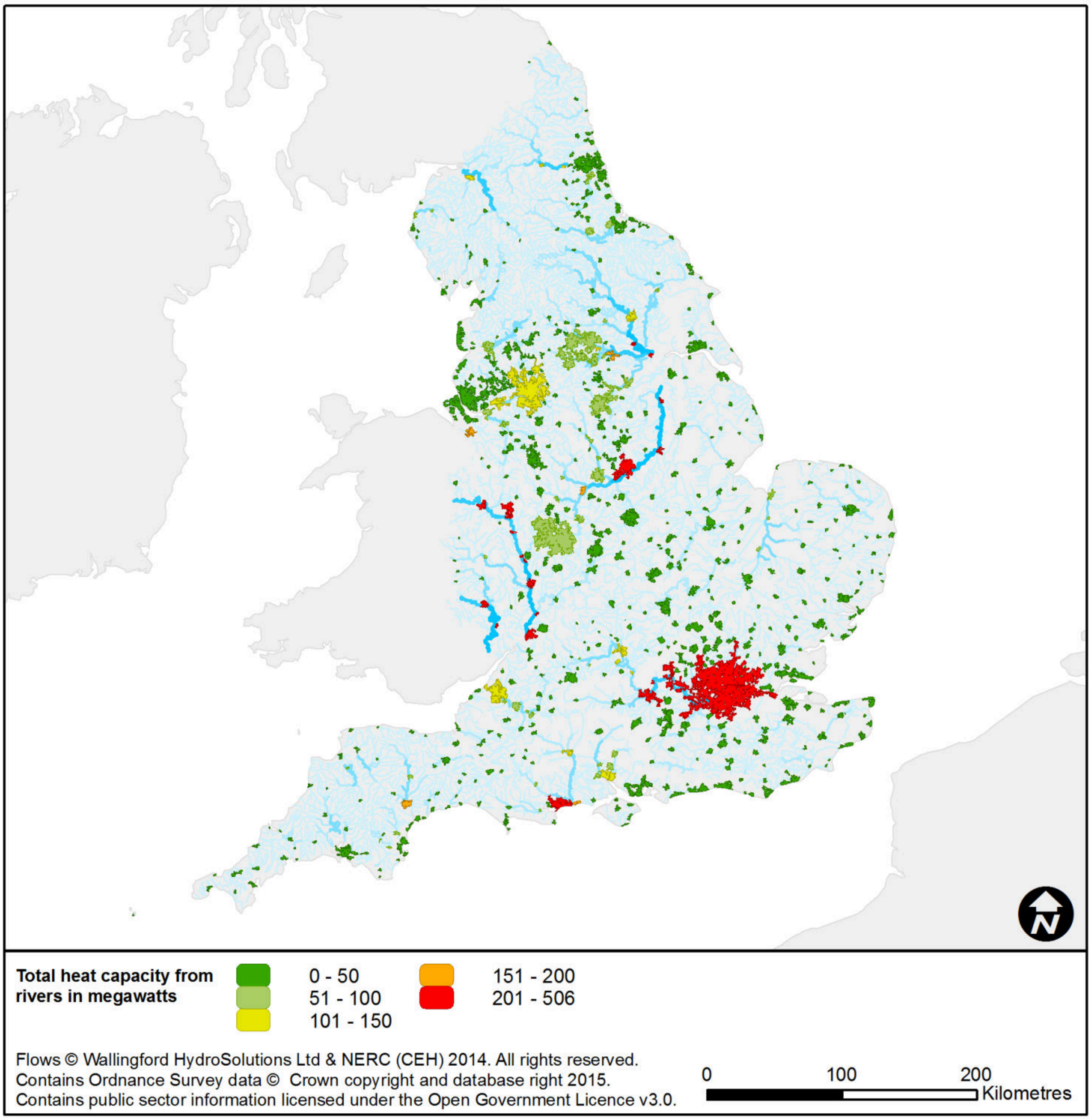

Figure C.1: Total heat capacity from rivers in megawatts for urban areas[77]

[77] https://assets.publishing.service.gov.uk/media/5a8068bfed915d74e33fa437/water_source_heat_map.PDF