SCOTTISH ENTERPRISE

ANALYSIS OF POTENTIAL FOR SCOTLAND TO BE A LEADER IN 5TH GENERATION HEATING AND COOLING NETWORKS

RAMBOLL

NOVEMBER 2021

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Key analysis findings

Potential for Scotland to be a Leader in 5th Generation Heat Networks

Summary

- Fifth Generation District Heating and Cooling **(5GDHC)** Networks use ambient temperature water for heat transmission combined with local heat pumps to supply heating and cooling at the required temperature for each building. This offers **system efficiencies,** particularly when both heating and cooling are required in an area, and **flexibility** to deliver heating and cooling at different temperatures according to the heating system requirements of each building.
- There is currently **no clear 'winner' between 5GDHC and fourth generation district heating (4GDH).** In contradiction to naming conventions using 'generations', 5GDHC should be considered no better or worse than other low-carbon heat networks, but rather should be considered as one of the many options, that will be more appropriate for certain contexts than others. It can also be **combined** with other district heating generations in **hybrid formats** to achieve decarbonisation of heating and cooling.
- The **European market** is dominated by **pilot projects** and leadership is determined by visibility and complexity of pilots. **Scotland currently lags behind the Netherlands and Switzerland** as perceived market leaders but this research suggests that it could gain leadership by developing more pilot projects, creating greater technology awareness, and further analysing Scottish potential.

Scottish 5GDHC market and capability assessment

- 5GDHC networks are **different from previous generations** because they use ambient temperatures, have bi-directionality of flow, and use heat pumps in every building to raise or lower the network temperatures as required. The main **benefits** compared with 4GDH include improved efficiency, flexibility of heat sources and flexibility to end-building heat temperatures. **Drawbacks** include high CAPEX, complexity of design and lack of an established business model.
- 5GDHC networks become more financially attractive where there is cooling as well as heating demand.
- **Scotland already has a lot of the capabilities** required to keep the value of developing 5GDHC networks within the country. The pipework used is similar to that used in gas and water mains, which Scotland already regularly installs. However **one large gap is manufacturers, suppliers and installers of small water/ground source heat pumps**.

European 5GDHC market and capability assessment

- Demand for low-carbon heating and cooling is expected to grow throughout Europe, but **the role of 5GDHC is unclear**, due to the immaturity of the technology, the small number of existing projects, and the relatively unproven business model.
- A **small number of European countries have developed pilot projects**, with the Netherlands' Minewater project (in Heerlen) the most complex and well-known. Although the market leader cannot be defined in terms of market share, **leadership perception is driven by pilot projects and research output**. The Netherlands, Switzerland, and Italy were all highlighted as frontrunners.
- It is **too early to assess market export potential**, but a number of drivers that affect demand can be identified, including local policies, awareness of the technology, and CAPEX – particularly cost of heat pumps.

The opportunity for Scotland

- There are several **opportunities and challenges for Scotland** to address in order to establish greater leadership within the potentially growing 5GDHC market. Opportunities include developing pilots, understanding approaches to integrating 5GDHC into energy planning, and improving the requirements and incentives for connection to DHC in general. Challenges include the business model for delivery, lack of understanding of current and future cooling demand, and lack of awareness of the technology, amongst others.
- However, the value associated with leadership is not clear, so it would be strategically prudent to **invest in areas that are also synergetic with other areas that will see future growth**, like heat recovery.
- Although **Scotland currently lags behind the Netherlands and Switzerland in perceived market leadership**, Scotland has the **potential to challenge current leaders** by focusing on complex pilot projects, prioritising research and development and influencing relevant policy. These form the basis of the recommendations for Scottish Enterprise to take forward from this project.

EXECUTIVE SUMMARY

Key analysis findings

Scottish 5GDHC market and capability assessment

- 5GDHC systems are defined as **decentralised networks** (i.e. a heat pump is located in each building) which operate at **ambient temperature** with one or two pipe **bi-directional flow** and are capable of supplying both **heating and cooling.**
- Distinguishing features are: 1). **Various sources of 'waste' heat can be added** to a 5GDHC network, such as from data centres or from waste-water treatment plants. 2). **Every building in the network has their own heat pump** to raise the temperature to appropriate building levels and 3). **Bi-directional flow** is a unique characteristic for 5GDHC networks. This enables supply of cooling demand as well as heating using the same infrastructure. The business case for 5GDHC is more favourable if there is a cooling demand within the network. Although Scotland has a relatively low cooling demand currently, this is set to grow in the future.
- Compared with 4GDH, 5GDHC generally has **less favourable CAPEX, reliability, and can be more complex to design.** These are considered the main drawbacks of 5GDHC compared with 4GDH currently.
- The main benefits of 5GDHC compared with 4GDH are improved **efficiency** and greater **flexibility.** Reducing heat losses, improving heat recovery, and more efficient generation contribute to greater efficiency overall. Two characteristics contribute to greater flexibility overall: firstly, heat pumps installed at building level allow flexibility in accommodating a range of different building system operating temperatures, and secondly, a low temperature network provides more opportunities to integrate low carbon heat sources compared with 4GDH.
- In the Scottish context, 5GDHC potentially offers more economic opportunities than 4GDH within the **pipework manufacture and installation** sectors, and potentially also using **mine water as a thermal store** (Scotland has a strong mining heritage). However, the potential challenges for Scotland to capitalise on a 5GDHC market are the **energy demand suitability** (specifically, a general lack of cooling demand), **spatial pipework requirements**, **infrastructure upgrade needs**, and **understanding of the technology**.
- **Potential heat sources** in Scotland include mines, wastewater and ground-source, but **rivers** offer the most attractive and permanent source of heat suitable for 5GDHC.
- The ideal 5GDHC site has **a mixture of heating and cooling demand** from domestic, commercial and industrial customers. It would also include long-term /seasonal thermal storage, short-term building-level thermal storage, and readily available renewable heat sources. The heat pumps on the networks would be powered by **renewable electricity**.
- Scotland currently has **two 5GDHC pilot projects**: the Advanced Manufacturing Innovation District Scotland (AMIDS) and the Clyde Gateway D2 Grids Project. Both are small pilot projects, with heat recovery from local wastewater treatment plants. Neither are yet fully operational.
- Scotland has **existing capabilities** with large ambient thermal storage, building-level thermal storage units, uninsulated pipework installers, and trenching capabilities. **Gaps include** small heat pump manufacturers, uninsulated pipework manufacturers, and GSHP/WSHP installers.

Notes: *Domestic Renewable Heat Incentive

EXECUTIVE SUMMARY

Key analysis findings

European 5GDHC market and capability assessment

- There is **no consensus on which country is the market leader** and traditional indicators of market share cannot be applied due to the emerging nature of the technology and market. **Widely-recognised pilot projects** and **quality research** outputs are seen as **leadership traits**.
- **Germany and Switzerland have the largest number of existing projects** but are relatively **simple and small scale**. The Netherlands' **'Minewater' project in Heerlen is considered the most advanced and leading pilot project**. France, Italy, Austria, and the Nordic countries are all in similar states of 5GDHC development to Scotland, with 1-5 pilot projects.
- The reasons that the Heerlen **Minewater** project is considered the leading example are **complexity and communication**. The network supplies heat and cooling to over 400 dwellings and 250,000 m2 of commercial buildings, with the goal to connect 30,000 homes and offices in the region by 2030. The project also uses mine water as a large seasonal storage. Minewater has been in operation since 2008 and has a strong focus on communication, with developments discussed in academic papers and online. The company behind it has also been responsible for setting up the EU-funded D2Grids project which is creating more pilot projects with France, the UK, Netherlands, and Germany.
- **Innovation gaps in Scotland include the business case and control systems**. Unique/novel characteristics, high CAPEX, and the importance of having sufficient cooling demand all contribute to a challenging business case for the technology.
- Although demand for low carbon heating and cooling is set to grow across Europe, it is **too early to assess export market potential** for 5GDHC. This is because there have not been enough projects or market assessments of 5GDHC against other types of technology.
- Despite export potential being unquantifiable currently, there are a number of **drivers with potentially significant impact on the future demand** for 5GDHC capabilities. These include: policy and legislation, awareness of technology, CAPEX, existing skills and capabilities, climatic factors, incumbent DH technology, and availability of high-grade waste heat.

Notes: *Domestic Renewable Heat Incentive

EXECUTIVE SUMMARY

Key analysis findings

The opportunity for Scotland

- Several **opportunities** and **challenges** for Scottish leadership in 5GDHC have been identified and analysed according to size of opportunity/ challenge and Scotland's ability to influence them. The most strategically relevant **opportunities** are: developing advanced **pilot projects**; influencing the **LHEES** methodology to ensure 5GDHC is considered, and improving the incentives and requirements for **network connection**. The most strategically relevant **challenge** Scotland can address is the **business case**.
- When assessing the leading European countries, **Scotland currently lags behind the Netherlands and Switzerland as perceived market leaders**. The indicators assessed were: market experience, policy environment, existing skills and capabilities, innovation score, and research output.
- Although Scotland is currently not considered a market leader, the market is still nascent with growth potential, so **there is an opportunity for Scotland to become a leader**, if it invests in the technology. However, value associated with leadership is not clear, so it would be strategically prudent to **invest in opportunities where there are synergies with other areas likely to see future growth, such as heat recovery**.
- **Four recommendations** for achieving Scotland's domestic and international potential are:
  - **Demonstrate advanced pilot projects**: either through expansion of existing projects and/or identify new, more complex pilots.
  - **Increase awareness of 5GDHC throughout the value chain** including policy makers, local authorities, developers, and investors.
  - **Map and match heat sources and heating/cooling demands**: to have a stronger understanding of where 5GDHC is suitable and applicable in Scotland, it will be beneficial to conduct a detailed spatial analysis of the potential sources, sinks, and stores in Scotland, considering their suitability specifically for 5GDHC. This analysis will allow a more targeted approach to project development and support.
  - **Research to develop 5GDHC business models**: If Scotland can support more research around the investment case, lifetime costs and charging structures around 5GDHC schemes, it is likely to increase market appetite for the technology. An output from this analysis could also be to identify areas where cost savings are required to make 5GDHC more competitive.

Notes: *Domestic Renewable Heat Incentive

RAMBOLL

INTRODUCTION

- This report presents the findings from a study conducted by Ramboll for Scottish Enterprise analysing the potential for Scotland to be a Leader in 5th Generation Heating and Cooling Networks (5GDHC).
- Fifth Generation District Heating and Cooling (5GDHC) Networks use ambient temperature water for heat transmission combined with local heat pumps to supply heating and cooling at the required temperature for each building.
- When applied in an appropriate location, this design has the potential to offer system efficiencies, particularly when both heating and cooling are required in an area. It also offers flexibility to deliver heating and cooling at different temperatures according to the heating system requirements of each building.
- This study explores the existing applications and understanding of 5GDHC in Scotland and across the rest of Europe, and identifies opportunities for Scotland to become a leader in the developing market.

RAMBOLL

Traditional 3G, insulated district heating pipes run at higher temperatures than 4G and 5G systems.

THE REPORT CONSISTS OF 3 MAIN SECTIONS AS DESCRIBED BELOW

	SCOTTISH MARKET AND CAPABILITIES	EUROPEAN MARKET AND CAPABILITIES	THE OPPORTUNITY FOR SCOTLAND
PURPOSE	• An analysis of the 5th generation district heating and cooling (5GDHC) market and supply chain in Scotland, in order to understand the current Scottish market and capabilities.	• An analysis of the 5th generation district heating market in the rest of the UK and Europe, in order to identify market leaders and potential export markets (if relevant) for Scotland. Also to identify the drivers for future growth in European markets.	• To identify opportunities and challenges for Scotland based on the research covering European countries, and to compare the market and capabilities within Scotland with the rest of Europe. Also to provide recommendations for how Scotland can increase its leadership.
METHODOLOGY	• Data collection process involving desktop research, Ramboll expert interviews, and Scottish, industry expert interviews. • Qualitative analysis to identify capabilities and gaps, and light quantitative analysis to identify potential heat sources in Scotland.	• Data collection process involving desktop research, Ramboll expert interviews, and Scottish, UK, and European industry expert interviews. • Qualitative analysis of trends from data collection to identify key themes from across the European market, including potential drivers for future market growth.	• Identification of European market leaders through analysis of interview data, followed by an assessment of leadership between Scotland and EU leaders. • The section also identifies and qualitatively prioritises opportunities and challenges for Scotland to address in order to develop leadership in the market.
READER'S GUIDE	• The section is structured as follows: 1. Definitions, benefits, and limitations of fourth generation district heating (4GDH) versus 5GDHC. 2. Assessment of the potential scale for application of 5GDHC networks in Scotland 3. Overview of Scotland's existing capabilities and gaps to support 5GDHC networks.	• The section is structured as follows: 1. Overview of European market capabilities, gaps, and innovation requirements 2. Assessment of European export market potential.	• The section is structured as follows: 1. Challenges and opportunities for 5GDHC leadership 2. Scotland's opportunity to become a leader 3. Placing Scotland's leadership potential in the context of a fledgling market 4. Key recommendations for achieving Scotland's domestic and export potential

DATA COLLECTION INVOLVED LITERATURE AND INTERVIEWS WITH VARIED STAKEHOLDER GROUPS

This research was informed by an extensive **literature and information review** including previous Ramboll studies, relevant academic research and market intelligence from publicly available sources and databases.

In addition, **19 expert interviews** were conducted across x15 companies and organisations. To ensure we had a broad knowledge pool, interviewees were put into four categories - Ramboll experts, Scottish experts, international experts and wider stakeholders.

The interviews covered 3 main topics:

1. State of the market;
2. Capabilities and gaps for supporting 5G networks;
3. Scotland's ability to be a leader in 5G district heating and cooling networks.

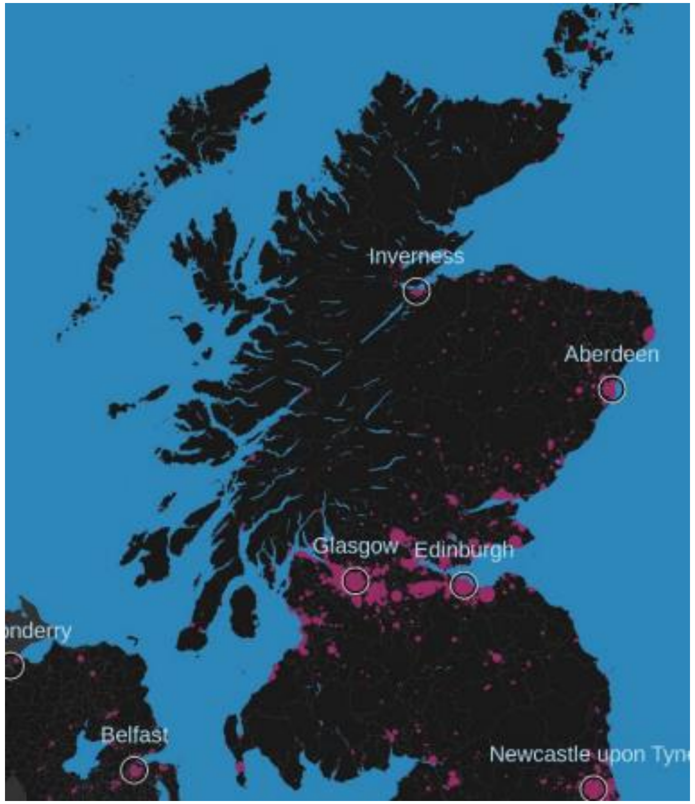
A representative from each of the following organisations were interviewed for this project, with the exception of Ramboll, where 4 experts were interviewed across the business:

Category	Type	Company
Ramboll Experts	Consultancy	RAMBOLL
Scottish Experts	Research	University of Glasgow
Wider Stakeholders	Government	Scottish Futures Trust
	Trade Association	ade – The Association for Decentralised Energy
	Government	Zero Waste Scotland

Category	Type	Company
Scottish Experts	Network Owner	Vattenfall
	Design/ Installation	FES
	Manufacturing	Sunamp
	Manufacturing	Star Renewable Energy
	Design/ Manufacturing	Kensa Heat Pumps – A Kensa Group Company

Category	Type	Company
European Experts	Consultancy	Nordic Heat
	Industry network and research hub	Euroheat & Power
	Manufacturing/ Research	Danfoss
	Research	HSLU Lucerne University of Applied Sciences and Arts
	Research	The Open University

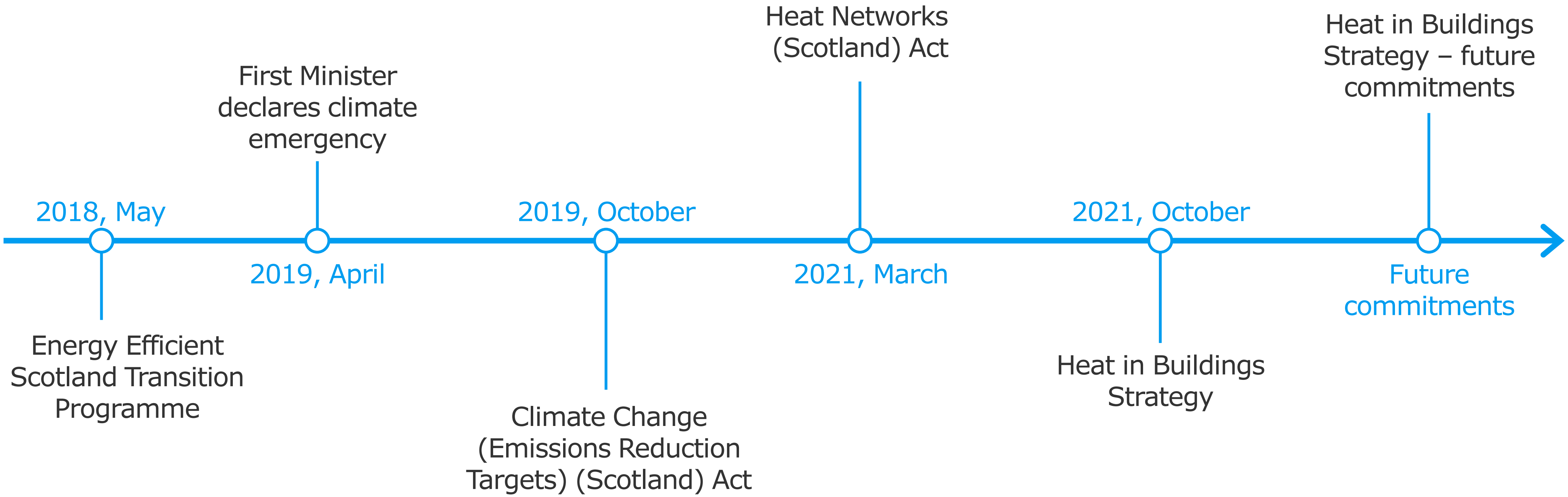
THE SCOTTISH ENERGY SYSTEM IS CHARACTERISED BY AMBITIOUS CARBON TARGETS, BUT HISTORICAL RELIANCE ON GAS



Areas with potential for economically viable heat networks (15TWh = 28% of total heat demand);
Source: Opportunity Areas for district heating networks in the UK, BEIS 2021

Characteristic	Description
Target to reach net zero by 2045	• In April 2019, the Scottish First Minister, Nicola Sturgeon, declared a Climate Emergency. This was followed by amendments to the Climate Change (Scotland) Act to update the legally binding **target to reach net-zero greenhouse gas emissions by 2045.**
High penetration of gas boilers for heating buildings	• ~80% of homes & 30% of non-domestic buildings use gas as the primary heating source. • The last estimate (2018) suggested ~1,176 GWh of Scotland's heat demand is supplied through heat networks. Most existing heat networks are small scale and rely on gas CHP. • There is low consumer awareness of district heating. • The commercial business case for low carbon district heating is challenging against the current counterfactual of gas boilers, but policy powers related to the gas network are reserved to the UK parliament.
District heating seen as a key technology for decarbonisation of heat	• In the short term, Scottish energy policy focuses on "no and low regrets" strategic technologies. This includes a focus on "areas most suitable for heat networks", that will be supported by a heat network zoning analysis conducted by local authorities. • District heating can offer efficiency gains to the energy system as a whole offering opportunities for thermal storage and utilization of waste heat sources.
Supply chain capacity and skills gaps	• There are a range of skills gaps creating challenges in the district heating sector, covering areas of project management, heat network design, installation and optimisation, as well as technical operation and maintenance. Successful rapid scale-up of heat networks in Scotland will rely on upscaling and upskilling of the supply chains across the whole sector.
Developing policy landscape to support low carbon district heating	• A suite of regulations and supporting policy framework, including the Heat Networks Act, is being developed to enable deployment of low carbon heat networks (see next page). • The Scottish Government Heat in Buildings Strategy (2021) committed to invest "£1.8bn capital funding over the lifetime of this parliament on energy efficiency and low carbon heat". See the next page for details.

A TIMELINE OF SCOTTISH POLICY AND REGULATION TO PROMOTE THE DEVELOPMENT OF DISTRICT HEATING (1/3)



Source: Scottish Government, Scottish Parliament

A TIMELINE OF SCOTTISH POLICY AND REGULATION TO PROMOTE THE DEVELOPMENT OF DISTRICT HEATING (2/3)

Date	Policy/ legislation	Key district heating points
2018, May	**Energy Efficient Scotland Transition Programme**	• Supported the piloting of **Local Heat and Energy Efficiency Strategies (LHEES),** aiming to develop a consistent approach to local energy planning, including identification of heat network zones. • **Funding** for local authorities to offer **end-to-end support for energy efficiency** in domestic and non-domestic markets • **Allocation of funding** for fuel poverty programmes
2019, April	**First Minister declares climate emergency**	• Followed by Climate Change action, amendments to the Climate Change Bill to set a legally binding target of net-zero greenhouse gas emissions by 2045.

2019, October	**Climate Change (Emissions Reduction Targets) (Scotland) Act**	• Introduces **three emission reduction targets**:
		  • 2045 as the net-zero emission target year
		  • Interim emission reduction targets for 2030 and 2040 (of 75% and 90% respectively)
		• Introduces changes to emissions accounting, reporting and planning duties, other duties, minor and consequential modifications, final provisions.

2021, March	**Heat Networks (Scotland) Act**	**Regulations to promote & support heat networks**, including: Technical standards; consumer protection; granting licenses; issuing permits (exclusive rights); and establishing planning for heat network zones. The Act sets specific targets for **heat networks** to supply 2.6 TWh of heat by 2027 and 6 TWh of heat by 2030. This should include connection of 120,000 homes by 2027 and 650,000 homes by 2030.

A TIMELINE OF SCOTTISH POLICY AND REGULATION TO PROMOTE THE DEVELOPMENT OF DISTRICT HEATING (3/3)

Date	Policy/ legislation	Key district heating points
2021, October	**Heat in Buildings Strategy**	• **Funding** will be available through a successor to the Low Carbon Infrastructure Transition Programme and a refocussed **district heating loan fund** • **Heat Network Pre-Capital Support Unit** in 2021 will provide technical, legal, financial and supply chain advice and support to those leading heat network project development. • A **Heat Network Investment Prospectus** will be published during the next financial year that will demonstrate the size and location of heat network opportunities across Scotland, as well as information on the decarbonisation requirements of existing networks in Scotland. • Creation of a **Heat Networks Delivery Plan** by April 2022 setting out how the Heat Networks Act and wider policy will increase the use of heat networks in Scotland (including meeting the targets set out by the Act).
Future	**Heat in Buildings Strategy – future commitments**	• Consult on proposals to require anchor buildings in the non-domestic sector to make adaptations to become **'heat network ready' to connect**, and use the non-domestic rates system to encourage such buildings to go on to use a local heat network. • Creation of a **National Public Energy Agency** with a remit to raise public understanding and awareness, coordinate delivery of investment and coordinate national, regional and local government delivery of heat decarbonisation and energy efficiency rollout. • Produce a **Heat in Buildings Supply Chain Delivery Plan** focussed on the development of energy efficiency and zero emissions heat in the buildings supply chain. • From 2024, new houses granted planning consent will be required to use renewable or low carbon heating.

2. SCOTTISH 5G HEAT NETWORK MARKET AND CAPABILITY ASSESSMENT

Introduction to report section

Executive Summary & Introduction | **Scottish market and capabilities** | European market and capabilities | The opportunity for Scotland

The following section includes an analysis of the 5th generation district heating market in Scotland and the supply chain. The analysis consists of three main deliverables:

1. A comparison of 4GDH and 5GDHC, including the equipment used and the benefits and limitations of each.
2. Assessment of the suitability of 5GDHC networks for Scotland, including analysis of potential sources of renewable heat.
3. Analysis of the current status of the Scottish district heating supply chain and its potential to support 5GDHC systems and the gaps Scotland has.

Methodology applied in report section

The overview of the Scottish 5GDHC market and capability assessment was conducted using the following method:

- Desktop research including the academic literature, previously conducted Scottish Enterprise consulting reports, government reports, and private sector literature.
- Ramboll expert interviews, and Scottish, UK, and European industry expert interviews.

The breadth of the interview groups was designed to provide confidence in the research findings, allowing triangulation of perspectives across different actors.

Highlighted conclusions

No clear winner between 4GDH and 5GDHC at this stage

The name implies that 5GDHC is a progression from 4GDH, but in reality this is not the case. They are two technological solutions which offer benefits for specific circumstances. Additionally, they are currently at different stages of maturity, making it difficult to compare the two. The systems should be considered design variations of heat networks, and determining the most suitable type of network should be considered at the design stage.

Cooling demand is vital for 5GDHC networks to be viable

Unlike 4GDH networks, 5GDHC networks have built in cooling capabilities. To make these networks financially viable a cooling demand is considered key. The cooling demand in Scotland is currently low, but is expected to rise in the coming years.

Many capabilities for 5DGHC already exist in Scotland, with one clear gap

Scotland already has many of the supply chain capabilities required to keep the value of developing 5GDHC networks within the country. The pipework is similar to that used in gas and water mains, which Scotland already regularly installs. However one large gap is manufacturers, suppliers and installers of small water/ground source heat pumps.

RAMBOLL

Executive Summary

1. Introduction

2. Scottish 5GDHC Market and Capability Assessment

2.1 Definitions, benefits, and limitations of 4GDH versus 5GDHC

2.2 Assessment of the potential scale for application of 5GDHC networks in Scotland,

2.3 Overview of Scotland’s existing capabilities and gaps to support 5GDHC networks

3. European 5GDHC Market and Capability Assessment

4. The Opportunity for Scotland

DEFINITIONS OF 4G DISTRICT HEATING AND 5G DISTRICT HEATING AND COOLING

5th Generation District Heating and Cooling (5GDHC)	4th Generation District Heating (4GDH)
5GDHC systems are defined as decentralised networks (i.e. a heat pump is located in each building) which operate at ambient temperature and are capable of supplying both heating and cooling.	**4GDH systems are defined as centralised heat networks which operate at low temperatures and incorporate renewable energy.**

Characteristics

5GDHC	4GDH
▪ The definition is still under debate. There is not yet a consensus across the DHC industry about the specific definition of a 5GDHC system, with shared ground loop technology considered a grey area. ▪ 5GDHC networks are characterised by low distribution temperatures (typically 5-25^{O}C), diminishing the need for pipe insulation and reducing heat loss. ▪ The network connects a combination of heating and cooling capacity through the use of distributed heat pumps located in decentralised building-level plantrooms to pressurise and balance the system – they are not normally centrally pumped. ▪ They utilise a wide variety of heat sources, offer a demand side response (i.e. can use electricity for heat pumps in off-peak hours) and integrate waste and excess heat capturing capability with storage. ▪ Flow is often bi-directional, meaning the water in the network flows one way or another depending whether heating or cooling is required.	▪ 4GDH networks are a clear progression from generations 1 to 3 with a higher efficiency and lower temperatures in the same centralised design. ▪ 4GDH systems commonly use 60^{O}C supply and 30^{O}C return temperatures, but centralised systems with temperatures between 30-70^{O}C can be classified as 4GDH. This is lower than the temperature of 3GDH systems, but higher than 5GDHC systems. ▪ Introduction of low temperature waste heat and renewable heat sources as part of supply, with large heat pumps often used. ▪ 4GDH systems cannot provide cooling without the addition of an extra network in a 4-pipe setup.

Equipment

5GDHC		4GDH
• Heat taken from cooling (these customers are referred to as prosumers) • Waste/low grade heat directly into loop	**Heat Sources**	• Large centralised heat pumps • High grade waste heat • Combined Heat and Power (CHP) • Energy From Waste
• Uninsulated pipework • Pumping generally done by distributed pumps in consumer buildings	**Transmission/ Distribution**	• Insulated pipework • Large centralised pumps
• Separate heat pump and chiller; or • Reversible/simultaneous heat pump	**Customer Connections**	• Heat interface units (i.e. heat exchangers); or • Direct connection to network (i.e. network flows directly into buildings)

5TH GENERATION CONTINUES THE TEMPERATURE AND EFFICIENCY TRENDS BUT BREAKS FROM TRADITION

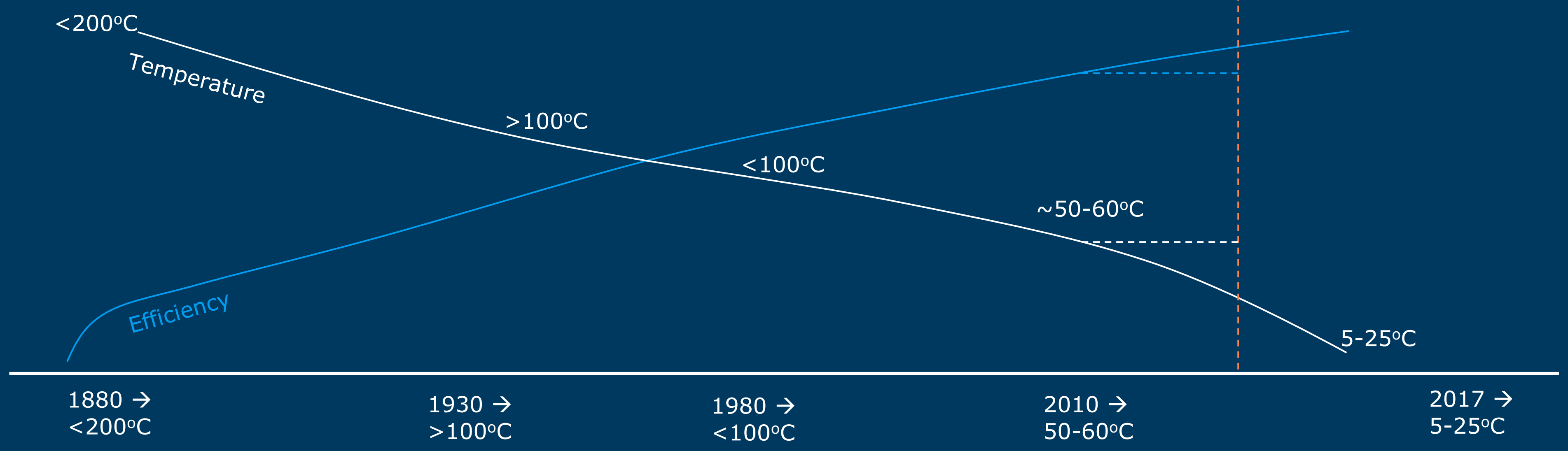
1st Generation
Steam
Pressurized steam pipes in concrete ducts

2nd Generation
On-site construction
Pressurized hot water
Heavy equipment
Large on site plant

3rd Generation
Off-site construction
Pre-insulated pipes
Off-site construction
Metering and monitoring

4th Generation
Multi-vector
Improved controls

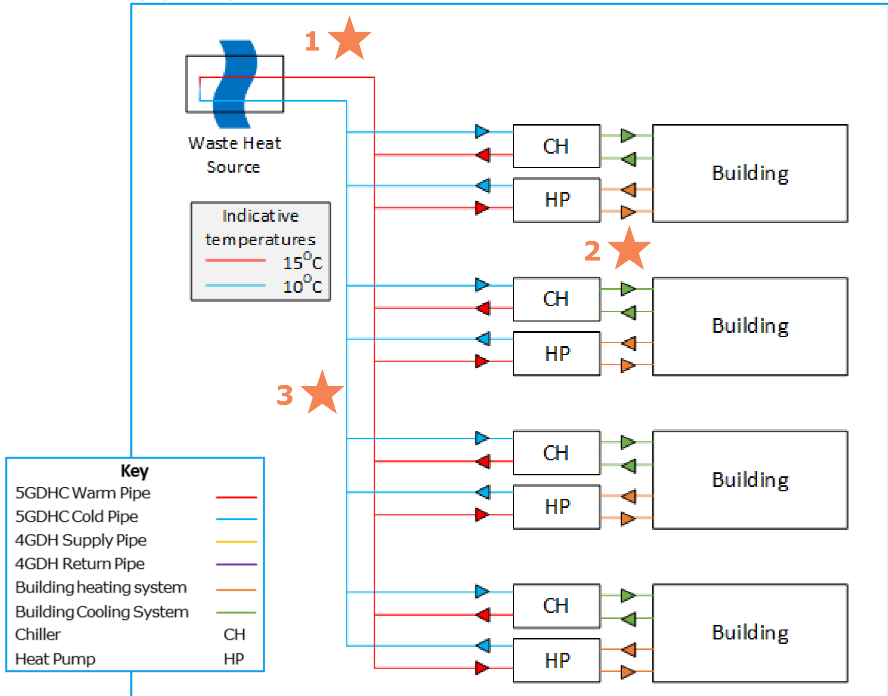
5th Generation
Ambient temperature
Controls integration
Heating *and* cooling
Modular expansion
Demand Side Management



Source: CIBSE (2019) Intranets for heat: Introducing BEN networks

SCHEMATICS FOR TYPICAL 4GDH AND 5GDHC NETWORKS SHOW DISTINGUISHING CHARACTERISTICS

5GDHC

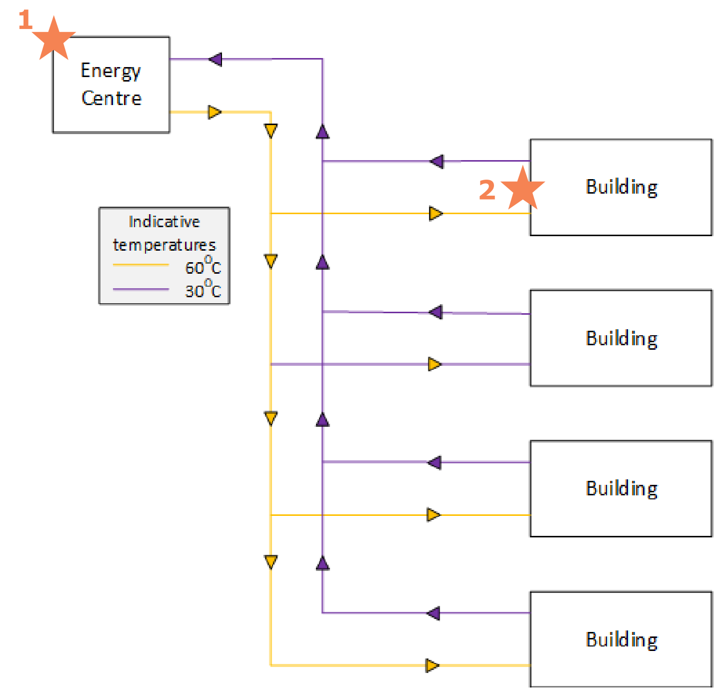


5th Generation District Heating and cooling (5GDHC) networks differ from previous generations because they deliver both heating and cooling capabilities, use decentralised sources of waste heat and cooling and relying on heat pumps and/or chillers in individual buildings in the network.

Distinguishing features

1. Various sources of 'waste' heat can be added to a 5G network, such as from data centres or waste-water treatment plants.
2. Every building in the network has its own heat pump to raise the temperature to the required level for each building.
3. Bi-directional flow (indicated in the figure by pipes with a lack of arrows) is a unique characteristic of 5GDHC networks

4GDH



4th Generation District Heating (4GDH) networks are the most advanced and efficient type of traditional district heating, with a centralised heat source (can be renewable energy) and uni-directional supply of heat to buildings within the network.

Distinguishing features

1. The energy centre in traditional district heating systems, including 4GDH, is commonly an energy from waste (EfW) plant, biomass thermal plant or a combined heat and power (CHP) plant. Large heat pumps or solar thermal plants can also be used.
2. In 4G networks, heat either goes directly into the building from the heat network, or a heat exchanger is used to transfer heat from the network into buildings.

THERE ARE CURRENTLY TWO SCOTTISH 5GDHC PROJECTS UNDER DEVELOPMENT: AMIDS AND CLYDE GATEWAY

Summary

There are two pilot projects currently under development in Scotland, but use of 5GDHC technology is not yet well established in the Scottish market and neither project is yet in operation.

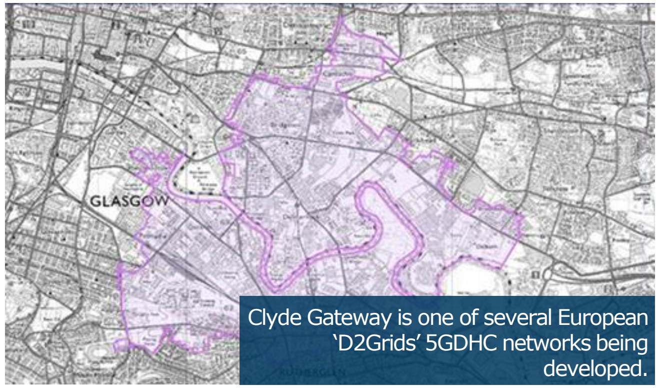
AMIDS: "The Advanced Manufacturing Innovation District Scotland (AMIDS) will be an internationally-recognised centre for advanced manufacturing – ideally placed in Scotland's industrial heartland."

- AMIDS is located in Paisley, Renfrewshire, and will have a 5th generation district heating network.
- The network is currently in the construction phase, with FES as the main contractor. Partners of the project include Renfrewshire Council, Scottish Water Horizons, Scottish Enterprise, Scottish Futures Trust and Zero Waste Scotland.
- The network will originally connect to two buildings; the National Manufacturing Institute Scotland (NMIS) and the Medicines Manufacturing Innovation Centre, with the capability to expand as more buildings are constructed in the district over the next 10 to 15 years.
- The network will recover waste heat from the final effluent of Scottish Water's Laighpark Waste Water Treatment Works through a heat exchanger. It is due to be completed by mid 2022.

AMIDS is located in Paisley, Renfrewshire and will recover waste heat from a wastewater treatment works. *Image: sdi.co.uk*

Clyde Gateway is "Scotland's largest and most ambitious regeneration programme" and is located in the east end of Glasgow.

- The regeneration programme will include two district heating networks, a traditional centralised network, which will begin operation in 2022, and a 5GDHC network, which is currently in the conceptual design stage and being designed by Ramboll. The networks are being developed in partnership with Scottish Water Horizons.
- The 5GDHC network is one of five Interreg D2 Grids pilot projects, which aims to set industry standards for 5GDHC.
- The 5th generation network will originally connect to 3 office buildings, with plans to increase this to 8 buildings in the future.
- The network will recover waste heat from the final effluent of a local waste water treatment works. It is due to be completed by early 2023.



Clyde Gateway is one of several European 'D2Grids' 5GDHC networks being developed.

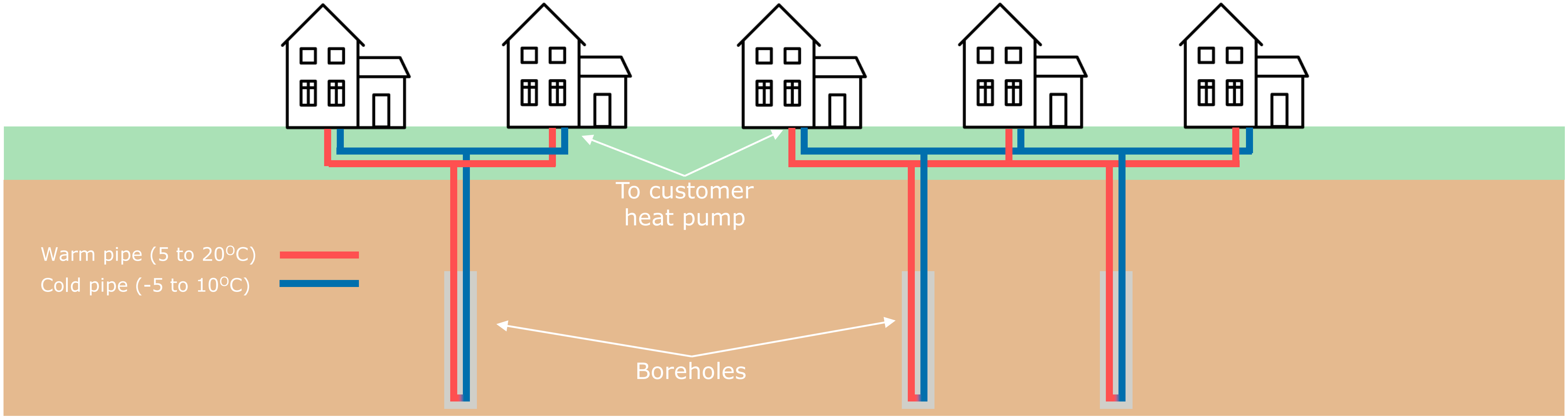
SHARED GROUND LOOP ARRAYS

A subset of 5th generation district heating

Shared ground loop (SGL) arrays are a subset of 5GDHC networks. They use a small heat pump in each dwelling/building they serve and are connected together by uninsulated underground pipework running ambient temperature water. Heat is generally supplied to the systems using a series of boreholes linked together to extract naturally occurring geothermal heat. Application of these systems was pioneered by Kensa Heat Pumps in the UK.

The key characteristics of shared ground loop arrays which differ from broader 5GDHC systems are:

- Shared ground loops typically use boreholes as their main heat source, whereas 5GDHC networks can incorporate many other sources of heat.
- In shared ground loops, the temperature inside the network is passive and cannot be controlled by the operator. In other 5GDHC networks the operator can optimise temperatures from different heat sources in the network to meet the heating and cooling demand requirements.
- At present, shared ground loops tend to be smaller systems (i.e. communal heating or a number of small buildings). This requires a different type of policy support from larger 5GDHC networks which have the potential to deliver greater system efficiencies when utilising multiple heat sources and offering increased flexibility in design and operation.



Source: Adapted from Kensa illustration https://www.kensacontracting.com/services/fifth-generation-district-heating-cooling/shared-ground-loop-arrays/

BENEFITS OF 5GDHC COMPARED WITH 4GDH INCLUDE EFFICIENCIES AND FLEXIBILITY

Advantages of 5GDHC vs 4GDH

Efficiency:

- **Heat losses**: 5GDHC networks have lower losses than 4DGH due to lower temperatures in the network
- **Heat Recovery**: 5GDHC systems directly incorporate heat recovered from cooling into the network, but a separate system would be required to do this with 4GDH.
- **Efficiency of generation:** The small heat pumps within 5GDHC, selected for each specific building, are likely to be more efficient than a large heat pump that needs to operate at the temperature suitable for the worst performing building.

Flexibility:

- **Connection type flexibility**: 5GDHC networks allow any end building temperature as the heat pump can be changed building to building, whereas all customers receive heat at the same temperature in 4GDHC networks.
- **Heat source flexibility**: The low temperature of 5GDHC systems mean they can use any heat source, allowing low temperature sources to be utilised in the network without being upgraded.
- **Multifunctionality:** 5GDHC can incorporate heating and cooling into a singular network with only two pipes, and free cooling can also be used as part of this. 4G systems require a separate cooling network.

Disadvantages of 5GDHC vs 4GDH

Cost

- **Cost of CAPEX:** Studies conducted to date (considering examples from across Europe) suggest that 4GDH systems are generally cheaper than 5GDHC systems. The exceptions to this are (i) when the networks are small scale, making the economics for a centralised system more difficult to justify, and (ii) when a separate cooling network would have otherwise been required. However, there are still relatively few examples of 5GDHC in operation so opportunities remain for innovative applications of the technology that might compete with 4GDH at scale.

Flexibility:

- **Off-peak electricity usage**: As all heat generation is done at the end user, the flexibility of 5GDHC systems is lower at the whole system level. 4GDH systems can use off-peak electricity to fill large thermal stores, whereas 5GDHC could only fill building level stores with high grade heat, which is more expensive.

Robustness:

- **Reliability**: 5GDHC networks include more components than 4GDH systems, meaning there is a higher chance of a breakdown within the system. In particular, 5GDHC networks are less likely to have back up heat pumps (which is standard practice for 4GDH) since the cost for a heat pump in every building is likely to be prohibitive. This affects the reliability of heat supply should a customer’s heat pump break down. Maintenance of a smaller number of large heat pumps within a 4GDH system is also easier than a large number of distributed heat pumps in 5GDHC, which is an important influence on reliability.
- **Proven design**: 4GDH networks have a proven centralised design, whereas the decentralised design of 5GDHC is fairly unproven and requires more complex hydraulics due to bi-directional flow. The business model or 4GDH systems is also much clearer.

IN A SCOTTISH CONTEXT THERE ARE ADDITIONAL ADVANTAGES AND DISADVANTAGES TO CONSIDER

Advantages of 5GDHC vs 4GDH in a Scottish context

Existing skillset:

- The uninsulated pipework required for 5GDHC is very similar to gas and water mains pipework. The existing gas pipework installers could install it with minimal training. There are very few qualified installers of pre-insulated steel pipework in Scotland for 4G networks and more extensive training would be required to specialise the existing workforce.

Use of existing resources:

- 5GDHC systems can more easily incorporate large underground storage, such as mines, which Scotland has available to it. Additionally, 5GDHC networks can more easily incorporate Scotland's waste heat from sewers, data centres, and more.

Disadvantages of 5GDHC vs 4GDH in a Scottish context

Energy demand suitability

- For 5GDHC networks to be viable there must be a cooling demand on the network. Cooling demand in Scotland is generally very low, with almost no domestic properties requiring cooling.

Pipework spatial requirements:

- The pipework for 5GDHC systems is large due to a lower temperature difference between the supply and return temperature in the network compared to 4GDH systems. However, the difference is not drastic after insulation is taken into consideration and the flexible pipework used 5GDHC can be easier to install in some cases.

Infrastructure upgrades:

- For 5GDHC there may be a requirement to upgrade the electrical infrastructure in each individual building, where as 4G systems only require electrical upgrades to a large energy centre.

Understanding

- There is currently a low understating of 5GDHC networks in Scotland and in general, which makes them very hard to include in the likes of LHEES. As the 5GDHC market matures and more projects are constructed around Europe it is expected the understanding in Scotland will also rise.

A CASE STUDY COMPARISON BETWEEN 4GDH AND 5GDHC NETWORKS

Queens Quay 4GDH Network (currently running as 3G)

The Queens Quay network is located in Clydebank, Glasgow, and uses large water source heat pumps to deliver heat to a centralised heat network operating with a supply temperature of 80°C. It is one of very few 4GDH compatible networks in the UK, however, in practice the network operates at higher temperatures than would be expected within a 4GDH due to the connections to existing buildings requiring higher flow temperatures. With a 5GDHC system this would not be required, as each building could have a different end temperature.

Storage: 130m^3 thermal store

Heat sources: 2x 2.65MW Water source heat pumps taking heat from the River Clyde and gas boilers for backup. Space for 2 more heat pumps as the network expands.

No. of connected buildings: Currently has 5 large customers, with an additional 1,200 newbuild homes to be connected when they are built.

Building connection: Plate heat exchanger

Supply temperature: 80°C

Return Temperature: 60°C

Flow direction: Uni-directional

Queens Quay Energy Centre located in Clydebank, Glasgow

Minewater 5GDHC Network

The Minewater network is located in Heerlen, the Netherlands, and is regarded as a flagship project for 5GDHC. It is a two pipe system with a 'warm' and 'cold' pipe and all customers can receive both heating and cooling. Originally, a large mine was used as a heat source, however, as the project has developed this has been converted to thermal storage due to the temperature dropping too low and not regenerating quickly enough to act as an effective heat supply. There is a range of building stock connected to the Minewater network, which is catered to by the ability of the network to vary the output temperature at the building level using heat pumps.

Storage: Flooded coal mine (low grade) and building level water tanks (high grade)

Heat sources: Data centre, geothermal, supermarket refrigerators, small industrial processes and space cooling.

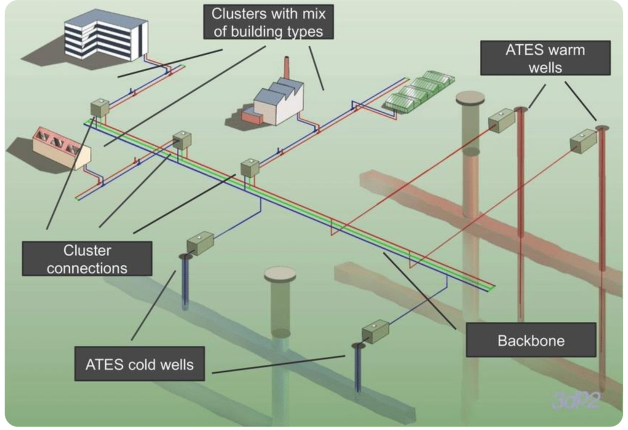
No. of connected buildings: 400 dwellings plus 10 large customers of varied size and building age, including a college Campus. Another four large connections are 'in preparation'.

Building connection: Heat pumps and chillers

Supply temperature: 45°C (heating) and 15°C (cooling)

Return Temperature: 30°C

Flow direction: Bi-directional



An artists interpretation of the Minewater network (Source Mijnwater B.V.)

2.2 ASSESSMENT OF THE POTENTIAL TO DEVELOP 5G HEAT NETWORKS IN SCOTLAND

Potential for heat networks

Heat networks currently meet circa 2% of heat demand in the UK, with natural gas as a primary fuel source. In Scotland, a national assessment by BEIS[1] found that economically viable heat networks could supply 28% of total heat demand, which was higher than England (19%), Northern Ireland (3%) and Wales (15%). 5GDCH could make up a subsection of this heat supply, although the immaturity of the technology makes it difficult to make a specific assessment of the exact scale for its application. This section considers key indicators that suggest a potential for effective application of 5GDHC and assesses their scale.

Indicators of potential for 5GDHC

Mixed building stock requiring different heat supply temperatures - As with any heat network, it is more efficient and economical to install 5GDHC systems into highly efficient buildings suitable for lower temperature heating systems such as new builds. However, it is also possible to retrofit systems and the technology offers advantages over 4GDH for supplying heat to areas with a mixed building stock requiring differing heating system temperatures within buildings. In 4GDH if any buildings require a higher temperature then the whole network must increase its temperature to connect it, which can be seen in the Queens Quay project in Glasgow (shown on page 17). At present there is no spatial analysis that might provide a quantification of how prevalent this characteristic is within heat network opportunity areas in Scotland. Instead, the optimum heat network design solution is determined at the design stage of a project.

Coincidence of suitable demand and low temperature heat sources – 5GDHC provides a solution for utilising low temperature heat sources (<40°C). Where there are higher temperature heat sources, it is likely to make more sense to use a 4GDH system. Areas that are likely to be most suitable for 5GDHC will therefore have a relatively high demand density (for both heating and cooling as per the indicator below) coinciding with a lack of high temperature heat sources. An analysis of heat sources in Scotland is presented on the next two pages.

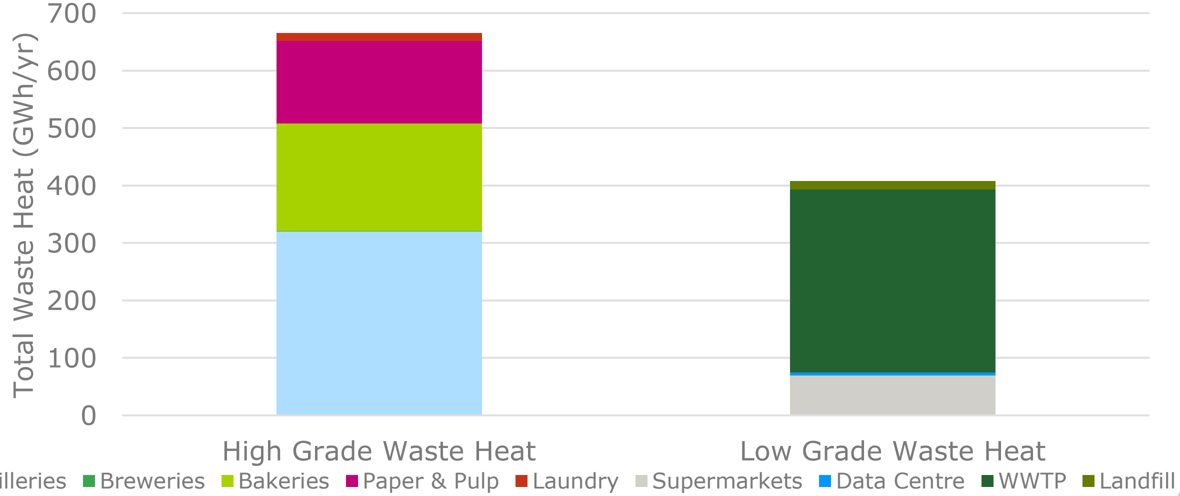
Balance of heating and cooling demands –For 5GDHC networks to be a technically and financially optimal low-carbon solution there is ideally a combination of heating and cooling in the network. Scotland's 2020 heat demand was estimated to be 53.0 TWh/yr in 2020, and is predicted to rise to 62.3 TWh/yr by 2050[1]. Scotland's cooling demand is significantly lower than the heat demand, estimated to be 3.2 TWh/yr in 2020[1]. However, it is estimated that Scotland's annual temperature will increase by 1.1°C by 2050 and 2°C by 2080 compared to the 1981-2000 baseline[2]. Based upon global heating at this extent, the International Energy Agency predicted that worldwide cooling demand would more than triple by 2050[3]. Although there is no estimate of cooling demand trajectories specifically for Scotland, it is reasonable to assume that an increase in cooling demand would be expected, increasing the opportunity areas for 5GDHC.

Sources: 1."Opportunity areas for district heating networks in the UK", BEIS (2020); 2."Evidence for the third UK Climate Change Risk Assessment (CCRA3) Summary for Scotland", UK Climate Risk (2021); 3. "The Future of Cooling", IEA (2018)

ASSESSMENT OF THE SUITABILITY OF HEAT SOURCES IN SCOTLAND FOR 5GDHC

Waste Heat Sources

- 5GDHC systems are flexible to incorporating a wide range of heat sources into the network, including low grade waste heat, without having to upgrade it.
- However, when high grade heat is available in large quantities it is better utilised in 4GDH systems. This is because if high grade heat is used in a 5GDHC system, the temperature of the waste heat is reduced when it is added to the network, then increased again by the building-level heat pump, which is less efficient than using it directly.
- This must be assessed on a case-by-case basis, as for small quantities of high grade waste heat the expensive insulated pipework required to utilise it within 4GDH may not be justifiable for the amount of heat available.



Grade	Heat Source	Average Waste Heat Per Site (MWh/yr)	Total Waste Heat (MWh/yr)
High Grade Waste Heat (>50ºC)	Distilleries	2,481	320,104
	Breweries	17	992
	Bakeries	2,562	187,040
	Paper & Pulp	23,901	143,405
	Laundry	1,631	13,341
Total High Grade Waste Heat			**664,882**
Low Grade Waste Heat (<50ºC)	Super-markets	162	69,889
	Data centres	505	4,546
	WWTP	13,287	318,905
	Landfill	76	13,680
Total Low Grade Waste Heat			**407,020**

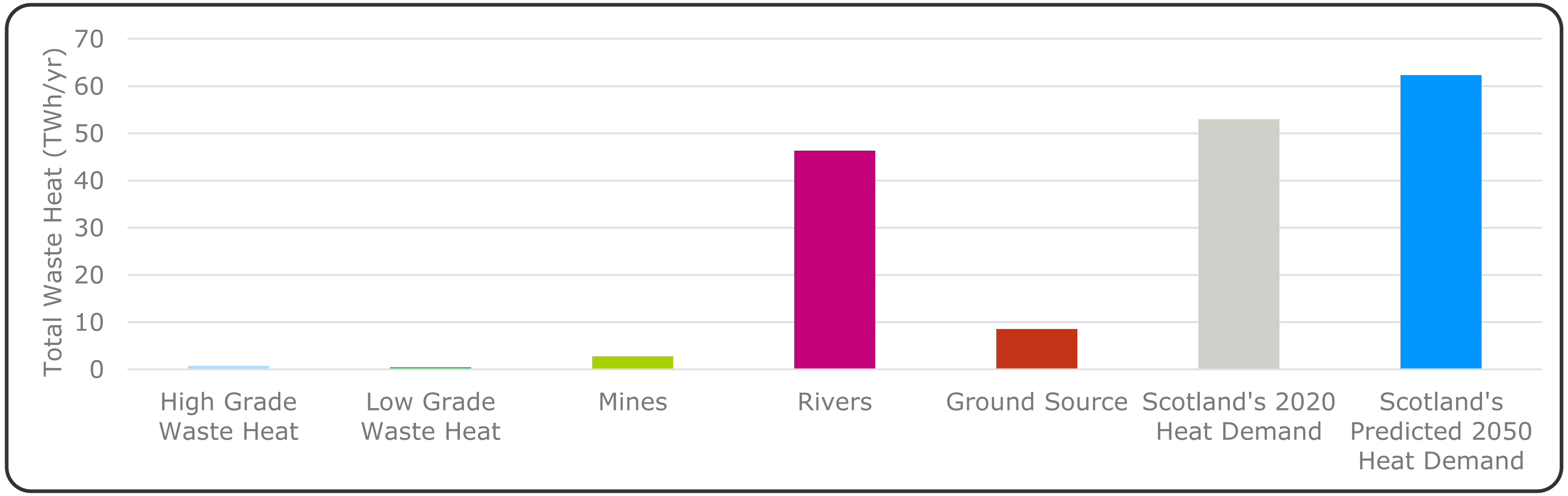
Source: "Potential sources of waste heat for heat networks in Scotland", ClimateXChange (2020)
Note: There are some uncertainties in these values and they should be used for indicative purposes only.
.

POTENTIAL HEAT SOURCES IN SCOTLAND

Heat Sources

- Using waste heat will only satisfy a small portion of Scotland's demand (see chart below). Therefore, Scotland must look to other sources to be capable of fulfilling the rest of it's heat demand, and as can be seen from the table, there is plenty of heat available to Scotland in various forms. In addition to the sources included in the chart, there is also heat available from the ambient air that can be used in ASHPs. A benefit of these sources is that they are seen as more reliable than waste heat in the long term, as they do not rely on the continued operation of another facility (e.g. a data centre) to provide heat.
- These sources can be suitable for both 4G and 5G networks, and it is important that the decision to choose which kind of heat network to use is not made too early in the design/planning process. Heat network areas should firstly be assessed, before determining which type of network is the most suitable.
- When making the decision on the preferred type of network its important to consider the demands in the area, the quantity of heat sources, the timing and frequency of their availability, and the location of the sources relative to the network.

Heat Source	Total Heat (GWh/yr)
Mines[1]	2,722
*Rivers[2]	46,312
*Ground Source[2]	30,272
High Grade Waste Heat[3]	665
Low Grade Waste Heat[3]	407



Sources: 1."Coupled hydraulic and mechanical model…", Todd et al. (2019); 2. Green Heat in Greenspaces National Results Report", Greenspace Scotland (2021) 3."Potential sources of waste heat for heat networks in Scotland", ClimateXChange (2020); Note: *Taken at assumption of capturing 20% of total potential heat available in Scotland.

THE 'IDEAL' 5GDHC NETWORK SCENARIO

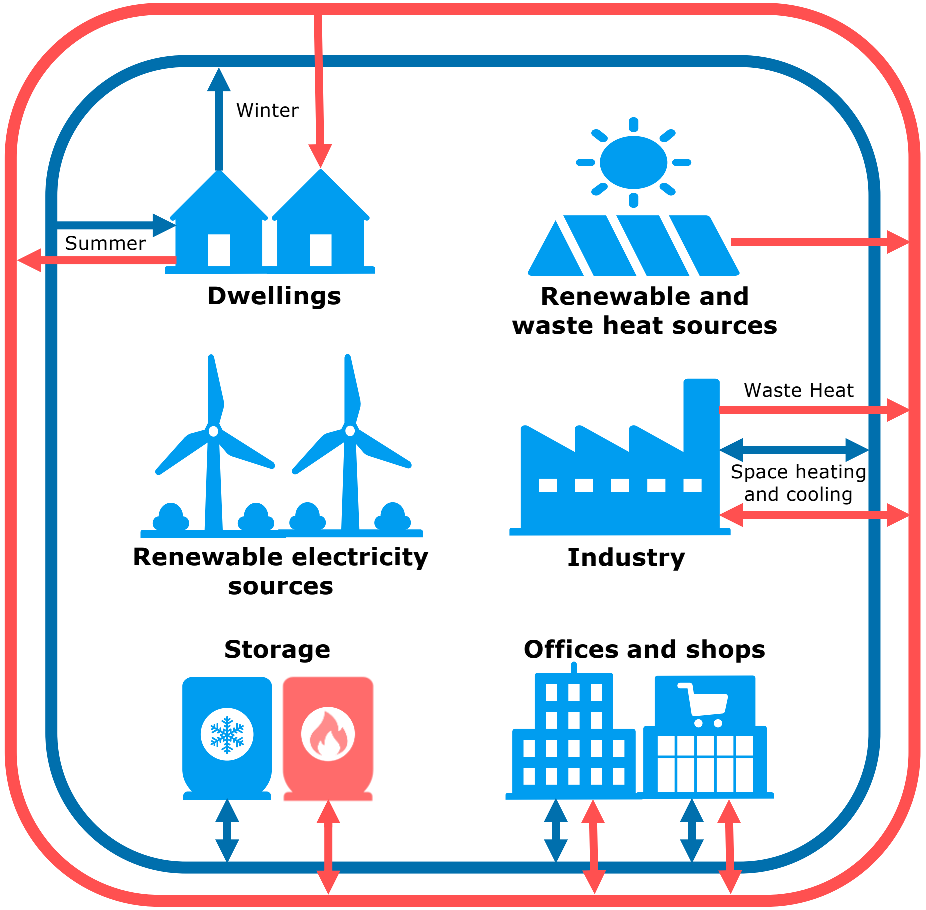
Summary

The following diagram represents an ideal 5GDHC network. It should have both heating and cooling, include storage, utilise waste heat and be powered by renewable electricity. However, 5GDHC networks are flexible, and many variations of this ideal setup are also feasible.

Dwellings
In general, heating and cooling demand in domestic dwellings will be dominated by heating, but may require some cooling during summer. The reduced distribution losses of 5GDHC mean that its application may be suitable in lower density residential areas than higher temperature systems.

Renewable electricity sources
The heat pumps on the network should be powered by renewable energy.

Storage
This can be long term (seasonal) storage, or short term storage. Seasonal storage may be large water cylinders or flooded mines, while short term is likely to be small building level water tanks or Sunamp units.



Renewable and waste heat sources
This can be a wide range of sources, such as solar thermal, sewage heat recovery, geothermal, water source, and more.

Industry
Industry can act as a source of heat supply, as well as heating and cooling demand. The temperature and capacity of waste heat from industry will vary, and will sometimes offer more benefits in higher temperature district heating systems. However, waste heat can be captured and used in 5GDHC where appropriate.

Offices and shops
Office buildings and shops require heating and cooling throughout the year and therefore offer important anchor loads for 5GDHC systems.

RAMBOLL

METHODOLOGY FOR IDENTIFYING AND ASSESSING SCOTTISH CAPABILITIES AND GAPS

Assessing Scottish capabilities throughout the 5GDHC value chain

In order to understand Scotland's current position in the 5GDHC market, the 5GDHC value chain in Scotland is firstly described, then assessed according to the level of existing Scottish capabilities.

The value chain is broken down into heat production, distribution and transmission, and consumption.

Product and service activities are defined as 1. Design, planning, and specification, 2. Equipment supply and construction/ installation, 3. Operation and maintenance, and 4. Investment and ownership.

Assessing capacity: Product and service activities were assessed for each value chain step on a 0-4, scale with 0 as the weakest and 4 as the strongest. This assessment was based on interviews and validated by Ramboll experts.

0 1 2 3 4

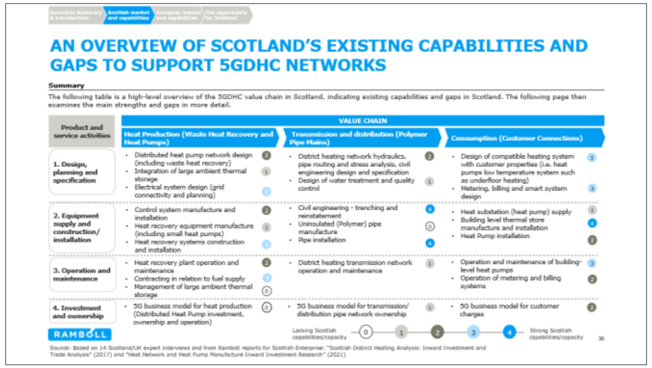
Deep dive into the main capabilities and gaps

The strongest and weakest links in the value chain (assessed as 4 and 0 respectively) are then further examined, including an assessment of their relative significance for Scotland's capacity to become a 5GDHC market leader.

The **main capabilities** are links in the value chain assessed to a score of 4. These capabilities and the rationale for assessing their significance is further described.

The main gaps are links in the value chain previously assessed to a score 0. These gaps and the rationale for assessing their significance is further described.

The significance of each capability and gap is assessed qualitatively based on the potential for that capability or gap to affect the ability of Scotland to become a leader in 5GDHC technology. This assessment was based on interviews and validated by Ramboll experts.



'An overview of Scotland's existing capabilities and gaps to support 5GDHC networks' examines the links in the 5GDHC chain and assesses Scotland's capabilities within each link.

The links assessed as the strongest and weakest are then further described in the main capabilities and gaps slide.

RAMBOLL

AN OVERVIEW OF SCOTLAND’S EXISTING CAPABILITIES AND GAPS TO SUPPORT 5GDHC NETWORKS

Summary

The following table is a high-level overview of the 5GDHC value chain in Scotland, indicating existing capabilities and gaps in Scotland. The following page then examines the main strengths and gaps in more detail.

Product and service activities	VALUE CHAIN					
	Heat Production (Waste Heat Recovery and Heat Pumps)		Transmission and distribution (Polymer Pipe Mains)		Consumption (Customer Connections)	
1. Design, planning and specification	• Distributed heat pump network design (including waste heat recovery) • Integration of large ambient thermal storage • Electrical system design (grid connectivity and planning)	2 1 3	• District heating network hydraulics, pipe routing and stress analysis, civil engineering design and specification • Design of water treatment and quality control	2 1	• Design of compatible heating system with customer properties (i.e. heat pumps low temperature system such as underfloor heating) • Metering, billing and smart system design	3 3
2. Equipment supply and construction/ installation	• Control system manufacture and installation • Heat recovery equipment manufacture (including small heat pumps) • Heat recovery systems construction and installation	2 1 3	• Civil engineering - trenching and reinstatement • Uninsulated (Polymer) pipe manufacture • Pipe installation	4 0 4	• Heat substation (heat pump) supply • Building level thermal store manufacture and installation • Heat Pump installation	1 4 2
3. Operation and maintenance	• Heat recovery plant operation and maintenance • Contracting in relation to fuel supply • Management of large ambient thermal storage	2 3 0	• District heating transmission network operation and maintenance	1	• Operation and maintenance of building-level heat pumps • Operation of metering and billing systems	3 2
4. Investment and ownership	• 5G business model for heat production (Distributed Heat Pump investment, ownership and operation)	0	• 5G business model for transmission/ distribution pipe network ownership	1	• 5G business model for customer charges	2

Lacking Scottish capabilities/capacity — 0 — 1 — 2 — 3 — 4 — Strong Scottish capabilities/capacity

Source: Based on 14 Scotland/UK expert interviews and from Ramboll reports for Scottish Enterprise: “Scottish District Heating Analysis: Inward Investment and Trade Analysis" (2017) and "Heat Network and Heat Pump Manufacture Inward Investment Research” (2021)

THE MAIN CAPABILITIES AND GAPS IN SCOTLAND'S 5GDHC VALUE CHAIN

	Capability/Gap	Significance	Description
Main capabilities for implementing 5GDHC and retaining value in Scotland	• Building level thermal storage units	Some significance	• Sunamp, located in Scotland, is the only thermal storage manufacturer in the world to be awarded A Grade RAL Certification, the independent quality mark and the only global standard for Phase Change Material (PCM) and PCM products, confirming reliability and long life of Sunamp thermal batteries. These units allow the use of off peak electricity for **storage of heat at the end user's property** with 3x the density of a water tank. They also avoid the growth of legionella, as they do not physically store water.
	• Uninsulated pipework installers	High significance	• The pipework used in 5GDHC networks is the same as in gas and water mains, which **Scotland has many installers for**.
	• Trenching capabilities	Some significance	• Scotland has **trenching capabilities** as these are already required for many other utilities.
Main capability gaps for implementing 5GDHC and retaining value in Scotland	• Small heat pump manufacturer	Very high significance	• Scotland has two heat pump manufacturers. Mitsubishi Air Conditioning Europe Ltd, manufacturing air source heat pumps and exploring wider applications for heat pump technologies and STAR Renewables, which manufactures air source and water source heat pumps for medium to large applications, but not **the smaller heat pumps required for 5GDHC.**
	• Uninsulated pipework manufacturers	High significance	• Scotland does not have a company that manufacture the pipework required for 5GDHC networks.
	• GSHP/WSHP heat pump installers	High significance	• Scotland has a lack of heat pump installers, however, this can be solved by upskilling gas boiler installers with a short (<1 week) course. This is currently a priority of the Scottish Government, but it is **important installers also learn to install GSHPs and WSHPs** a well as ASHPs.
	• Management of large ambient thermal storage	High significance	• Scotland does not yet have any DH networks that utilise large ambient thermal storage. However, there are many large mines which could be used for long term storage in ambient networks, suggesting a key capability gap that might support the 5GDHC market.

Significance of capability/gap in Scotland's ability to implement 5GDHC and retain value: Some significance ◔ Medium significance ◑ High significance ◕ Very high significance ●

RAMBOLL

RAMBOLL

3. EUROPEAN 5GDHC MARKET AND CAPABILITY ASSESSMENT

Introduction to report section

Executive Summary & Introduction → Scottish market and capabilities → **European market and capabilities** → The opportunity for Scotland

The following section includes an analysis of the state of the market in the rest of UK and Europe. The analysis consists of two main deliverables:

1. An overview of the European 5GDHC market, including: the distribution of 5GDHC projects and competencies; an analysis of why one complex pilot project can indicate leadership more than many smaller pilot projects; and a summary of the current innovation gaps.
2. An assessment of the export market potential, including the main drivers and their relative significance.

Methodology applied in report section

The overview of the European 5GDHC market was conducted using the following method:

- Desktop research including the academic literature, previously conducted Scottish Enterprise consulting reports, and private sector literature.
- Ramboll expert interviews, and Scottish, UK, and European industry expert interviews.

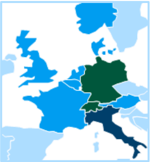
The breadth of the interview groups provides confidence in the findings from the interview and data collection process, and the semi-structured, open interview style allowed for further questioning and triangulation of previous findings.

Highlighted conclusions

Demand for low-carbon heat and cooling will grow, but the role of 5GDHC is unclear.

As the regulatory environment tightens for fossil fuels across Europe, the demand for low-carbon heating and cooling is set to grow. It is not yet clear though what role 5GDHC will play in this future due to the small number of existing projects and the relatively unproven business case.

A small number of countries are establishing themselves as market leaders with pilot projects.



Typical of emerging technologies, market leaders cannot be defined using traditional measures such as market share. Instead, perception of leadership in the interviews was influenced heavily by the complexity of pilot projects that exist. The Netherlands and Switzerland were two countries consistently described as current leaders.

It is too early to assess export potential but drivers for demand include local legislation and CAPEX.

The low levels of awareness and implementation across Europe combined with poorly developed understanding of business case means that export potential cannot yet be quantified. However, a number of key drivers for export potential are identified that will affect potential future demand. These include local policy and legislation as well as awareness of the technology and CAPEX – particularly cost of heat pumps.

RAMBOLL

OVERVIEW OF EUROPEAN 5GDHC MARKET

State of the market

No clear market leader (a)

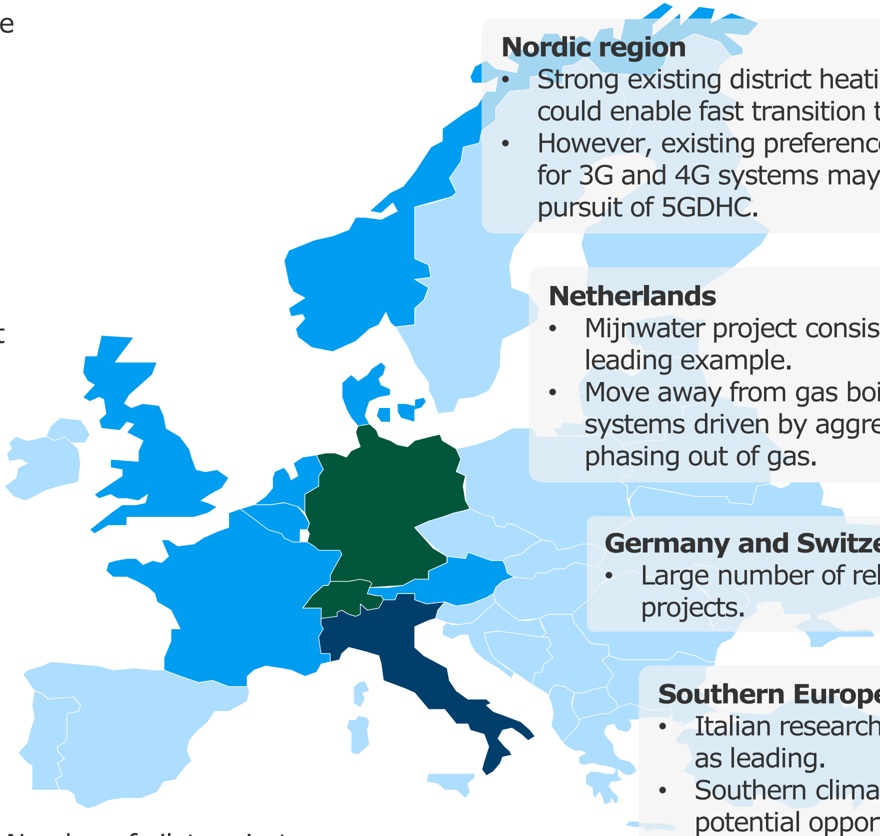
- There appears to be no consensus on which country is the market leader. One article[1] suggested Germany and Switzerland were leading the way, but interviewees did not corroborate this. The Netherlands, Switzerland and Italy were all suggested.
- Widely-recognised pilot projects and quality research outputs were highlighted as reasons for choosing countries as leaders. The Dutch Mijnwater project was consistently highlighted as the most developed example.

Pilots convey leadership (b)

- There was widespread consensus that the 5GDHC market could only currently be considered nascent. The majority of projects are pilots and supported by public funding.
- The district heating industry did not yet have a well established understanding and definition of what 5GDHC was, and pilots offer an opportunity to experiment and generate evidence to inform this.
- Interviewees considered project complexity, rather than quantity of pilots, as a sign of leadership.

Gaps include economics and control systems (c)

- A key reason highlighted for the lack of projects was the lack of skills and experience required for assessing the feasibility of 5GDHC compared with more traditional district heating systems.
- The flexibility of 5GDHC systems prevents general business case development. Each setting must be assessed with the unique characteristics.
- Control systems were also identified as a currently missing innovation requirement.



Nordic region

- Strong existing district heating capabilities, which could enable fast transition to 5GDHC leadership.
- However, existing preference and infrastructure for 3G and 4G systems may reduce likelihood for pursuit of 5GDHC.

Netherlands

- Mijnwater project consistently highlighted as leading example.
- Move away from gas boilers to district heating systems driven by aggressive policy for phasing out of gas.

Germany and Switzerland

- Large number of relatively simple 5GDHC projects.

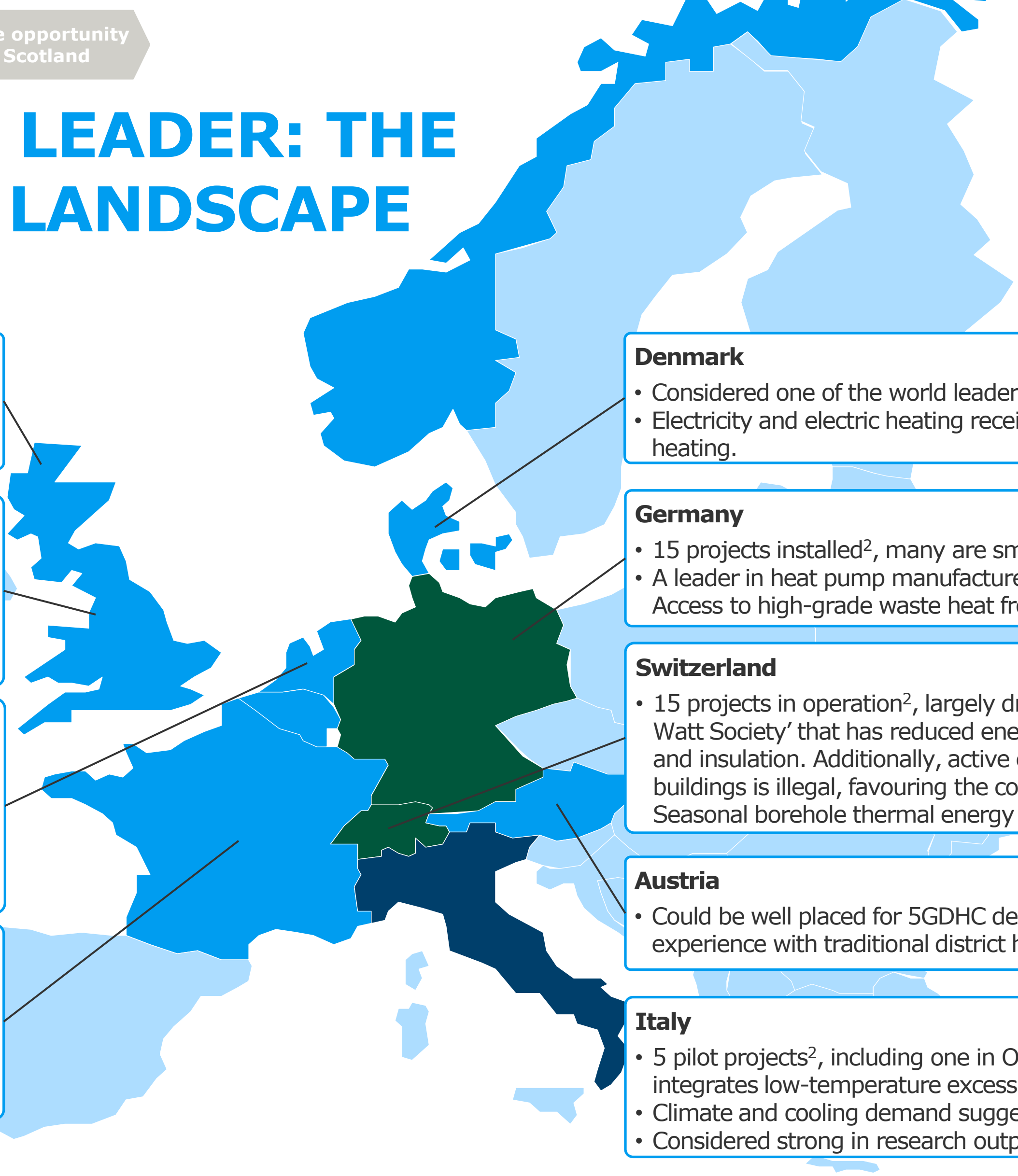
Southern Europe

- Italian research capacity highlighted as leading.
- Southern climate suggested as potential opportunity for 5GDHC due to (growing) cooling demand.

RAMBOLL

Sources: 1). Buffa et al. 2019. 5th generation district heating and cooling systems: A review of existing cases in Europe. 2). Interviews with Ramboll experts, and UK and European industry experts.

a NO CLEAR MARKET LEADER: THE EUROPEAN 5GDHC LANDSCAPE



Scotland

- Two projects in development: AMIDS & Clyde Gateway. See Chapter 2 for full overview of Scottish market and capability assessment.

Rest of UK

- Similar landscape to Scotland but more traditional district heating systems. 5GDHC projects under development or in operation: Plymouth, Nottingham (D2Grids), Bristol, and London. Less than 2% of heat currently met from heat networks.[1]

Netherlands

- Historical reliance on gas boilers, similarly to the UK, but they have started transitioning faster than the UK, with a ban on gas boilers in new builds in 2018, and a phasing out of boilers in existing stock. Mijnwater is the flagship 5GDHC project that was referenced by many interviewees.

France

- Paris-Saclay project (D2Grids) one of several pilot projects mentioned. E.ON also commercialising a 5GDHC offering called 'ectogrid'. Target in law for 38% of heating to come from renewable energy sources by 2030 driving investment in low-carbon heating technologies.

Denmark

- Considered one of the world leaders in traditional 3G district heating systems.
- Electricity and electric heating receive lower taxes to encourage electrification of heating.

Germany

- 15 projects installed[2], many are small scale and considered relatively simple.
- A leader in heat pump manufacture (e.g. GEA, Stiebel Eltron and Viessmann). Access to high-grade waste heat from industry, particularly in the west.

Switzerland

- 15 projects in operation[2], largely driven by policy factors including the '2000 Watt Society' that has reduced energy consumption through greater efficiencies and insulation. Additionally, active cooling exploiting chillers in residential buildings is illegal, favouring the cooling that can be supplied by 5GDHC. Seasonal borehole thermal energy storage a common feature in Swiss systems.

Austria

- Could be well placed for 5GDHC demand, with heating and cooling demand, and experience with traditional district heating systems.

Italy

- 5 pilot projects[2], including one in Ospitaletto (LIFE4HeatRecovery) that integrates low-temperature excess heat.
- Climate and cooling demand suggested as a positive driver for uptake in Italy.
- Considered strong in research output of 5GDHC networks, e.g. EURAC facilities.

Number of pilot projects:

0 | 1 – 5 | 5 – 10 | >10

RAMBOLL

1). BEIS 2018. Clean Growth – Transforming Heating. Overview of Current Evidence.
2). Buffa et al. 2019. 5th generation district heating and cooling systems: A review of existing cases in Europe.

b WHY COMPLEX PILOT PROJECTS DEMONSTRATE LEADERSHIP MORE THAN QUANTITY OF PROJECTS

Summary

Mijnwater is considered the **leading European 5GDHC network**, affording the **Netherlands leadership status** amongst the majority of interviewees of this study. The two primary **leadership factors** that explain this are the **complexity** and **communication** of the project.

Leadership factors

1. **Complexity:** The Mijnwater project is complex due to a number of factors, creating a recognition of the Netherlands' ability to implement a complex, multi-stakeholder project.
   - **Size and the expansion** of the system: In 2020, the system supplied heat and cooling to over 400 dwellings and 250,000m^2 of commercial buildings. The goal is to connect 30,000 homes and offices in the region by 2030[1].
   - **Diversity of customers**: The network has developed clusters of dwellings, supported by a mix of local sustainable resources, and by the mine water grid and mine water reserve (*Figure 1*). Energy exchange is realised between buildings through local cluster grids and between clusters by the existing mine water grid. The system can expand by adding in new clusters of buildings to the system.
   - **Large seasonal storage**: the abandoned coal mine tunnels under Heerlen were originally estimated to be able to provide 7,026 TJ per year[2] for heating, however the mine water is now being utilised for thermal storage rather a direct heat source.

2. **Communication**

The Mijnwater project has been running since 2008 and has a strong focus on communication of developments, resulting in a wide awareness of the project's set up and results to date. Channels include:

- **Academic papers** (e.g. sources 1-4)
- **Contribution to scaling other projects**: Mijnwater BV (social enterprise) is a lead partner organisation for the D2Grids project, an EU-funded initiative accelerating the rollout of 5GDHC, with 5 pilot sites in FR, UK, NL, and DE.

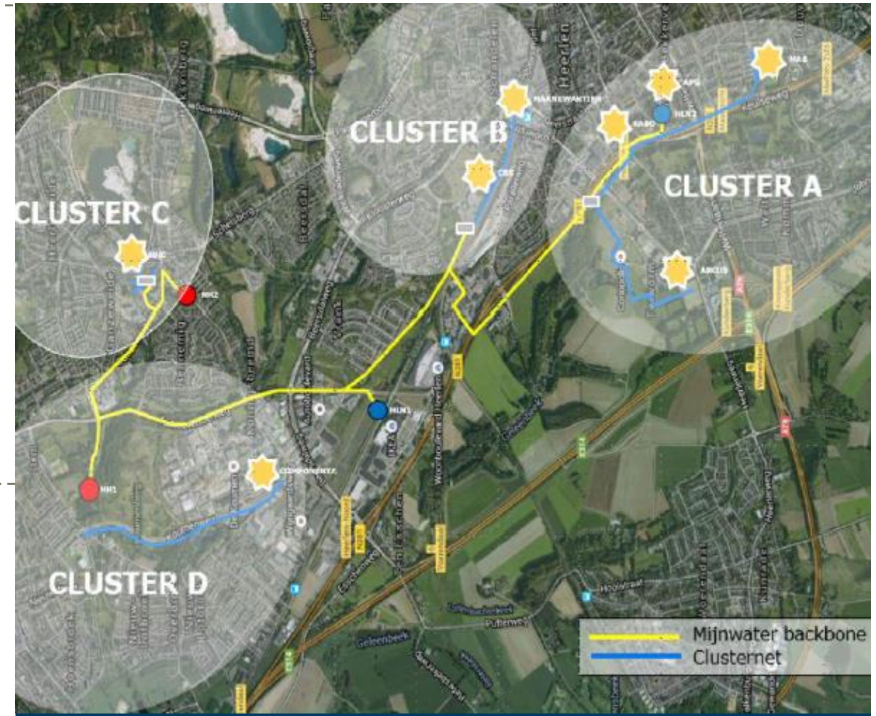


Figure 1). The clusters of Mijnwater 5DHC network in Heerlen. Each cluster has their own sources of waste heat. The backbone balances heat and cooling between clusters and connects to the mines as a seasonal thermal storage.

Sources: 1). IEA 2021. Low-temperature district heating implementation guidebook, Annex TS2.
2). Helga et al., 2011. Transforming flooded coal mines to large-scale geothermal and heat storage reservoirs: what can we expect?
3). Buffa et al. 2019. 5th generation district heating and cooling systems: A review of existing cases in Europe.
4). Boesten et al., 2019. 5th generation district heating and cooling systems as a solution for renewable urban thermal energy supply

C

GAPS INCLUDE ECONOMICS AND CONTROL SYSTEMS

Summary

Amongst the **innovations** that are **required** for **5GDHC** networks to realise their **full potential**, the **business case** and the **control systems** were the two most frequently highlighted by interviewees and within the literature.

Innovation gaps

1. **Business case:** Three factors suggest that the business case for 5GDHC is still undeveloped and incomparable to e.g. 3/4G, which could be considered a gap for further development of 5GDHC:
   - **No 'one size fits all':** Each 5GDHC system has unique characteristics of heat and cooling demand, sources, and storage. Compared with more traditional 3GDH networks with a central and predictable energy source, this makes it challenging to compare the economics for 5GDHC and previous generations.
   - **CAPEX of heat pumps still burdensome:** The price of individual heat pumps in every 5GDHC dwelling is an expenditure source that currently weighs heavily on the cost of 5GDHC systems.[1] One interviewee estimated that costs of heat pumps would have to come down by around 70% before they could be cost competitive with 4GDH networks.
   - **Cooling and storage:** Studies and interviews indicate that 5GDHC systems benefit in their business case compared when there is cooling demand and thermal storage is utilised[2]. One case study that compared a 4GDH system with a 5GDHC system without cooling found the 4GDH system to be significantly cheaper[1]. More studies are needed to conclude the effect of cooling on

2. **Control systems:** No control approach for optimizing the 5GDHC system operation and network temperatures has yet been presented, creating high development and operating costs.
   - **Bidirectionality a challenge:** Due to the large number of opposing effects in a bi-directional system performing heating and cooling, the optimal control of network temperatures is a challenging task, meaning higher operating costs for both users and network operators.
   - **No technical standards or guidelines** have been developed for designers, making it a challenge to both assess and design new 5GDHC networks, and therefore creating high development costs.

District heating pipes in Ås Norway. *Image: Statkraft*

RAMBOLL

Sources: 1). Gudmundsson et al., 2022. Economic comparison of 4GDH and 5GDH systems – using a case study.
2). Millar et al., 2021. Identification of key performance indicators and complimentary load profiles for 5th generation district energy networks.

RAMBOLL

TOO EARLY TO ASSESS EXPORT POTENTIAL BUT MARKET DRIVERS CAN BE IDENTIFIED (1/2)

Summary

Demand for **low-carbon heating and cooling is forecast to increase towards 2050**, but it is **too early to be able to assess export market potential of 5GDHC**. There was a wide range of opinions about the future applications and demand for 5GDHC. This **speculation is due to a lack of projects and research** in order to base conclusions. There are a handful of pilot projects that exist, but they **do not offer sufficient basis for economic comparison with other low carbon counterfactuals** and it is unclear if or where 5GDHC could be an economically preferable solution. However, a number of drivers with potentially significant impact on the future demand for 5GDHC capabilities can be identified and assessed in order to better understand the export potential as the market develops.

Key drivers for export potential	Potential impact
Policy and legislation (national and EU) can have a significant effect on demand for 5GDHC, both positively and negatively. For example, the planned phasing out of gas in the Netherlands has created a clear incentive for local planners to investigate low-carbon heating, such as 5GDHC. Policy can also block 5GDHC if other technologies are prioritised (e.g. hydrogen). Local legislation and the ability of cities to invest will also have a large impact at the local level.	Very High Impact
Awareness of technology: 5GDHC is still a nascent technology, with low awareness throughout the value chain. Investors, housing developers, design engineers, and policy makers all need improved awareness of 5GDHC in order for export demand to grow in the European market.	Very High Impact
High CAPEX for 5GDHC networks: largely due to individual heat pump costs for every network user, which tend to outweigh savings from cheaper pipe systems. However, at current sales levels the European heat pump market will double every 10 years which should result in a cost reduction of approx. 20% by 2024[1]. This could make 5GDHC more attractive in the future.	Very High Impact


Installation of 5GDHC pipes in the Mijnwater project, Netherlands. *Image: Mijnwatercentrumleiding*

Continues on the next slide...

RAMBOLL

Significance of key drivers for export potential: Some impact | Average Impact | High Impact | Very High Impact

Sources: 1). EHPA 2015. European Heat Pump Market and Statistics Report.

TOO EARLY TO ASSESS EXPORT POTENTIAL BUT MARKET DRIVERS CAN BE IDENTIFIED (2/2)

Key drivers for export potential, continued — **Potential impact**

Existing skills and capabilities in other countries are likely to influence their demand for 5GDHC skills and services. The higher the existing skills and capabilities, the lower the likelihood of demand for importing those skills from elsewhere. The Nordic region, for example, already has skills and capabilities required for much of 5GDHC networks, and therefore less likely to have demand for importing skills from elsewhere.

Climatic factors: 5GDHC is most optimal when heating and cooling demand are balanced more evenly. Therefore, countries with more of a mixed demand for heating and cooling could be more preferable for 5GDHC. As Europe experiences greater heating under climate change, there is likely to be greater cooling demand – especially in central and southern European countries, leading to greater 5GDHC demand.

Incumbent DH technology can affect the demand for 5GDHC because countries with existing 3G or 4G industry and infrastructure are less likely to pursue new and different technology. In the Nordic countries for example, who are more experienced with 3G and 4G DH systems and already have significant existing heat network infrastructure, there is likely to be less appetite for 5GDHC, at least until the technology is more mature and proven.

Availability of high-grade waste heat can favour more traditional 3G district heating systems. In western Germany, for example, heavy industry provides a strong supply of waste heat that can be utilised in higher-temperature district heating. This heat would need to be down-graded in order to be used for an ambient temperature system.

Denmark, with a long history of traditional district heating, may be less likely to explore different types of district heating such as 5GDHC.

Significance of key drivers for export potential: Some impact, Average Impact, High Impact, Very High Impact

RAMBOLL

4. THE OPPORTUNITY FOR SCOTLAND

Introduction to report section

Executive Summary & Introduction → Scottish market and capabilities → European market and capabilities → **The opportunity for Scotland**

The concluding section summarises the opportunity of 5GDHC for Scotland with the following assessments:

1. Challenges and opportunities for 5GDHC leadership
2. Scotland's opportunity to become a leader
3. Placing Scotland's leadership potential in context of a fledgling market
4. Recommendations for achieving Scotland's domestic and export potential

Methodology applied in report section

The identification of opportunities and challenges for 5GDHC utilised the following method:

- Desktop research including the academic literature, previously conducted Scottish Enterprise consulting reports, and private sector literature.
- Ramboll expert interviews, and Scottish, UK, and European industry expert interviews.

The analysis of the opportunities and challenges was completed using a qualitative ranking against two scales: size of opportunity/ challenge; and ability of Scotland to influence. This was validated through a workshop with Scottish Enterprise.

The assessment of Scotland's opportunity to become a leader was based on data collected from interviews. Five indicators were used to assess Scotland's performance against these two leading countries. The results were then placed in a context of an emerging market.

Highlighted conclusions

Opportunities include developing advanced pilots and challenges include the business case.

Six opportunities and five challenges were identified as possible for Scotland to either exploit or address to grow leadership in 5GDHC. The most strategic opportunities to pursue included developing advanced pilot projects, ensuring 5GDHC is incorporated into LHEES, and considering connection incentives and requirements for 5GDHC networks. The business case remains a challenge.

Scotland is not currently a market leader but this can change quickly in such an emerging market

The Netherlands is considered the European market leader in 5GDHC, despite not having as many pilot projects as Switzerland, Germany, or Italy. The Mijnwater pilot project was cited by many as a primary indicator of leadership. The Netherlands also performed well for other indicators of leadership including policy environment and R&D.

Scotland should develop advanced pilot projects, continue to prioritise R&D, and influence policy

In order to demonstrate greater leadership in 5GDHC, Scotland should focus on raising awareness and research outputs, especially around the business model and mapping appropriate networks for 5GDHC, and should develop advanced pilot projects to position Scotland as a leader in the European market.

METHODOLOGY FOR IDENTIFYING AND PRIORITISING OPPORTUNITIES AND CHALLENGES FOR LEADERSHIP

Importance of opportunity/ challenge

This metric indicates the main opportunities and challenges for Scottish leadership in 5GDHC networks. Opportunities and challenges were gathered during the data collection process.

Opportunities for leadership include social, economic, political, and cultural opportunities for leadership.

Challenges are actual or potential factors that may prevent or limit Scotland from demonstrating leadership in 5GDHC. For example, policies that may bias investment towards other technologies.

Size of opportunity/ challenge was estimated based on interview data, as well through a qualitative assessment of how the opportunity or risk could impact Scotland's ability to become a leader in 5GDHC (through improved skills and capabilities, policy environment, innovation, research, etc.) This was further validated in a workshop with Scottish Enterprise and reasoning for placement is presented on the slide following the attractiveness matrix.

Scotland's ability to influence the opportunity/challenge for leadership

This metric indicates whether Scotland could influence the opportunity or the challenge for leadership.

Some **opportunities** are easier to influence than others. For example, the fact that Scots have a familiarity with boilers may be an opportunity, but it is not one than could be easily increased or extended for Scotland to be a leader.

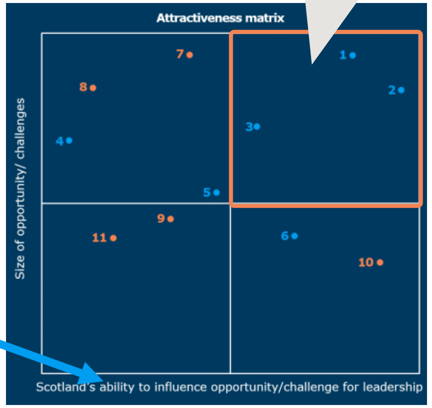
Challenges can be reduced and/or overcome in order to increase Scotland's 5GDHC leadership potential.

Scotland's ability to influence was estimated based on internal knowledge and awareness of the capabilities within Scotland's socioeconomic institutions, as well as the nature of the challenge or opportunity. This was further validated in a workshop with Scottish Enterprise and reasoning for placement is presented on the slide following the attractiveness matrix.

Attractiveness matrix

The assessment can help to prioritise the most strategically relevant opportunities and challenges for Scottish Enterprise to focus effort on. The exercise is designed to be illustrative rather than exact, to help show the relative positions of the opportunities and challenges.

Most strategically relevant quadrant



IDENTIFYING AND PRIORITISING CHALLENGES AND OPPORTUNITIES FOR 5GDHC LEADERSHIP

Reasoning for placement of opportunities and challenges on next slide

Opportunities

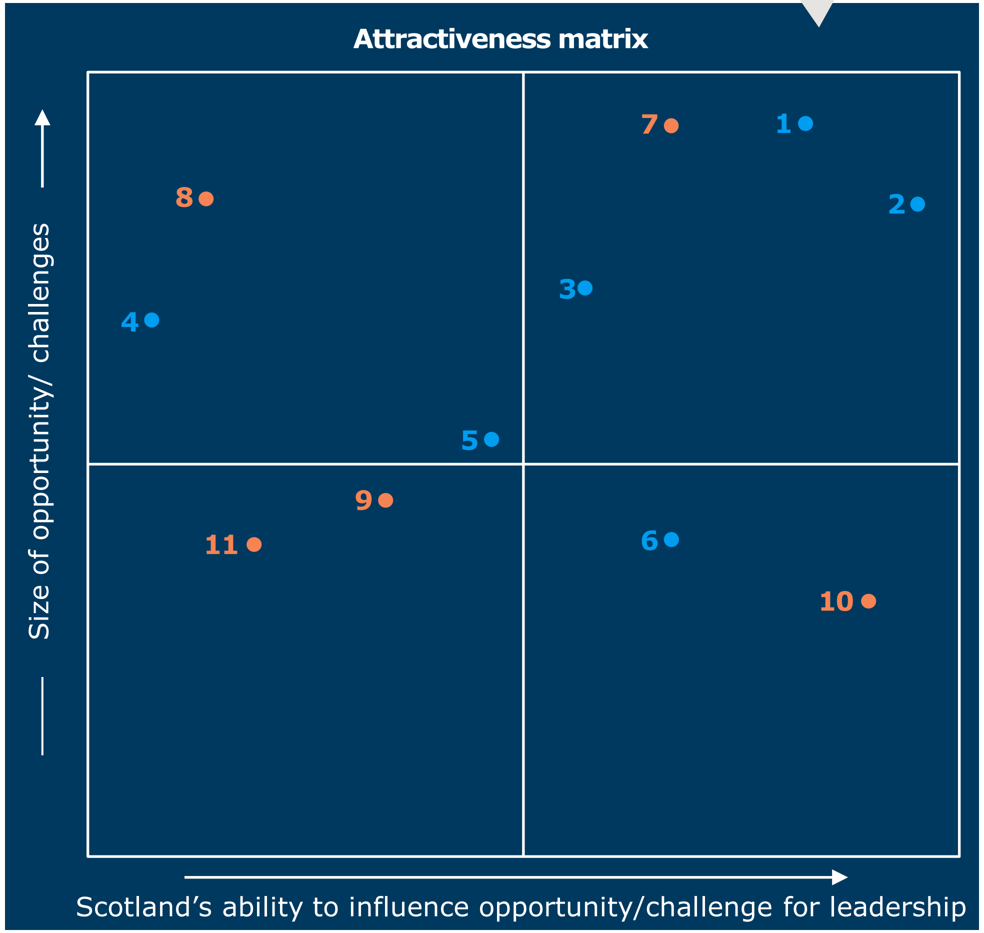
Size of opportunity

1	**Develop advanced pilots**	If Scotland can establish complex demonstration projects, this would be a great opportunity for leadership demonstration.
2	**LHEES**	the LHEES heat zoning methodology should be reviewed by Scottish Government as the understanding of 5GDHC applications develops to ensure that 5GDHC opportunities are considered by local authorities.
3	**Connection incentives & requirements**	Incentives and requirements for connections in new builds or existing public buildings are opportunities for Scottish 5GDHC development. E.g. zero emissions heating building regulations for new builds from 2024.
4	**Relatively little incumbent DH industry**	Compared with the Nordic region, in Scotland there is relatively little vested interest in traditional 3G or 4G DH systems.
5	**Existing research strengths**	Strength in research capabilities in the field (e.g. University of Strathclyde, University of Glasgow) is an opportunity to demonstrate leadership in the emerging field.
6	**Boiler familiarity**	Scottish boiler familiarity may be a positive for 5GDHC compared with 4GDH, which could increase likelihood of acceptance and uptake.

Challenges

Size of challenge

7	**Business case**	The business case for 5GDHC systems is still largely unproven, and in some cases has been shown as unfavourable. The risk profile is also uncertain for investors. If Scotland can demonstrate a favourable business case, this would demonstrate leadership.
8	**Cooling demand**	Overall, Scotland has a low cooling demand. This has been suggested as a challenge to creating optimal and cost efficient 5GDHC systems.
9	**Policy picking winners**	There is a risk that UK or Scottish government may develop policies favouring other low-carbon technologies as part of decarbonisation efforts, before 5GDHC is market ready.
10	**Lack of awareness**	Lack of awareness throughout the supply chain is making it difficult for 5GDHC systems to be considered, especially by contractors and developers.
11	**Complexity**	5GDHC is inherently more complex than any of the previous generations due to bidirectionality and flexibility of heat sources and stores. This creates challenges for feasibility assessments at scale.



RAMBOLL

ARGUMENTATION FOR OPPORTUNITY AND CHALLENGE ASSESSMENT

Summary

The points listed in the tables below summarise why they have been placed as they have in the Attractiveness matrix.

	Opportunities	Size of opportunity	Scotland's ability to influence
1	**Develop advanced pilots**	• Large/complex pilots are considered as clear indicators for market leadership.	• Scotland has the ability to either expand existing projects or create new pilots in 5GDHC.
2	**LHEES**	• LHEES will be a key policy driver for introducing heat networks in Scotland, including 5GDHC networks.	• Scotland can ensure that the key stakeholders for LHEES (i.e. local authorities) have awareness of 5GDHC.
3	**Connection incentives & requirements**	• Improving the incentives and requirements for connecting to 5GDHC networks could help to accelerate and scale the technology.	• Scotland has the ability to influence the Scottish policy and legislative environment but will also rely on changes in UK-wide policy.
4	**Relatively little incumbent DH industry**	• The lack of traditional district heating industry to influence new network development is an opportunity for 5GDHC to be considered evenly.	• There is relatively little capacity for Scotland to influence this opportunity as this is the current state of the market, resulting from historical reliance on gas boilers.
5	**Existing research strengths**	• Scotland's universities can continue to produce leading research on 5GDHC to gain European recognition.	• Scotland can have some influence on the research topics of the universities and promote 5GDHC research topics.
6	**Boiler familiarity**	• Cultural familiarity with domestic boilers may present an opportunity with 5GDHC rather than more unfamiliar 4GDH systems.	• Research to understand consumer perceptions of 5GDHC.

	Challenges	Size of challenge	Scotland's ability to influence
7	**Business case**	• The business case of 5GDHC is still largely unproven, with some studies indicating a preference for 4G heating and cooling networks when directly compared.	• Scotland has some ability to influence through research focused on the investment and business case. • However, the price of heat pumps is a significant factor that is difficult for Scotland to influence.
8	**Cooling demand**	• Balancing heating and cooling demand in 5GDHC networks is key to success of economically attractive 5GDHC networks. There is limited cooling demand in Scotland.	• Cooling demand is primarily driven by climatic factors.
9	**Policy picking winners**	• There is a chance that policy and legislation may support a different technology before 5GDHC reaches a point of maturity where it is market ready.	• Scotland can influence Scottish policy but influencing UK policy is more difficult.
10	**Lack of awareness**	• 5GDHC is still a largely unknown technology, even for people with knowledge of district heating industry. • This challenge affects all parts of the value chain.	• Scotland can influence awareness through educational and awareness raising with targeted communication campaigns.
11	**Complexity**	• 5GDHC is an inherently more complex network than more traditional forms of district heating, making it difficult for people to design and implement.	• Whilst Scotland cannot influence the actual complexity of the technology, it is possible to improve the understanding and awareness throughout the value chain.

ASSESSING SCOTLAND'S OPPORTUNITY TO BECOME A LEADER: METHODOLOGY

Leadership criteria

In order to assess Scotland's opportunity to become a leader, it is first important to assess the levels of maturity and leadership in the market as of now. As the market is not mature enough to use traditional indicators such as market share, five indicators have been chosen by Ramboll experts based on experiences in these markets, to assess the market leadership:

Market experience indicates both the number of 5GDHC projects that have been developed, as well as the complexity of these projects.

Policy environment indicates the level of policies that could act as drivers for 5GDHC networks. For example, policies that disincentivise fossil-fuel heating technologies or incentivise low-carbon heating solutions.

Existing skills and capabilities indicates the skills and capabilities required to design, develop, construct, and operate 5GDHC networks. A full description of the skills and capabilities required can be seen on page 33.

Innovation score indicates ranking according to the Global Innovation Index 2021, the 14th edition, created by the World Intellectual Property Organization. It presents the worldwide innovation landscape and annual performance rankings of 132 economies, 39 of which are classified as in Europe.

Research output reflects the number of academic papers that have been published per country according to a literature search using Google Scholar with the search terms of "Fifth generation district heating" and "5th generation district heating" included in the title. A total of 20 results were returned, with authors from institutes in 9 European countries.

Selecting contenders

As previously identified, there is no clear market leader in the traditional sense of market share. Instead, leadership is currently defined through visibility, i.e. prominent projects or research.

Buffa et al.[1] indicated that Switzerland and Germany were the pioneers of 5GDHC networks but during interviews, Germany in particular was not seen as a market leader due to the primitivity of the networks.

Switzerland was highlighted several times, often due to research strength or some pilot projects which demonstrated innovative features.

The Netherlands was a clearly perceived leader in the interviews due to the Mijnwater pilot project (see page 40).

The Netherlands and Switzerland have therefore been selected as benchmarks to compare Scotland against.

Overall market leadership

Having ranked the five leadership criteria across the three countries, the overall rank is indicated. This is a qualitative and relative ranking that helps to indicate where Scotland is in relation to the Netherlands and Switzerland, based on the data collected.

1). Buffa et al. 2019. 5th generation district heating and cooling systems: A review of existing cases in Europe.

SCOTLAND CURRENTLY LAGS BEHIND THE NETHERLANDS AND SWITZERLAND AS PERCEIVED MARKET LEADERS

	Scotland	Netherlands	Switzerland
Market experience	• 2 small projects either in design or construction.	• A large pilot project – Mijnwater - was cited by many as industry leading and innovative.	• Many small and relatively simple projects have given Switzerland market experience.
Policy environment	• LHEES and other heat-network focused policies could enable growth, but no specific 5G-focused policies.	• Gas boilers banned in new builds in 2018 and to be phased out in all buildings.	• 2000 Watt society increased insulation efforts, making 5GDHC more suitable.
Existing skills and capabilities	• Lack of prior district heating experience means Scotland is relatively low on existing skills and capabilities.	• Previous experience with traditional district heating systems and some new 5GDHC experience.	• Previous experience with traditional district heating systems and some new 5GDHC experience.
Innovation score	• UK ranked 4th on the Global Innovation Index 2021.	• Ranked 6th on the Global Innovation Index 2021.	• Ranked 1st on the Global Innovation Index 2021.
Research output	• Joint 5th ranked in number of papers from Scottish institutes in a sample literature search.	• Joint 5th ranked in number of papers from Dutch institutes in a sample literature search.	• Joint 5th ranked in number of papers from Swiss institutes in a sample literature search.
Overall	• Scotland ranks averagely in a European context, with some pilots and experience.	• A strong policy environment and a leading EU pilot project indicate Netherlands as a potential market leader.	• Many pilot projects and strong research and innovation indicate Switzerland is close behind NTL.

Key: Low performance/ progress; Average performance/ progress; High performance/ progress; Very high performance/ progress

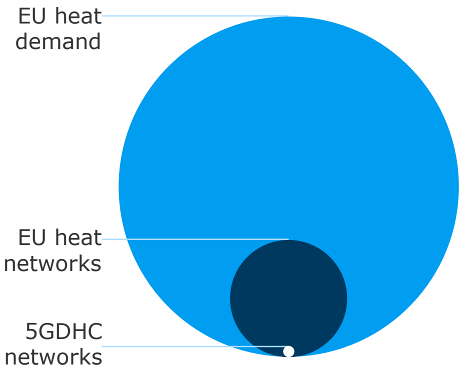
PLACING SCOTLAND'S LEADERSHIP POTENTIAL IN CONTEXT OF A NASCENT MARKET

1. Scotland is not currently considered a market leader…

- Scotland is perceived as less experienced in 5GDHC and with lower existing skills and capabilities than other European countries such as Switzerland and Netherlands.
- However, with two 5GDHC pilot projects, Scotland is also not the least experienced.

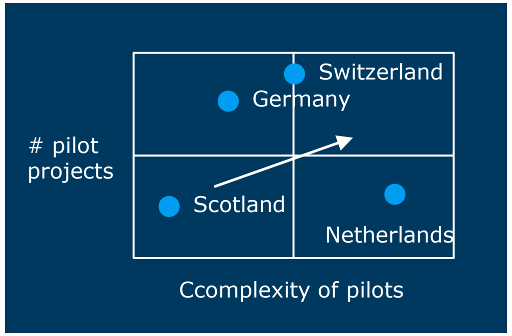
2. …but the market is still nascent, with growth potential.

- The 5GDHC market makes up around 1% of the European heat networks (number of networks), which in turn are only responsible for supplying around 11-12% of total EU heat demand.[1]
- However, there is forecast growth in the EU low-carbon heating and cooling market. The UK has a goal of meeting 43% of heating demand with energy networks by 2050[2].



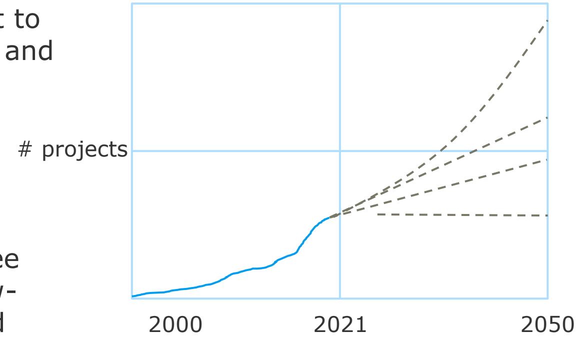
3. Scotland could therefore become a leader…

- Small markets allow for dynamic repositioning of leaders, because market share can change quickly and innovations can create competitive advantage.
- If Scotland were to be the first to demonstrate feasibility of a large scale pilot project, then it could quickly be seen as a leading nation in 5GDHC.



4. …but value associated with leadership is not yet clear

- A strong business case has still yet to be seen for 5GDHC, so the growth and value of future market is still uncertain.
- The value of leadership is still therefore uncertain.
- However, heat recovery, a core component of 5GDHC, will likely see growth in the future with other low-carbon heat technologies. Scotland could seek synergies here.



Historical growth rates illustrative only

1). Euroheat & Power, 2017. Country by Country Survey.
2). ADE 2018. Market Report: Heat Networks in the UK.

RECOMMENDATIONS 1 AND 2 FOCUS ON PILOT PROJECTS AND 5GDHC AWARENESS RAISING (1/2)

	Description	Opportunities and challenges addressed	Comment on next steps
1. Demonstrate advanced pilot projects	• While the market is still emerging, pilot projects are key signals of leadership. Currently Mijnwater in the Netherlands is cited as the European leader in 5GDHC. • Scotland can either further develop existing projects or create new ones, demonstrating application to varied end user temperatures, heating and cooling demand, and use of thermal storage. • This will help Scotland to gain a reputation as a 5GDHC leader within Europe. • Pilots can also create valuable insight into the economic case for 5GDHC. Pilots could explicitly compare the costs of the project to an alternative scenario (3G or 4GDH).	1 Develop advanced pilots 6 Boiler familiarity 7 Business case 10 Lack of awareness	• Scotland's existing pilot projects do not yet demonstrate the scale or complexity to attract international leadership recognition. • Scotland can further develop the collaboration work with D2Grids to either expand the scale of the Clyde Gateway or AMIDS projects, or use the knowledge and lessons learned to promote new 5GDHC pilots. • Recommendation 3 is to map and match sources and demand for heating, cooling, and storage. This will help to identify areas for potential new pilot schemes. • Developing new or expanding current pilot projects can also contribute to increasing awareness of 5GDHC (recommendation 2) and developing the business model (recommendation 4).
2. Increase awareness throughout value chain	• In order to develop skills and capabilities, and increase the likelihood of 5GDHC projects being developed, there needs to be a greater awareness of the technology across all of the value chain. • Local authorities and policy makers in particular need to have an understanding of 5GDHC to allow uptake. • This will help to improve the chances of 5GDHC uptake in Scotland.	2 LHEES 10 Lack of awareness	• Create a strategy for raising awareness in all parts of the value chain of the potential applications and benefits of 5GDHC. • For policy makers in the long-term, it may be appropriate to include 5GDHC as one of the considered technologies for LHEES heat network zoning. This may require that local councils have access to the right technical and impartial advice. • The Clyde Gateway and AMIDS projects can be highlighted as useful case studies for awareness raising efforts.

RECOMMENDATIONS 3 AND 4 FOCUS ON MAPPING SCOTTISH POTENTIAL AND DEVELOPING THE BUSINESS MODEL (2/2)

	Description	Opportunities and challenges addressed	Comment on next steps

3. Map and match sources and demand 	• To have a stronger understanding of where 5GDHC is suitable and applicable in Scotland, it will be beneficial to conduct a detailed spatial analysis of the potential sources, sinks, and stores in Scotland.
	• This analysis will allow a more targeted project development approach.
		2 LHEES
		5 Existing research strengths
		9 Cooling demand
		11 Complexity
			• Commission a study on sources, demand, and storage opportunities in Scotland, in order to analyse where 5GDHC could be the most beneficial choice.
			  • The first part of this study could explicitly map Scotland's low-grade heat sources and storage opportunities, including Scotland's mine water as thermal storage (building on the Green Heat in Greenspaces study* and the BEIS National Comprehensive Assessment**).
			  • Such a study could contribute to an indicative energy masterplan for DHC in Scotland, highlighting where 5GDHC might offer benefits over 4GDH, and vice versa.

4. Develop the business model 	• The business case for 5GDHC is still largely undefined. If Scotland can improve the research around the investment case, lifetime costs and fee structure of 5GDHC, it is likely to increase the appetite for the technology. • An output from this analysis could also be to identify areas where cost savings are required to make 5GDHC more competitive.	5 LHEES 7 Business case 9 Cooling demand 11 Complexity	• It would be beneficial to commission targeted research on business models for 5GDHC, informed by pilot projects where possible. • Aspects of the business model that would benefit from particular focus include approaches to customer billing and cash flows, ownership and governance, and the investment risk profile. • Business models may also focus on where alternative sources are costly.

* Greenspace Scotland (2021) Green Heat in Greenspaces National Results Report
** BEIS (2021) Opportunity areas for district heating networks in the UK: second National Comprehensive Assessment

Authors:

Arran Kirkbright, Engineer, District Energy UK

Jack Robinson, Senior Consultant, Management Consulting

Dr Ruth Bush, Principal Consultant, Energy Strategy and Planning