Urban District Heating Network Delivery: A Socio-technical Analysis of Large-scale District Heating Network Implementation in Urban Environments

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LIST OF ACRONYMS

ACT	Advanced Conversion Technology
ADE	Association of Decentralised Energy
ANT	Actor Network Theory
BEIS	Department of Business Energy and Industrial Strategy
BHIVE	BEIS Heat Investment Vehicle
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture And Storage
CDDP	City Deep Decarbonisation Projects
CHP	Combined Heat and Power
CIBSE	Chartered Institution of Building Services Engineers
CMA	Competition and Markets Authority
CO_2	Carbon Dioxide
DBOM	Design Build Operate and Maintain
DECC	Department for Energy and Climate Change
DEEP	Decentralised Energy Enabling Project
DERA	Danish Energy Regulatory Authority
DH	District heating
EED	Energy Efficiency Directive
EfW	Energy from Waste
EPA	Environmental Protection Agency
ERDF	European Regional Development Fund
ESCO	Energy Service Company Energy Transition Region
ETR	Energy Transition Region
EU	European Union
FCCA	Finnish Competition and Consumer Authority
GHG	Greenhouse Gas
GLA	Greater London Authority

GMCA	Greater Manchester Combined Authority
GM	Greater Manchester
GHNF	Green Heat Network Fund
HeatNIC	Heat Network Industry Council
HELGA	Heat Network and Electricity Generation Assets
HN	Heat Network
HNDU	Heat Network Delivery Unit
HNES	Heat Network Efficiency Scheme
HNIP	Heat Network Investment Project
HNOO	Heat Network Optimisation Opportunities
HNTP	Heat Network Transformation Programme
IEA	International Energy Agency
IETF	Industrial Energy Transformation Fund
IHRS	Industrial Heat Recovery Support Programme
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rates of Return (IRR)
LA	Local Authority
LEA	Local Energy Accelerator
LEP	Local Enterprise Partnership
LNG	Liquefied Natural Gas
MLP	Multi-level Perspective
MSW	Municipal Solid Waste
$MtCO_2e$	Mega Tonnes Of CO_2 Equivalent
NA	National Authority
OJEU	Official Journal of the European Union
OPEC	Organisation of Petroleum Exporting Countries
OPSS	Office for Product Safety and Standards
PSDS	Public Sector Decarbonisation Scheme
PWLB	Public Works Loan Board
RA	Regional authority
RHI	Renewable Heat Incentive

ROC	Renewables Obligation Certificates
SCOT	Social Construction Of Technology
SEMI	Swedish Energy Markets Inspectorate
SNA	Social Network Analysis
SNM	Strategic Niche Management
SPV	Special Purpose Vehicle
UK	United Kingdom
UKDEA	United Kingdom District Energy Association
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHNCA	Waste Heat and National Comprehensive Assessment
WtE	Waste to Energy
WSSEP	Whole System Smart Energy Plan Yorkshire Purchasing Organisation
YPO	Yorkshire Purchasing Organisation

ABSTRACT

The aim of this study is to explore the implementation of large-scale city-based district heating (DH) networks from a socio-technical perspective with a view to identifying key success factors and effective governing measures that can overcome the main barriers limiting the uptake and delivery of district heating at scale. DH is an area that has been regarded as underexplored yet with a potential play a key role in providing greater opportunities for decarbonisation, increased energy efficiency and cost-effectiveness in the heat sector. The study addresses this knowledge gap by assessing the factors that promote the take up and delivery of DH at scale by examining the perspectives and experiences of social actors, as well as the framings and factors that influence the distinct interrelationships between socio-technical systems, context, and settings in the DH implementation process.

Through the application of the multilevel perspective on socio-technical transitions to analyse the case study cities, this research examined the salience and influence of five sociotechnical elements: (1) the implementation strategy; (2) technical solutions and heat sources; (3) policy instruments and regulatory framework; (4) pricing and consumer protection (5) financial instruments and incentives. Investigating these five factors provides insights into the key success factors that aid the implementation of large-scale city based DH networks as well as the barriers to DH implementation.

The study employs a multi-case study analysis, drawing on qualitative methods to explore the DH network implementation strategies in secondary and primary case studies cities, which represent two contexts with differences in political, technical, financial, social, business models, governance processes and policy approaches to DH development. The secondary data analysis of DH implementation in Copenhagen, Stockholm and Helsinki provided an in-depth understanding of how DH has been successfully implemented in these regions to derive meaning and analytical understanding of the phenomena being studied. The data from semi-structured interviews with twenty key stakeholders was examined, reviewed, and interpreted using a combination of document and thematic analysis to explore their perspectives and to capture the early stages of the DH development and implementation process in Greater Manchester.

The findings in this research revealed key barriers limiting the uptake of DH as well as key success factors essential for the implementation of large-scale city-based DH network, which include various organisational, technical and policy design considerations. The study contributes to a growing body of research that emphasizes the importance of spatial perspectives and the crucial role of city regions in transition processes and the perceived need to adopt governance mechanisms to support DH implementation on the urban scale.

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1. CHAPTER ONE: INTRODUCTION

1.1. Introducing the Research

A growing number of stakeholders and policymakers are becoming aware of the potential of district heating and the opportunities it provides in terms of energy efficiency and climate mitigation objectives (BEIS, 2018e; Vadén *et al.*, 2019; Acheilas, Hooimeijer and Ersoy, 2020). Failures of DH implementation identified in several locations in the United Kingdom (UK) and in other European countries are often caused by a variety of factors, including difficulty in meeting development and capital costs, poor network design, construction and operation as well as a lack of knowledge and skills in all aspects of direct implementation of DH systems. As a result of the concerns surrounding DH implementation, extensive research analyses of DH strategies, technical solutions, knowledge, skills, policies, regulations, pricing, consumer protection, and financial instruments have been deemed necessary to inform appropriate design and policy decisions for the successful implementation of DH networks (Acheilas, Hooimeijer and Ersoy, 2020, CMA, 2018, CIBSE and ADE, 2020, DECC, 2013a).

The heat sector has the largest share of energy consumption globally, accounting for a third of global energy related carbon emissions. Due to its strong dependency on fossil fuels and the low cost of implementing individual heating systems, such as gas boilers, it is considered to be one of the most difficult sectors to decarbonise (BEIS, 2018a). Emission reduction is often achieved through an increase in the share of renewable energy, and district heating (DH) is a key technology which facilitates the transition from current fossil fuel-based energy to low-carbon energy sources. DH enables a clean and cost-effective transition to net zero, delivering a wide range of environmental, consumer, and economic benefits. It creates the energy infrastructure to support all forms of renewable technologies which can aid the decarbonisation of the heating sector (Rämä and Wahlroos, 2018; Vadén *et al.*, 2019). However, the implementation of a DH network is capital intensive and, therefore, the economic case depends on achieving a large market share as soon as possible. In several cities this has been achieved through regulatory means or market forces such as high taxes on the use of fossil fuels. Also, a major challenge is how to significantly eliminate technical, social, organisational and legal barriers limiting the large-scale implementation of DH (Woods and Overgaard, 2015; Vadén *et al.*, 2019).

Countries and cities across the globe vary greatly in the way in which heating is provided in their buildings. These differences reflect various resources, expertise, technology, processes, infrastructure, governance approaches and policy choices. This research explores how cities implement large scale DH networks from a socio-technical perspective with a view to identifying key success factorsand effective governing measures that can overcome the main barriers limiting the uptake and delivery of district heating at scale. It seeks to contribute to the development and delivery of effective policies that would drive the successful implementation of low carbon DH networks. Drawing on socio-technical transitions literature, this research analyses the institutional, social, political, and technical solutions integral to the delivery of low carbon DH networks through secondary case study research in Copenhagen, Stockholm and Helsinki and primary case study research in Greater Manchester (GM).

DH networks, also known as heat networks (HN), have the potential to play a significant role in the decarbonisation of the heating sector (BEIS, 2018a; Rämä and Wahlroos, 2018). Its capacity to use a wide variety of low carbon heat sources, such as industrial waste heat, ocean and river source heat, solar thermal and geothermal heat, is seen as a major advantage in increasing supply diversity and reducing reliance on fossil fuels (Petersen and Energi, 2017; HM Government, 2020a). While DH provides greater opportunities for decarbonisation, increased energy efficiency and cost-effectiveness in the heat sector, it is not an easy technology to implement. Countries and regions new to DH or seeking to implement DH at scale as part of a low carbon energy system, need to establish innovative governance structures, policy approaches and business models to address the complex barriers to DH development and implementation. A number of key barriers would need to be addressed in order to make DH competitive in comparison with alternative heating technologies. Investing in low-carbon heating solutions such as DH will improve air quality while also attracting inward investment, creating jobs, and enhancing social welfare (Werner, 2017b; Le Quéré *et al.*, 2018; BEIS, 2020c). It has therefore become increasingly important to explore the key mechanisms that would help shape the implementation of efficient low-carbon heat source DH systems (Woods and Overgaard, 2015; Werner, 2017b; Vadén *et al.*, 2019).

This study provides a detailed analysis of the strategies, technical solutions, expertise, policies, regulations, pricing, consumer protection and financial instruments vital to the successful implementation of efficient DH networks to draw lessons on how cities implement large scale DH networks and to bridge the knowledge gap on the expertise and resources required to promote wider usage and integration of DH as part of a low-carbon energy system. It focuses on exploring the preconditions, processes and context-specific conditions rooted in the underlying patterns of development that enable the successful implementation of a low carbon, affordable and efficient energy technology such as DH. Where available, it will also provide information on the policies, targets and strategies for the decarbonisation of existing and new DH networks (Connolly *et al.*, 2014; Fahl and Dobbins, 2017; Rao *et al.*, 2017).

The secondary case study research involved the collection of data from Copenhagen, Stockholm, and Helsinki through documentary analysis of published reports, policy documents and academic literature. This provided in-depth understanding of how DH has been implemented in these cities, where they were a more predominant form of domestic heating. Identifying prospective research directions on how to conduct the primary case study research, who needs to be involved and what data needs to be collected from GM. It also aided in identifying the key drivers as well as barriers to DH implementation, to help understand how the barriers emerged, how they have been overcome and can be addressed. It identifies socio-technical systems that enable successful implementation of DH in order to bridge the knowledge gap on the expertise and resources required to promote wider usage and integration of DH systems. This is to gain a deeper understanding of how to successfully implement DH networks in cities to deliver increased energy efficiency and climate mitigation objectives. GM is in the early stages of large-scale DH implementation across GM which makes it an ideal case study for this research.

The Heat Decarbonisation Challenge

Heat is used for a variety of end uses such as water heating, space heating and industrial processes at different scales, ranging from small scale local level domestic applications, to large scale applications in industries and heating networks *(*IEA*, 2014)*. The heating sector has the largest share of energy consumption globally, and accounts for 40% of global energy-related carbon emissions (IEA, 2017). As shown in figure 1, heat demand accounts for more than 50% of the world's final energy consumption (across the residential, commercial and industrial sectors) with over 75% of this demand met by fossil fuel, while only 10% of heat demand is met by renewable energy (IEA, 2015). Due to its strong dependency on fossil fuels and the low cost of implementing fossil fuel powered heating systems, such as gas boilers, it is considered to be one of the most difficult sectors to decarbonise (IEA, 2015, 2017).

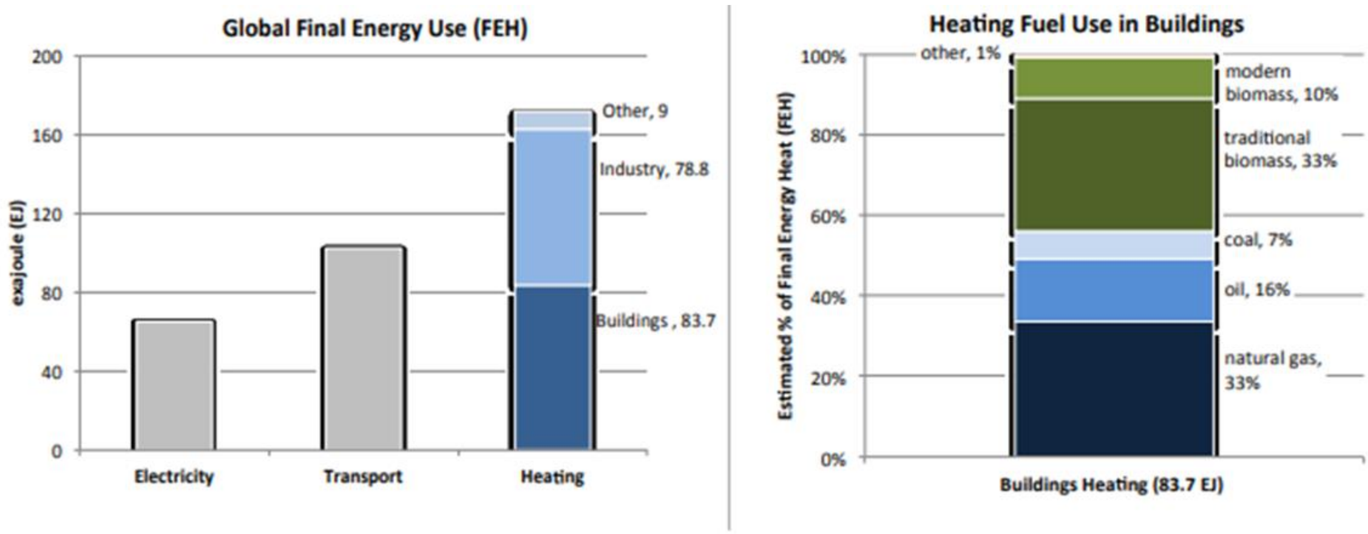


Figure 1: Global Final Energy Consumption and Heating Fuel Consumption in Buildings (IEA, 2014).

The International Energy Agency has described renewable heating as the ‘’sleeping giant’’ of low carbon saving, owing to its inherent potential to achieve significant reduction in carbon emissions (Connolly *et al.*, 2014; IEA, 2014, 2015). Decarbonising heat is a transformative challenge for many countries and a critical global climate mitigation approach that requires shifts to clean energy technologies that provide sustainable, secure, adequate, reliable, and affordable delivery of low carbon heat with high levels of efficiency and environmental performance. The scale of the transition to a decarbonised heat sector requires strategic coordination, careful planning, collaborative efforts and informed policy making decisions within the next decade (Singh *et al.*, 2019).

Heat has unique features that distinguish it from other decentralised energy systems. Distributed heat requires new forms of fuel supply, network design and construction, and operations and management, all of which require fundamentally different built-environment configurations. Heat is an excellent example of “how energy transitions are spatially constituted” in a variety of ways, in terms of differences in geographical location, contexts, settings, opportunities, and challenges, as well as economic, material and cultural aspects of energy systems (Bridge *et al.*, 2013).

The urgent need to transition to clean energy technologies to address issues such as climate change, fuel scarcity, the depletion of natural resources, fuel poverty, accessibility, affordability, reliability of energy services and energy security has been widely accepted to be essential for sustainable growth and development (United Nations, 2017). The Paris Agreement commitments to reduce carbon emissions and to keep global temperature rise to well below 2°C above pre-industrial levels, requires a 50% reduction in carbon emissions by 2030 and net zero carbon emissions by 2050 (Le Quéré *et al.*, 2018). The rising need for a reliable, cleaner and more efficient low carbon heat supply and affordable heating has led to increased interest in DH due to the flexibility of integrating various natural and renewable heat sources into the technology as well as its cost effectiveness (Connolly *et al.*, 2014; Millar, Burnside and Yu, 2019).

In June 2019, the UK set a world leading net zero target into law to make the transition to clean energy by 2050. The target requires eliminating all greenhouse gas emissions from all sectors including domestic and commercial buildings (HM Government, 2020a). Along with the net zero target, the UK has set ambitious interim emission reduction targets, known as the Carbon Budgets, that call for a 57% reduction in emissions across the UK economy by 2032. The major challenge is how to leverage resources, innovation, and leadership to develop the ideal socio-technical configuration that will trigger the required transition to clean energy technologies in various geographical locations, contexts, settings, and energy sectors as part of a low carbon energy system. Decarbonizing heating is a top priority to achieve a 50% reduction in CO_2 emissions by 2030 and net-zero emissions by 2050 (Werner, 2017b; Le Quéré *et al.*, 2018; BEIS, 2020c; HM Government, 2021b, 2021d).

To reduce carbon emissions, significant adjustments to current energy systems are required. While the transition to low carbon technologies has been identified to be effective in mitigating climate change, the major challenge is how to significantly eliminate technical, social, organisational, and legal barriers to the large-scale deployment of low carbon technologies across all the sectors in the energy system. Existing systems establish stable technological trajectories, which act as barriers to energy technology transitions and system innovations. Consequently, transitions will require disruptions in the established order and a whole system reconfiguration with transformational change, not only in technologies, but also in consumer behaviours, policies, infrastructure, production networks, business models and market culture referred to as socio-technical transitions (Geels, 2011, 2018; Geels *et al.*, 2017).

Heat Decarbonisation at scale would need to be well-established by the 2030s and continue beyond 2050 to meet the legally binding carbon reduction targets set out in the Climate Change Act, as well as delivering on the Paris Agreement commitments (Le Quéré *et al.*, 2018). This is particularly important in the case of residential and commercial space heating and hot water, which account for between a fifth and a quarter of total carbon emissions (Bell *et al.*, 2016; MacLean *et al.*, 2016). According to Lowes and Woodman (2020), while it may seem to be a few years away, planning and preparation for decarbonising the heat sector must begin now in order to pave the way for cost-effective and appropriate levels of disruption in this critical sector without adverse effects on the economy, environment, or society.

A key attribute of heat is that it can be derived from a diverse range of fuels and at different temperatures (IEA, 2014). While a range of technological innovations with distinct characteristics and challenges have the potential to contribute to the decarbonisation of the heat sector, this study considers the dynamics of governing the transition to low carbon heat with a specific focus on city-based DH networks and the pathways that enable their delivery at scale. The following section discusses the heat decarbonisation problem, the need for decarbonisation and the role of DH in decarbonising heat.

The Role of District Heating in the Decarbonisation of Heat

District heating networks distribute heat energy from a central source to customers through an underground network of hot water pipes serving various combinations of building types. DH networks vary in size, they can be massive and cover an entire city, or they can be small and supply a small cluster of buildings. It removes the need for individual boilers or electric heaters in each building and is also referred to as "central heating for cities " (BEIS, 2018a).

DH networks are one of the most cost-effective ways to reduce carbon emissions associated with heating, address rising fuel costs, and fuel poverty, and provide diverse and secure energy systems due to their capacity to be integrated with a wide range of low carbon energy sources, thereby promoting energy security and efficiency. The rising need for a reliable, cleaner and more efficient low carbon heat supply and affordable heating has led to increased interest in DH due to the flexibility of integrating various natural and renewable heat sources into the technology, as well as its cost effectiveness (Connolly *et al.*, 2014; Millar, Burnside and Yu, 2019). It is considered to be a viable and efficient solution to fuel poverty, which is a situation in which a low-income household is unable to keep their home warm at an affordable cost (Boardman, 1991). This is due to less capital investment to customers, low maintenance fees and high efficiency of managing the shared assets of a DH scheme more effectively than individual heating options with the potential to prevent high heating costs resulting from rising fossil fuel prices. This has been a major justification for the use of DH in fuel poverty eradication initiatives (Agrell and Bogetoft, 2005; Walker, 2008; Davies and Woods, 2009; Kelly and Pollitt, 2010; Andrews *et al.*, 2012).Emission reductions are often achieved through an increase in the share of natural and renewable energy sources and DH is one of the only ways many of the most affordable low-carbon heat sources such as waste heat from industrial processes or power generation plants, geothermal heat from abandoned coal mines and ocean or water source heat, can be transmitted for use in buildings (BEIS, 2018e, 2018a).

DH has the potential to be a key technology in the transition from current fossil fuel-based energy to low-carbon energy sources. It provides the infrastructure to support all forms of renewable technologies which can aid the decarbonisation of the heating sector. One of the functionalities of DH is that they are technology agnostic. This means it can be integrated with various clean energy technologies such as solar and wind, and geothermal energy. The oil crises of the 1970s and the need to reduce dependence on imported fossil fuels led countries like Finland, Sweden, and Denmark to adopt DH (Galindo Fernández *et al.*, 2016; Ministry of the Environment and Statistics Finland, 2017; Millar, Burnside and Yu, 2019; Värri and Syri, 2019).

DH networks can be expanded over time as new heat demands and heat sources are introduced and are connected to more buildings, their efficiency and carbon-saving potential increases. It is important to ensure that the cost of the transition to net zero is fair and affordable (HM Government, 2020a), meaning that low-carbon technologies should aim to be less expensive than their fossil fuel counterparts for consumers as this will help reduce the impact on fuel poor households. DH has been used for the purpose of alleviating fuel poverty because it can be both low carbon and cheap for customers as compared to a building level low carbon solution, as evidenced in Denmark, Germany, Sweden, Iceland and Finland (Woods and Overgaard, 2015; Petersen and Energi, 2017; Dahal, Juhola and Niemelä, 2018). They have the potential to provide multiple benefits to the environment, customers, and the wider economy such as cost effectiveness, increased energy efficiency and enabling greater proportion of renewables (IEA, 2017; Chauvaud De Rochefort, 2018). However, DH networks are not the right solution in all areas. Due to the high costs of network construction, one of the key barriers to the DH implementation is that it may not be economically viable in some areas, especially in rural or sparsely populated areas with widely spaced buildings. DH networks are particularly best suited to urban areas with high heat demand density and a mix of different building types: such as city centres, new build developments, schools, as well as some rural off-gas grid communities. Ultimately, the appropriate scale and location for a heat network is determined by the physical, cultural and institutional context of the area; some of the limitations of DH will be discussed in subsequent sections (IEA, 2017; Chauvaud De Rochefort, 2018). The following section provides an overview and context of the research on large-scale implementation of city-based DH networks.

1.2. Overview and Context of the Research: Heat and Cities

Cities consume over 66% of the world's energy which is derived majorly from non-renewable (fossil fuels) and most recently renewable sources, such as wind, solar and geothermal energy (Global Covenant of Mayors, 2018). Cities also account for approximately 70% of global carbon emissions, mainly from energy, transport, buildings and waste management sectors, with the increasing population of inhabitants causing high energy demand as well as infrastructural and economic activities which contribute to the high level of emissions in cities (Global Covenant of Mayors, 2018; Tu, 2018).

As nations and cities continue to confront the challenge of decarbonising heat, evidence increasingly shows the potential for DH to play a major role in achieving a low-carbon energy system (Connolly *et al.*, 2014; Lake, Rezaie and Beyerlein, 2017). Local renewables resources can be used more efficiently by expanding district heating such that some of the heat that is currently being wasted in the existing energy system can be recycled. It is flexible with the wider energy system offering seasonal storage options, enabling the use of heat from solar energy storage during winter and the use of energy storage from intermittent renewable energy sources such as wind turbines. DH can operate on a variety of scales ranging from two-building networks to networks that span entire cities.

Countries like Finland, Sweden and Denmark provide evidence for the take up of DH, which was mainly triggered by the oil crises of the 1970s. The combined heat and power (CHP) plants, which were originally gas-fired, are being replaced with a wider range of low carbon heat sources, in order to decarbonise their heat supply through the expansion of their district heating network. The total market share of DH in Finland, Sweden and Denmark is approximately 46%, 57% and 63% of citizens respectively (Galindo Fernández *et al.*, 2016; Ministry of the Environment and Statistics Finland, 2017; Värri and Syri, 2019). Cities are also adopting DH systems to achieve important benefits such as (UNEP, 2016):

- Affordable energy provision
- Community economic development and control of energy supply
- Increased share of renewables in the energy mix
- Local air quality improvements
- Carbon emission reductions
- Reduced reliance on energy imports and fossil fuels

Currently, a significant number of major district heating systems can be found in cities such as Hamburg, Milan, Helsinki, Stockholm, Copenhagen, Paris, Prague, Sofia, Bucharest, Vienna, New York, Berlin, Kiev, Seoul, Warsaw, Moscow and St. Petersburg. The total number of systems was estimated at 80,000 with approximately 6,000 systems in Europe (Werner and Frederiksen, 2013; Werner, 2017b). Space heating and domestic hot water in Helsinki, Stockholm and Copenhagen is currently mostly based on the district heating accounting for 92%, 80% and 98% of total heat demand (Galindo Fernández *et al.*, 2016; City of Helsinki, 2019b). Since DH networks vary in scale, the geographical, cultural, and structural context of a region determines the most appropriate size and location for a DH network, as it is not suitable for all areas. However, networks with large capacity are known to provide greater environmental and economic benefits by combining multiple and potentially intermittent heat sources such as waste heat from industrial processes, or combination of heat from CHP plants or heat generation plants (Woods *et al.*, 2005; Wang, 2018; Buffa *et al.*, 2019). Due to the wide range of low-carbon heat supply options that can be integrated into the DH technology, as well as the high capital investment required, it is predominantly used as a solution for high density urban areas with high heat demand (Connolly *et al.*, 2014; Lake, Rezaie and Beyerlein, 2017). The main focus of this study is therefore to explore measures that can overcome the barriers limiting the implementation of city-based DH networks which provide greater opportunities for decarbonisation and increased efficiency in order to draw lessons for actors seeking to implement DH networks in cities.

1.3. Problem Statement

DH systems can be an efficient method of supplying heat, capable of playing a significant role in the transition to a sustainable low carbon, secure, reliable, and affordable energy system, as it can be powered by renewables from biofuels, waste heat and energy from waste (Connolly et al., 2014). Despite the benefits of DH, the degree of expansion, market penetration and the proportion of households supplied by district heating varies from country to country. The percentage of citizens that have their energy supplied from DH networks varies from country to country with 92% in Iceland, to 63% in Denmark, to 52% in Sweden and 2% in the United Kingdom (Euroheat & Power(BEIS, 2019b), 2015; Colmenar-Santos et al., 2016). District heating, like most low-carbon energy solutions, will only succeed when properly implemented, which requires careful consideration and planning. District heating could become a burden for decision-makers and consumers when it is inefficiently operated as they are custom-built technologies that require appropriate social, technological and economic analysis in order to verify the economic viability of the system. The engineer must ensure the chosen plant capacity can meet the demand requirement of the consumers. Good engineering design and resource optimisation are key factors to be considered in the development of viable DH systems (Kelly and Pollitt, 2010).

There are several known cases in Europe where poor consumer focus, low efficiency, excess capacity, lack of investment and inadequate policy framework have led to the inefficient operation of DH systems giving rise to the decline in the uptake of DH systems. Also, there are speculations that poor design and operation of DH systems have intensified fuel poverty in Central and Eastern Europe (Tirado Herrero and Ürge-Vorsatz, 2012). Energy efficiency is clearly an important advantage in DH systems, and therefore DH systems must be well designed to reduce heat losses from the distribution networks in order to ensure DH continues to be an effective solution for buildings. Well-designed DH networks can reduce carbon emissions, lower heating bills, and tackle fuel poverty while also contributing to energy security.

DH implementation in the United Kingdom context is particularly challenging, largely due to the highly centralised energy system, a liberalised energy market, and extensive natural gas networks with individual building-level gas boilers providing a relatively cheap and conventional means of heat supply to consumers (Hawkey, Webb and Winskel, 2013; (ADE, 2018c; CMA, 2018; CIBSE and ADE, 2020).

Consequently, the major barrier to the uptake of DH networks is how to significantly eliminate technical, social, financial, organisational, and policy barriers limiting the large-scale implementation of DH. Some of the key barriers to DH implementation at scale are outlined below (DECC, 2013a; Hawkey, Webb and Winskel, 2013; ADE, 2018c; CMA, 2018; CIBSE and ADE, 2020):

- Difficulties with meeting development and capital costs
- Uncertainties relating to reliable heat sources
- Absence or lack of enabling policies and regulation
- Lack of local capacity to design, build and operate community energy systems
- The inability to effectively position and market DH as a viable, sustainable option
- The choices made by heat providers
- Uncertainties regarding longevity and reliability of customer heat demand
- Lack of guidance, support, leadership or political will for planning and implementation
- Lack of established role for local authorities
- Lack of knowledge, skill, and capacity to implement DH
- Lack of generally accepted contract mechanisms
- Lack of suitable financial investment options

The implementation of a DH network is capital intensive and therefore, the economic case depends on achieving as large a market share as soon as possible. In several cities, this has been achieved through either regulatory means or market forces, such as high taxes on the use of fossil fuels (Woods and Overgaard, 2015; Vadén *et al.*, 2019). Economic risk, regulatory uncertainty and lock-in of existing technology are the most significant barriers to DH development. Furthermore, the economic viability of DH networks is dependent on several issues, such as organisational and regulatory frameworks, the optimisation of engineering design, as well as economic and financial factors (Kelly and Pollitt, 2010).

District DH networks have been used successfully in the Scandinavian countries, and implementing such networks has the potential to reduce carbon emissions significantly. Therefore, it can be argued that the decarbonisation challenge is no longer about finding viable solutions for achieving a decarbonised energy system, rather the challenge now pertains to how to set in motion the processes for delivering decarbonisation in a timely manner while ensuring secure, efficient, affordable, adequate and sustainable delivery of energy services. The commitment to reduce emissions to accelerate decarbonisation within shorter time frames, in order to achieve net-zero emissions by 2050, requires the redesign and innovative transformation of energy generation and supply systems to keep global temperatures well under 2°C and to address fuel poverty and security of supply challenges (Change, 2016). If DH is to play a significant role in achieving climate change targets, evidence increasingly supports the need for collaborations between public and private organisations as well as strong local government participation in the coordination, leadership, management and deployment of DH infrastructure (Kelly and Pollitt, 2010).

While the implementation of large-scale DH systems in Copenhagen, Stockholm and Helsinki have been largely successful, with all three cities having a significant share of their total heat demand derived from DH, they are still partially powered by fossil fuel combustion technologies, which have adverse environmental impacts. The use of fossil fuels as a heat supply source for DH networks must be minimised; otherwise, the DH network will not be considered an energy efficient low carbon solution unless the heat supply is derived from a low carbon/renewable energy source at a competitive price, which is a key consideration for DH advocacy (Connolly *et al.*, 2014). Also, the decarbonisation of DH is a common challenge in many countries, as they are seeking ways to shift away from fossil fuel-based heat generation and supply, while reducing carbon emissions and lowering costs, in order to develop a smarter fossil fuel free DH network within their target plans to achieve carbon-neutrality (Woods and Overgaard, 2015; Vadén *et al.*, 2019).

A key challenge is that the current landscape for low-carbon energy generation and supply in cities is not moving at a rapid pace towards a clean energy future, as it requires investment decisions that promote low carbon energy technologies with robust short-and long-term energy policy implications (Dahal, Juhola and Niemelä, 2018). Since energy policies are one of the key mechanisms required to promote the influx of low carbon technologies, they need to be properly designed and implemented for effective delivery and to attract the required investments and stakeholders. The need to strengthen local capacity to design, build and operate a decentralised energy technology such as DH, as well as the ability to effectively position and implement DH as a viable, sustainable option, calls for a detailed research analysis of how DH can be implemented at scale in cities in order to identify/

develop effective policy design considerations, strategies and solutions that can increase DH implementation as well as the share of renewable energy in the DH supply mix for sustainable low carbon heat generation and supply. This study aims to gain a better understanding of how DH can be implemented successfully and to identify key success factors that can help address the main barriers limiting large-scale DH uptake and delivery. This will help educate policymakers and key stakeholders involved in urban DH implementation process to make informed policy, investment and strategic decisions. It will also provide insight into how social and political issues (such as societal acceptance of technologies, political feasibility, institutional changes, the nature and setting of policies and their paradigm) interact or co-evolve with current and future changes in technology.

1.4. Research Justification

Globally, climate change poses significant threats to carbon-intensive energy systems (IPCC, 2014). The Paris Agreement introduced in 2015 by the United Nations Framework Convention on Climate Change (UNFCCC) has set the world on a common path to reduce carbon emissions to safeguard our environment from the harsh impacts of climate change. The agreements target is to reduce carbon emissions to keep temperature rise to well below 2°C above pre-industrial levels and to strive to limit it to 1.5°C. Climate change predictions estimates that further increase in carbon emissions could lead to a rise of 1°C to 5°C in the average global temperature over the next fifty years (Robin *et* al., 1992). This poses huge challenges as global carbon emissions have continued to rise in spite of the Paris Agreement's carbon reduction targets (Seneviratne *et al.*, 2018). To achieve the target put forward by the Paris Agreement it is required that a 50% reduction in carbon emissions is attained by 2030 and a net zero carbon emissions by 2050 (Le Quéré *et al.*, 2018). Consequently, policy makers in various parts of the world are faced with the challenge of developing effective climate change policies that foster emissions reduction, energy efficiency and a transition to clean energy technologies. While the rate of decarbonization process may vary from country to country, the undeniable fact is that greenhouse gas (GHG) emission reduction requires worldwide participation in order to meet the global objectives on climate change (Edward, Kenneth and Wolfram, 2017). Ultimately, significant decline in global carbon emissions will start to occur when global carbon emissions continue to decrease despite the increase in population and global energy demand as a result of the rapid transition to low or no carbon technologies (Jackson *et al.*, 2018).

In recent years, growing environmental concerns and awareness campaigns on climate change have seen the development of policies, responses and initiatives targeted at reducing GHG emissions above pre-industrial levels which is essential for future climate stabilisation (UNFCCC, 2016; Seneviratne *et al.*, 2018). There have been several transformative initiatives introduced in various nations and cities around the world to promote the transition of energy systems towards sustainability through the implementation of low-carbon transition policies. However, lock-in to existing fossil fuel-driven developmental paths creates resistance to new technology markets and policy failures which inhibit the widespread deployment and diffusion of low carbon technologies in spite of their evident environmental and economic benefits (Unruh, 2000a; Frantzeskaki *et al.*, 2017).

The major challenge is how to leverage resources, innovation and leadership to develop an appropriate socio-technical configuration that will trigger the required transition to clean energy technologies in various geographical locations, contexts and settings, which is further complicated by the diversity of stakeholders. Another challenge is how to significantly eliminate technical, social, organisational and legal barriers to low-carbon transition to drive the transformative levels of change required to secure a clean energy future, as existing large and networked systems such as the gas network system create path-dependencies that constrain transition (Papachristos, 2014; Geels, 2018). Existing systems establish stable technological trajectories which act as barriers to energy transitions and system innovations. In the context of climate change mitigation strategies and the reduction in the over-dependence on carbon-based energy sources in urban environments, district heating (DH) systems have the potential to play an important role in the efficient supply of renewable heat energy in the heating sector (Lake, Rezaie and Beyerlein, 2017; Dahal, Juhola and Niemelä, 2018).

DH has become a significant part of the heat supply in many countries and cities, particularly in the Scandinavian countries over the last 50 years. Its capacity to use a wide variety of heat sources, such as industrial waste heat, renewable energy and CHP, is seen as a major advantage in increasing supply diversity and reducing reliance on imported fuels. It contributes to more efficient energy use and reduces carbon emissions, and in many high density cities it will also be the lowest form of heating costs (Woods and Overgaard, 2015). DH can be a complex technology to implement, which poses a significant barrier to DH take up. A growing number of stakeholders and policymakers are becoming aware of the district heating potential and the opportunities it provides in terms of energy efficiency and climate mitigation objectives and are seeking to overcome the barriers to large-scale DH implementation (BEIS, 2018c; Vadén et al., 2019; Acheilas, Hooimeijer and Ersoy, 2020). The financial viability of a DH network is underpinned by a low-cost heat source and, in order to gain acceptance, it will need to deliver carbon savings without having a major effect on the local environment (Woods and Overgaard, 2015; Vadén *et al.*, 2019).

Failures in the past in several regions, as well as a lack of expertise with direct implementation of district heating systems, have raised concerns about the strategies, technical solutions, expertise, policies, regulations, pricing, consumer protection, and financial instruments required to deliver efficient DH systems. This calls for a detailed research analysis on the implementation of DH systems in order to identify/ develop effective policies, strategies and solutions that can overcome key barriers and to facilitate more appropriate decision making towards the uptake and delivery of DH systems in urban environments (Acheilas, Hooimeijer and Ersoy, 2020).

The emergence of local energy action plans and the adoption of climate action plans at local levels have been studied extensively (Wheeler (2008), Bedsworth and Hanak (2013), Dixon and Wilson (2013) and Damsø, Kjær and Christensen (2016)). However, there is a dearth of literature on case studies of what actually happens during the implementation phase of a climate mitigation plan. The resulting deficiency of impact studies highlighted by several researchers (Wheeler, 2008; Bulkeley, 2010; Salon, Murphy and Sciara, 2014) calls for a need for it to be addressed. In addition, researchers (Frantzeskaki and Loorbach, 2010; Markard, Raven and Truffer, 2012; Geels, 2018) in the field of sustainability-oriented innovation and technological studies have identified the need for low carbon transitions research to intensify and expand its engagement with social sciences in order to provide a deep understanding of the ''whole system'' transformational shifts in socio-technical systems. This will aid in identifying processes that are compliant with low carbon transitions that would benefit policymaking decisions to strengthen sustainable transitions to low carbon technologies. Also, much of the technocratic government approaches and modelling scenarios on transitions often focus on identifying cost-effective pathways using techno-economic measures while ignoring the importance of societal acceptance, political feasibility and public engagement which have given rise to various snags that have rendered a number of low-carbon strategies ineffective (Geels, 2018).

This research explores low carbon transition in the heat sector with a specific focus on the city-scale implementation of DH technology from a socio-technical perspective. It analyses the large-scale implementation of DH systems in Copenhagen, Stockholm and Helsinki, with extensive use of DH systems, and in Greater Manchester (GM), which is in the early stages of implementing large-scale DH networks. The dearth of available data in failed DH implementation case studies, which could be useful in providing insights on how to avoid failures, was one of the main reasons this study was not a counter-factual one or a comparison of successful and failed DH implementation strategies. This is why it focuses on two different contexts, one representing a well-established DH sector and the other representing the early-stage development of a DH implementation plan, in order to capture the DH implementation process at the start of the journey. It seeks to draw lessons on how to effectively implement large-scale DH systems from successful case study cities to contribute to bridging the knowledge gap on the expertise and resources required to promote wider usage and integration of DH as part of a low-carbon energy system. This will be useful for actors seeking to implement DH to identify relevant policy design considerations that can potentially address barriers limiting the implementation of urban DH systems and to outline strategic directions towards the implementation of large-scale DH networks within the target of a carbon neutral city region. It will also contribute to further research into the global drive for emissions reduction, energy efficiency and environmental sustainability in the heating sector to deliver climate mitigation goals and a clean energy future.

Furthermore, the significance of place (especially cities) in socio-technical transitions literature has been criticized in the sustainable transitions literature (Eames *et al.*, 2006; Coutard and Rutherford, 2010; Hodson and Marvin, 2010a, 2010b, 2012; Bridge *et al.*, 2013). Although transition theories acknowledge the interaction and interpenetration of various landscape (macro), regime (meso), and niche (micro) levels, the role of the city and regional scale in transition processes has largely been overlooked. According to Markard, Raven and Truffer (2012), studies on socio-technical transitions often focus on national-level systems with little attention on geographical scales of urban or regional contexts. A “spatial turn” in sustainable transition studies has addressed this to some extent in recent years (Coenen and Truffer, 2012b; Coenen, Benneworth and Truffer, 2012; Hansen and Coenen, 2015; Sengers and Raven, 2015; Wolfram and Frantzeskaki, 2016; Sengers, Wieczorek and Raven, 2019). However, more extensive analysis of how cities contribute to sustainable transitions is still necessary (Karvonen and Guy, 2018). This requires a detailed examination of the dynamics of socio-technical interactions across the levels of niches, regimes and landscapes as well as multilevel systems of governance to develop a more geographically nuanced understanding of niche development (Rohracher and Späth, 2014).

Cities are regarded as key areas that have consistent environmental and societal tendencies that are suitable for piloting innovative ideas to drive change (Tu, 2018). Cities with efficient DH systems can provide important lessons to foster the successful implementation of DH systems through the transfer of knowledge and good practices and the provision of road maps that model the processes involved in the implementation of DH systems. Also, local governments are the lowest tier of government that have the closest interaction with citizens with the potential to effect change and deliver true impacts at local levels (Global Covenant of Mayors, 2018a). The case study exploration of urban delivery of efficient DH systems in leading transition cities will explore the potential of actors across various sectors to undertake governing actions to promote niche processes that drive the transition to DH. This research is in line with the United Nations Sustainability Development Goals (SDGs) which advocates the need for the development of local-level solutions with the aim to join forces to assist in helping to resolve environmental sustainability challenges (United Nations, 2015b). It seeks to provide a comprehensive understanding of the interaction between technology, institutions and actors which will be useful in establishing effective policy regimes and strategies on how to successfully implement DH systems and to identify prospective research directions in the delivery of efficient DH systems. Greater understanding of the role of DH in meeting set targets for low carbon heat generation can reduce resistance to DH implementation and any related constraints in the transition process. It can also support efforts to coordinate actions among various stakeholders and to mobilize support from other levels of government.

This research presents an opportunity to provide DH delivery lessons to cities to help achieve the Paris Agreement goals by supporting changes to consumption patterns, transition to renewable energy, energy efficiency improvement and increase in the market penetration of affordable low carbon energy technologies. As more cities (such as Helsinki, Vancouver, Oslo, Melbourne, Copenhagen, and Stockholm) are becoming successful at taking the lead to address their energy and climate problems, it can be argued that local level decentralised smart energy systems could be the path to a global clean energy future (Julia et *al.*, 2019). However, the concept of how cities can effectively implement low carbon technologies, such as DH, in order to reduce carbon emissions and achieve carbon neutrality is not yet fully understood, as the capability of local governments to successfully transition to low carbon technologies is significantly dependent on the network of legally binding agreements and policies through which it is governed (Tyndall Centre for Climate Change Research, 2017; Tu, 2018; Julia *et al.*, 2019). Also, researches in the field of transition studies have sought to highlight the role of cities in shaping transition processes as liberalisation reforms, concerns relating to the security of centralised provision, and the decarbonisation agenda are uncovering new spaces of agency at local and regional level (Hodson and Marvin, 2010a; Bulkeley *et al.*, 2011; Bolton and Foxon, 2013). However, the influence of policy and regulation has not been a prominent aspect of this literature to date.

The justification for this research is that the findings will contribute to the growing body of literature on low carbon transitions in urban environments with a specific focus on DH technology from a socio-technical perspective. The decision to take on a multi-case study strategy is to explore this path and to fulfil the need for an approach that allows for the analytical and practical depth and details of the DH implementation process in cities. This approach will involve engagements with a variety of key stakeholders ranging from local authority officers, business leaders, technology experts, innovators, policymakers with a view to providing detailed understanding of the challenges in the implementation process in order to find effective strategies that can potentially overcome the barriers to DH implementation. It will also provide the opportunity to capture the critical analysis of different perspectives, patterns, and complexities of the implementation processes in order to understand how technological transitions occur through social and technical systems to address the research gaps. This provides justification for this research and demonstrates a unique and original contribution to knowledge.

1.5. Rationale for Selection of Case Study Cities and Scope of the Study

There are a number of reasons why this research involved a multi-case study analysis which includes secondary case study research of three Scandinavian cities with extensive DH networks and a primary case study research in GM which is in the process of implementing DH networks at scale. A key factor for the selection of these Scandinavian cities is the good amount of robust and reliable evidence and a range of critical success factors enabling the framing of the primary case study research in GM. As previously explained the dearth of available data in failed DH implementation case studies is a key reason why it was not considered. The early stage of DH development in GM makes it an ideal primary case study for this research to provide an understanding of what actually happens during the DH implementation phase. Copenhagen, Stockholm, and Helsinki are exemplar cities for DH network implementation, with extensive knowledge, experience, and expertise in the delivery and operation of DH networks spanning over 50 years.

The multi-case study strategy allows for the cross-case analysis of the secondary and primary case studies which represent two contexts with differences in political, technical, financial, social, business models and policy approach to DH development. The secondary case studies have well established DH networks which has aided the decarbonisation of their heating sectors while GM is seeking to expand the penetration of DH networks as part of their heat decarbonisation strategy within the target to achieve carbon neutral living in the city region by 2038, leading the way for the UK to achieve net zero by 2050 (HM Government, 2019).

The secondary case study research provided an in-depth understanding of how DH has been developed and implemented in other regions, in terms of the key stakeholders involved and the key elements of DH implementation process which was used to inform the primary case study research. It aided in identifying the key success factors, effective governing measures as well as barriers to DH implementation to understand how the barriers emerged, how they have been overcome and can be addressed. It was also useful in drawing lessons on how to support the development of DH in areas with little history of DH networks. The primary case study research involved the collection of data through semi-structured interviews with key stakeholders involved in the implementation of DH networks in Greater Manchester across the public and private sectors ranging from local authority officers, business leaders, technology experts, innovators, and policymakers in order to explore how the transition to district heating is governed in the pursuit to decarbonise the heat sector in Greater Manchester.

The need to provide an in-depth understanding reflects on the chosen data collection methods. An objective, systematic and empirical investigation of the experience of actors seeking to govern the transition to district heating, the constituted elements of the socio-technical system involved in the transition process will be carried out to identify the barriers to the widespread penetration of district heating in GM in order to proffer solutions to overcome the identified barriers in the pursuit to decarbonise the heat sector in GM. This is to provide insights into the situation and context in GM with details of the unique drivers, challenges and barriers to DH development in GM. It also provided a stakeholder view of DH implementation in GM, the policy landscape in the heat network sector, ownership and management of DH networks, business models as well as the role of the public and private sector in DH development.

1.6. Research Aim, Questions and Objectives

The overall aim of this thesis is:

- To explore how cities implement large scale district heating networks from a socio-technical perspective with a view to identify key success factors and effective governing measures that can overcome the main barriers limiting the uptake and delivery of district heating at scale.

Research Questions

- How do cities implement large scale heat networks from a socio-technical perspective?
- What are the key barriers limiting the uptake and implementation of DH?
- How can these barriers be overcome?
- What are the policies and strategies that can drive the implementation of DH networks?

Research Objectives

The following objectives will be explored using a case study narrative:

1. To undertake secondary and primary research to identify key success factors in the large-scale implementation of city-based district heating networks.
2. To critically analyse the strategies of the key stakeholders and their impact on DH development.

3. To identify key instruments, interventions, drivers and barriers to DH implementation in order to understand how these barriers emerge, how they have been overcome and can be addressed.

4. To provide evidence-based guidelines for the creation of policies and pathways that can address the identified key barriers in order to help shape future government policies and strategies.

1.7. Thesis Structure

This thesis is organised into nine chapters as illustrated in Figure 2, which provides a diagrammatic representation of the thesis structure.

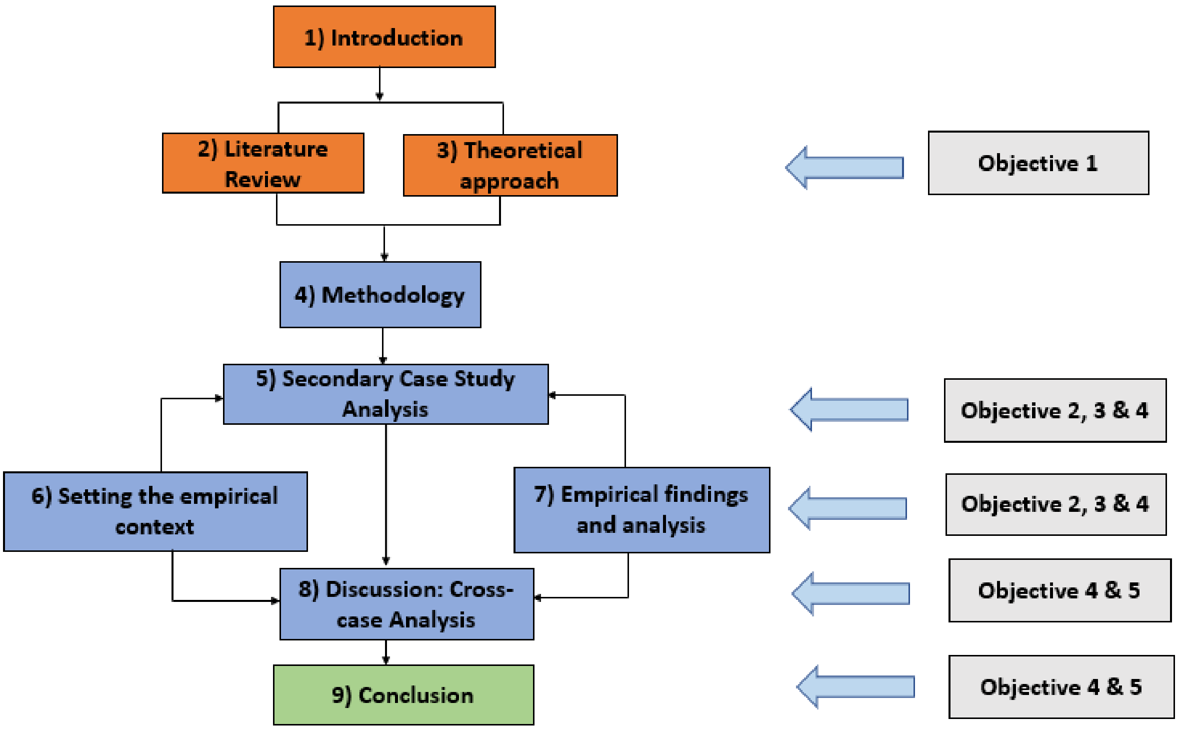


Figure 2:Overview of the report structure by chapter

There are five key factors explored in this study in order to understand how cities implement large scale DH networks from a socio-technical perspective, with a view to identify key success factorsand effective governing measures that can overcome the main barriers limiting the uptake and delivery of DH at scale:

- Implementation strategy
- Technical Solutions and heat sources
- Policy instruments and regulatory framework

- Pricing and consumer protection
- Financial instruments and incentives

The following provides a breakdown of the discussions in each chapter.

Chapter 1 provides an introduction to the research by providing background information and context of the research, reflecting on key areas of discussion and justification for undertaking the study as well as the aim and objectives of the research.

Chapter 2: Literature review: District heating

Chapter 2 provides a detailed literature review of the district heating technology discussing the key technological aspects of district heating, heat sources, and the sociotechnical, economic and environmental assessment of DH networks.

CHAPTER 3 Urban energy systems and the multilevel perspective on socio-technical transitions

Chapter 3 details the literature on transition and transition pathways theory conceptualisation of transitions, it includes relevant theoretical frameworks and approaches applied to urban socio-technical studies of energy system change. It then narrows it to the theoretical concept underpinning this research, outlining the socio-technical network approach.

Chapter 4: Methodology

Chapter 4 explains and justifies the adopted methodology, it describes the research design and explains the adopted philosophical paradigm underpinning this research. It outlines the methods used to address the research questions, source of data, data collection protocols and analysis to answer the research questions of this thesis.

Chapter 5: Secondary case study analysis

Chapter 5 presents a comprehensive case study analysis of DH implementation in Copenhagen, Stockholm and Helsinki to help design and frame the primary case study and to gain more knowledge on the subject area and for better understanding of how to conduct the primary case study research.

Chapter 6: Setting the empirical context a ***short history of DH development in the UK***

Chapter 6 outlines the empirical context of the primary case study by providing a synthesised account of DH development in the UK in order to provide the context for the structures, functions and dynamics of DH development in GM.

Chapter 7: DH Development and implementation in GM

Chapter 7 presents the findings of the data analysis. It examines a number of inductive themes that emerged from the interviews on DH development and implementation strategy in GM through the interactive mechanisms between social groupings of key actors and energy system institutions. The data analysis highlights the influence of the technical and social aspects of socio-technical elements characterised by social actors, as well as the interactions between these elements within the DH sector.

Chapter 8: Discussion: Cross-case analysis

Chapter 8 presents a discussion of the main findings of the study by identifying similarities, differences, relationships, and themes that emerged from findings drawn from the data analysis of the interviews in the primary case study (GM) as well as the analysis of the secondary case study cities.

Chapter 9: Conclusion

Chapter 9 presents the main conclusions of the study, it highlight the contributions to knowledge, the policy implications of the research, recommendations, limitations, and opportunities for future research. It reflects on the theoretical and empirical contributions of the thesis, as well as policy implications and recommendations. It also outlines the limitations of the research and identifies opportunities for further research. The appendices A to E contain the ethics approval certificate and further information on the primary case study research.

1.8. Chapter Summary

This chapter provided an overview of the research and discussed the significant role of DH can play in decarbonising heat, as well as relevant aspects of the research context. It provides justification for the selection of the primary and secondary case study cities. In addition, the chapter discussed gaps in the applied socio-technical transitions literature and outlines the research aim, questions, objectives and contributions to knowledge. The following chapter provides a review of the existing theoretical literature on DH and discusses the relevant aspects/key components that were used to inform the research structure and analysis of data from the secondary and primary case studies.

2. CHAPTER TWO LITERATURE REVIEW: DISTRICT HEATING

2.1. Introduction

The aim of this chapter is to provide a review of existing theoretical literature on DH development and delivery to gather the information necessary to carry out the data analysis from the secondary and primary case studies, as well as to shape the research focus and selection of research participants. The historical development of district heating is discussed, with examples from various countries, to identify developments in both technology and heat sources. The main features of a modern large-scale district heating scheme, which deals with each of the four major elements: the building's heating system, the building connections, the heat distribution network, and the heat source, are described in greater detail. It also discusses key aspects of DH, the economic and environmental analysis of DH, the advantages/opportunities and disadvantages/barriers limiting the implementation of DH at scale, the role of actors as well as non-technical organisational aspects, which are critical to the delivery of successful DH schemes.

2.2. District Heating Technology

District heating, also known as DH networks, are made up of a decentralised network of insulated pipes. These pipes transport heat energy in the form of steam or hot water from a central heat source (energy centre) such as power stations or industrial sites to multiple buildings with heat demand through transmission and distribution (Euroheat & Power, 2013) DH supply residential and commercial buildings heat for space heating and hot water. In certain cases, DH networks supply heat to entire cities and their surrounding areas. District heating differs from communal heating, which is the distribution of heat from a central source to a single building with multiple customers. Buildings served by DH networks do not need their own individual boilers (UKDEA, 2014) It is the collective provision of heat to multiple buildings from a single heat supply system (Ratheal, 2013). DH can be powered by a variety of low-carbon heat sources, which opens up innovative opportunities to decarbonise the heat sector. Heat can be supplied to DH networks from a variety of sources, which include heat extracted from power plants and industrial processes, waste-to-energy facilities, large-scale heat pumps, biomass combined heat and power (CHP) plants, gas-fired CHP systems, electric boilers, and solar thermal arrays. (Ratheal, 2013; UKDEA, 2014; Woods and Overgaard, 2015). Figure 3 shows the structure of a typical heat network which consists of a thermal store; a large tank of water used to store heat to help the CHP operate more efficiently. Pumps which keep hot water circulating in the system constantly; a Hydraulic Interface Unit (HIU), which connects the home heating radiators to the DH system. Boilers using gas or other fuels provide back-up and additional heating capacity, the householder has full control over their heating without the need to have a boiler of their own. The CHP units generate heating and electricity efficiently using gas or other fuels (UKDEA, 2014; Parsons Brinckerhoff, 2014).

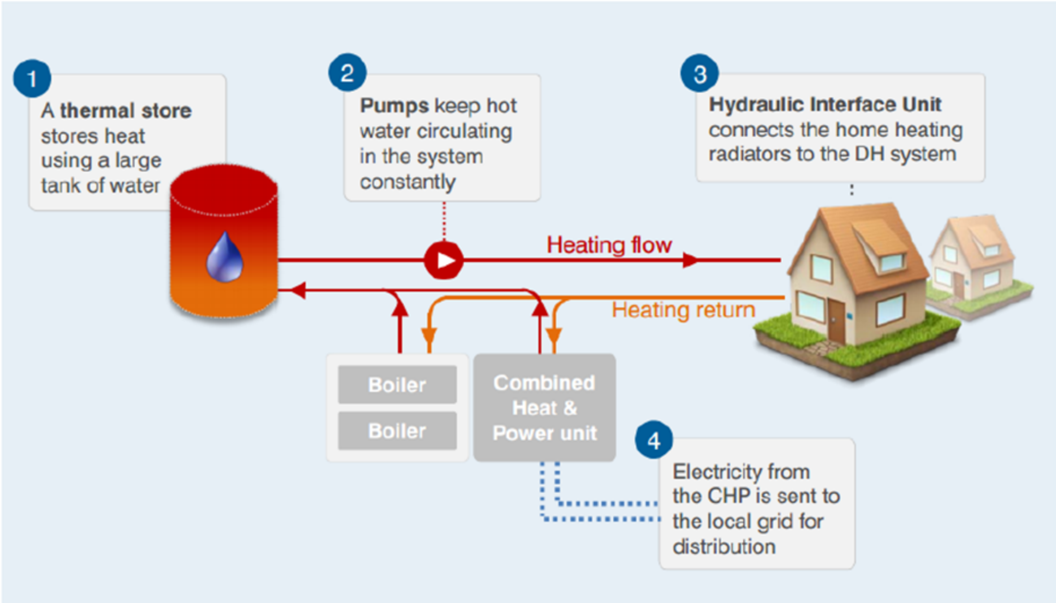


Figure 3:The structure of a typical heat network(Parsons Brinckerhoff, 2014) (UKDEA, 2014).

DH networks are local infrastructures based on physical pipe networks, as shown in figure 4. The early pipes were mostly made of concrete, but were replaced with high-quality pre-insulated pipes to facilitate improved efficiency and ease of use (DECC, 2013b).

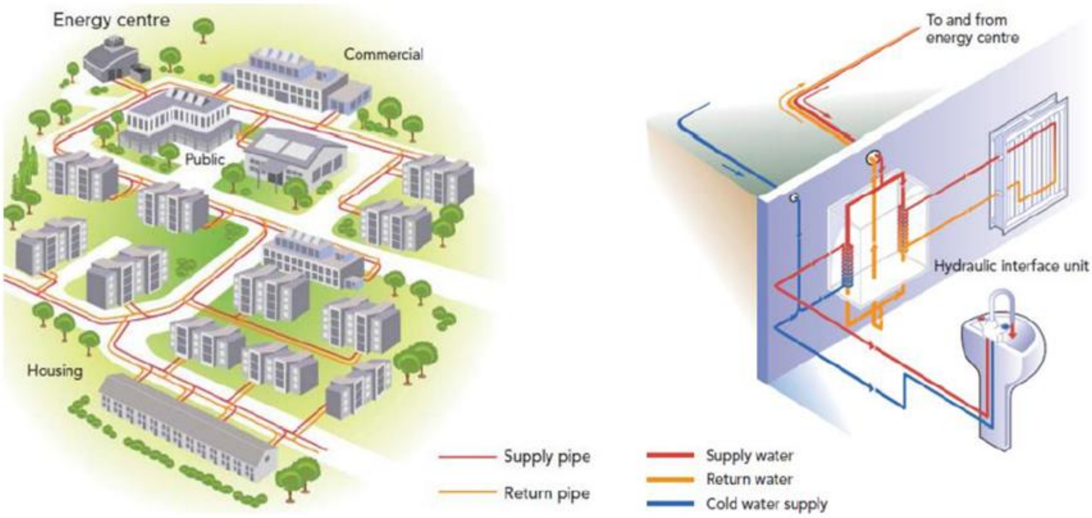


Figure 4:The network of district heating pipes (left) and the hydraulic interface unit (Wiltshire, 2011).

The DH system consists of three basic components: an energy centre that includes heat sources, a hydraulic interface unit for each consumer, e.g. heat exchangers, and a network of pipes that transmits heat to each consumer from the heat source(s) (Wiltshire, 2011). District heating systems have undergone incremental innovation through multiple changes of its technological components, such as prime movers and integration with supporting technologies. Prime movers are mechanical machines (engines, turbine) that drive the energy generator. It is regarded as the core component of CHP systems and its appropriate selection is essential for its successful implementation (Weber, 2014; EPA, 2017).

2.2.1. Advantages of District Heating

District heating can provide local populations with cost-effective and low-carbon energy, such as space heating during cold weather and year-round hot water (Finney, Sharifi, *et al.*, 2012). They are increasingly being recognized as an important component in decarbonizing heat and accelerating the transition to a low-carbon economy (Kelly and Pollitt, 2010; Wiltshire, 2011);. In summary, the benefits offered by DH networks include (Connolly *et al.*, 2014; Euroheat & Power, 2013; Woods and Overgaard, 2015):

Lower operational, maintenance costs and increased price stability in comparison to individual heating systems: DH gives rise to reduced energy generation costs as well as increased price stability through the use of alternative fuel sources which reduces exposure to fluctuating gas and electricity prices which is responsible for its use in tackling fuel poverty. DH customers do not have to deal with the typical costs associated with in-building heating systems, such as insurance, maintenance, upgrade, and replacement costs for boilers, multiple storage tanks, and other associated equipment.

Capacity to meet heat demand with a wide range of energy generation technologies: DH provides energy the infrastructure to support multiple forms of renewable energy technologies helps in meeting climate mitigation objectives. Its use of heat from a range of energy sources, and integration of renewable energy technologies, results in lower greenhouse gas emissions than fossil fuel-based systems.

Improved energy efficiency**:** DH offers increased efficiency through the simultaneous generation of heat and electricity which makes it less resource intensive, more efficient and provides greater energy security. DH can also be used to provide heating and cooling which is now increasing in demand to provide efficient exchange and redistribution of energy.

Enables the transport and provision of heat to a wide range of consumers: DH enables the supply of heat energy in the form of steam or hot water to multiple residential and commercial buildings operating on a variety of scales ranging from two-building networks to networks that span entire cities and their surrounding areas.

Increased job creation: DH provides increased local job creation which contributes to increased employment and economic development within the community.

In addition, these advantages bring about a number of desirable outcomes:

- Facilitates the widespread reach of renewable energy sources.
- Significant decrease in carbon emissions.
- Diversified use of fuel promotes energy security and efficiency.
- Alleviation of fuel poverty

Ultimately, DH use of alternative energy sources and greater efficiency produces fewer greenhouse gas emissions than what is produced by fossil fuel-based systems. It is capable of playing a significant role in the transition to a sustainable low carbon, secure, reliable and affordable energy system, providing flexibility through the powered by a range of energy sources; renewables from biofuels, geothermal heat, waste heat and energy from waste (Connolly *et al.*, 2014; Woods and Overgaard, 2015).

2.2.2. Disadvantages of District Heating

Some of the disadvantages of DH are summarised below (Connolly *et al.*, 2014; Euroheat & Power, 2013; Woods and Overgaard, 2015):

DH is capital intensive with requiring significantly high upfront capital investment costs for both energy generation and distribution systems in advance of any financial return from energy sales. It is therefore critical to ensure that the capacity of the generation and distribution networks is appropriately matched to the projected demand and build-up of building energy loads.

Electricity consumption and heat loss, DH uses electrical energy in the pump and suffers heat loss in the network of pipes to the ground.

DH is not suitable for all areas; it is best suited to high density areas with high heat demand.

Significant risk attached to the development, installation, and operation of DH such as the risk of pipe installation in the ground affecting other utilities during construction, drilling and retrofitting as well as installation difficulties in terms of technical difficulties relation to the compatibility of buildings with DH networks.

It is important to note that these are the general advantages and disadvantages of DH. The drivers, barriers and challenges to district heating are more place based and are often determined by the physical, cultural, and institutional context of the geographical location. The drivers, challenges, and barriers to DH in the case study cities of Copenhagen, Stockholm, Helsinki and GM are discussed in chapter 5 and 7.

2.3. Historical Development of District Heating

The need for heat has been a driving force for human actions since the prehistoric times when fires were used to provide warmth and protection. (Boardman *et al.*, 2005; Geddes *et al.*, 2011; DECC, 2012). For centuries, buildings have been heated by various fuels supplied to buildings, which are then burned in various ways for heat. There has been a shift from charcoal to oil, coke, petrol, and now natural gas and other sources have emerged (Woods and Overgaard, 2015). Archaeological and historical records have provided evidence for district heating systems in Europe since the 14th century (Marshall, 1931; Gibert and Jaudin, 1999; Guo, 2002; Steingisser and Marcus, 2009; Rogers, 2011). The Chaudes-Aigues hot water distribution constructed in the fourteenth century in France, which is still in operation to date, provides evidence of a successful DH system and is often cited by historians as the earliest example of DH (Gibert and Jaudin, 1999; Woods and Overgaard, 2015) However, the importance of a warm environment within the confines and security of a home was not understood until it began to be explored in the late 19th century (Boardman *et al.*, 2005; Geddes *et al.*, 2011). DH networks have been widely used in Scandinavia, Eastern Europe, Germany, South Korea, and major cities in the United States and Canada (Woods and Overgaard, 2015).

At the beginning of the 1800s, Robertson Buchanan, a Scottish engineer, described the possibility of using a single boiler power plant to heat several nearby buildings (Buchanan, 1807, 1810). In 1853, the American Naval Academy built the first DH system on its campus in Annapolis (Rezaie and Rosen, 2012). The Romans were known to transport heat around their buildings. Water from a variety of geothermal sources was used in thermal baths and to heat about 30 homes along the hot water supply path. The steam delivery systems, developed in the United States in the late 1870s, marked the beginning of modern district heating. The initial aim of steam systems was to provide steam to generate electricity in the connected buildings – this changed a decade after electricity networks started to emerge.

The founder of modern DH is regarded to be the American engineer Birdsill Holly, for his major involvement in the establishment of the first commercially viable DH system at Lockport, New York in 1877 (Austin, 2010). The New York City steam distribution system, which was the first cogeneration plant, i.e. a heat and electricity generating plant, also known as Combined Heat and Power (CHP), designed and built by Thomas Edison in 1882, is one of the world's largest DH networks in terms of supply capacity (Rezaie and Rosen, 2012; Woods and Overgaard, 2015). Steam DH systems also became popular in Europe and were developed in a number of major cities. However, hot water systems were discovered to have a range of advantages over steam systems, and they became the main choice for modern DH schemes. The early steam systems were maintained and, in some cases, expanded, but as the disadvantages of steam delivery which was higher heat loss due to the high temperature became more apparent, they were eventually converted into hot water systems, or were replaced in most cities. The waste heat from power stations was identified to be a valuable source of heat, new incinerators were built to address the waste disposal problem in Europe's rapidly growing cities and the waste heat was used to provide heat. The first Danish DH scheme became a reality in 1903, when the first waste incinerator in the Copenhagen area of Frederiksberg supplied heat to the nearby hospital (Woods and Overgaard, 2015). Bloom St in Manchester (UK) is another early example of DH. The power station, which was constructed in 1901, began supplying steam to local warehouses and factories in 1911. The steam supply continued to expand, delivering heat to buildings up to 1.5 kilometres away. Long after the power station was shut down, customer demand forced the continuation of steam supply (Woods and Overgaard, 2015). Despite the early use of DH in the UK it currently accounts for 2% of the domestic, public sector, and commercial buildings heat demand in the UK (DECC, 2015a; Colmenar-Santos *et al.*, 2016; ADE, 2018a; CMA, 2018). Canada's first DH system was constructed in the commercial hub of Winnipeg in 1924 (Marinova *et al.*, 2008).

Around 1900 it became increasingly popular in most developed economies to burn fuel to heat water or generate steam, which was then circulated throughout the building to supply radiators, known as central heating. This began with larger buildings and progressed to domestic buildings. With the widespread availability of natural gas in the United Kingdom in the 1970s, the use of individual boilers in each dwelling became the norm. Larger apartment buildings were originally designed with centralised boilers, which were initially powered by coal or oil, but many of these systems were later converted to individual gas boilers in each dwelling (DECC, 2013b; Woods and Overgaard, 2015).

The major expansion of DH on a large-scale in Europe began in the 1970s, when the price of oil, which was the main alternative heating fuel, increased rapidly as a result of the actions taken by the Organization of Petroleum Exporting Countries (OPEC). The oil crisis hit in 1973 and the price of a barrel of oil quadrupled. This left countries who were reliant on imported fuel in a very difficult situation. In the aftermath of this crisis, a switch from oil to coal in the power sector was an obvious option for countries with limited access to alternative fuels. Some countries started investing heavily in the development of DH in order to use the waste heat from power plants. At the time, Sweden had no access to natural gas, and Denmark had been reluctant to exploit its North Sea reserves. Both countries developed several of DH schemes, with Denmark emerging as Europe's leading DH country due to its change in energy policy which supports investment in renewable energy and DH - 40 years later, DH networks supply heat to 63% of its citizens. In the early 1980s, the Netherlands had a period of DH growth, but as natural gas prices fell, existing schemes ran into financial difficulties and new projects were no longer economically viable (Woods and Overgaard, 2015; Lake, Rezaie and Beyerlein, 2017; Buffa *et al.*, 2019).

Scandinavian countries are currently the leading users of district heating networks, with a range of countries making significant progress toward sustainable district heating networks (Lake, Rezaie and Beyerlein, 2017). DH development has taken very different paths across Europe because each European country has its own experience with access to energy resources, infrastructure availability, policy initiatives, energy taxation, and building standards. DH development was mostly in response to the need to increase primary energy efficiency and to reduce the reliance on imported fuels. Finland was heavily reliant on imported fuel (coal, oil, and liquefied natural gas -LNG) before it discovered that DH schemes could increase fuel efficiency and decided to build a strong DH industry within a few decades. Through DH, some countries have been able to use indigenous energy resources. Iceland, for example, discovered that its abundant geothermal resources could be effectively used to heat buildings through DH, which was identified by Winston Churchill during a visit to Reykjavik in 1942. Other countries discovered that DH was an effective way to utilize energy from municipal waste, which was a key factor for the development of DH networks in Germany, Switzerland, and Austria. Waste-to-energy has also played a role in northern Italian cities with DH networks, as well as in France, which has a small number of DH networks (Woods and Overgaard, 2015; Lake, Rezaie and Beyerlein, 2017; Buffa *et al.*, 2019).

The push for greater energy efficiency, as well as the shift from oil to coal in the power sector in some countries, caused combined heat and power generation (CHP) to be in high demand, and DH temperatures became critical to the overall efficiency of the cogeneration process. The DH sectors in Denmark, Sweden, Germany, and Finland, in particular, invested time and resources in DH research and development. Pre-insulated piping systems were first introduced in the 1960s, but they needed to be improved to become reliable and cost-effective for modern DH networks. As CHP supplied more heat to DH networks, finding the right balance between supply and return temperatures, network design and capacity, investment in production and distribution facilities and operational costs became more important. The heating systems of buildings connected to DH networks had a significant impact on the temperature and pressure requirement of the DH network. This changed over time, allowing DH utilities to supply heat at lower temperatures and the return of low temperatures from customers (Woods and Overgaard, 2015; Lake, Rezaie and Beyerlein, 2017; Buffa *et al.*, 2019).

The research and development on DH networks resulted in an increase in the overall energy efficiency of DH systems, as well as more efficient and cost-effective piping technology, enabling more schemes to be more financially viable. Lower temperatures not only allowed for more extensive use of CHP, but also allowed the use of renewable energy sources (Ratheal, 2013; UKDEA, 2014; Woods and Overgaard, 2015). Renewable heat sources are often available at low temperatures, and the use of solar thermal and geothermal heat in DH networks has increased in recent decades, which would not have been possible with higher temperature networks (DECC, 2013b; Woods and Overgaard, 2015; Statistics, 2018). Lower temperatures have also simplified and reduced the cost of heat storage, and the performance of the more recent seasonal heat stores, which are still in the early stages of development, is dependent on DH network supply temperatures far below 100 °C. The implementation of DH has been found to help reduce air pollution in some cities. In the 1950s, when air pollution from open coal fires was at an all-time high, this was a major driving force behind the construction of the Pimlico DH Utility in London (see below), which was supplied from Battersea power station. The replacement of oil-fired boilers with DH in cities such as Stockholm and Copenhagen have contributed to significant improvement in air quality (DECC, 2013b; Woods and Overgaard, 2015; Statistics, 2018).

Following the Rio summit on global warming in 1987, the advantages of DH in reducing CO_2 emissions have become increasingly evident, and governments recognized the need for emission reductions from both heat use and electricity generation which have been incorporated into the design of energy policy by policy makers. Consequently, DH networks have had a high profile in energy and climate policy in recent years to foster emission reduction, energy efficiency and transition to clean energy technologies. The UK developed extensive natural gas reserves in the North Sea since the 1970s and for the next 40 years, individual gas-fired boilers were the preferred heating method, with the gas grid expanding to meet the demand for heat. Gas-fired heating remained competitive with other heat sources, including off-peak electricity, which was mostly restricted to off-gas grid areas and high-rise apartment buildings. As a result, gas-fired heating accounts for 85% of total heat demand in the UK while DH only accounts for 2%. As demonstrated in Denmark, the capacity for DH systems to integrate flexibly with a wide variety of heat sources combined with effective thermal storage has resulted in recognition of the broader role that DH networks can play in managing intermittent wind energy on the electricity grid (DECC, 2013b; Woods and Overgaard, 2015; ADE, 2018b; Statistics, 2018). Russell (1986, 1993), provides a detailed analysis of the reasons why DH failed to establish a strong foothold in the UK. The dominance of centralized producer interests, the lifting of local authority power in the energy sector following post-war nationalisation, and a general lack of focus on the potential for end-use efficiencies are some of the factors identified by Russell's study. While there have been several attempts to develop the industry, government efforts were piecemeal, and DH lacked the required policy framework to compete with incumbent gas and electricity suppliers. Furthermore, Russell cites the prioritization of commercial interests in the energy sector as a barrier to the development of energy infrastructure to achieve a broader range of socially oriented goals at the local level.

The 20th century saw the development of new power plants further away from urban areas, as the distance between the power plants and urban areas increased, the supply of waste heat for district heating became economically less viable. Consequently, the focus began to shift towards the provision of individual heating systems for housing in Western countries as notable early 20th century architects such as Walter Gropius, Charles Rennie Macintosh, Le Corbusier, Ludwig Mies van der Rohe and Frank Lloyd Wright did not include district heating systems in their designs as they concentrated on individual energy systems in buildings (Sharp, 2002). In order to achieve a reliable standard, most district heating systems around the world require upgrades (i.e., retrofitting). Figure 5 illustrates the evolution of district heating systems, including their improved efficiency and heat source diversification. The future district heating standard is known as 'fourth-generation systems' and is the natural progression of an advanced third-generation network (UNEP, 2016).

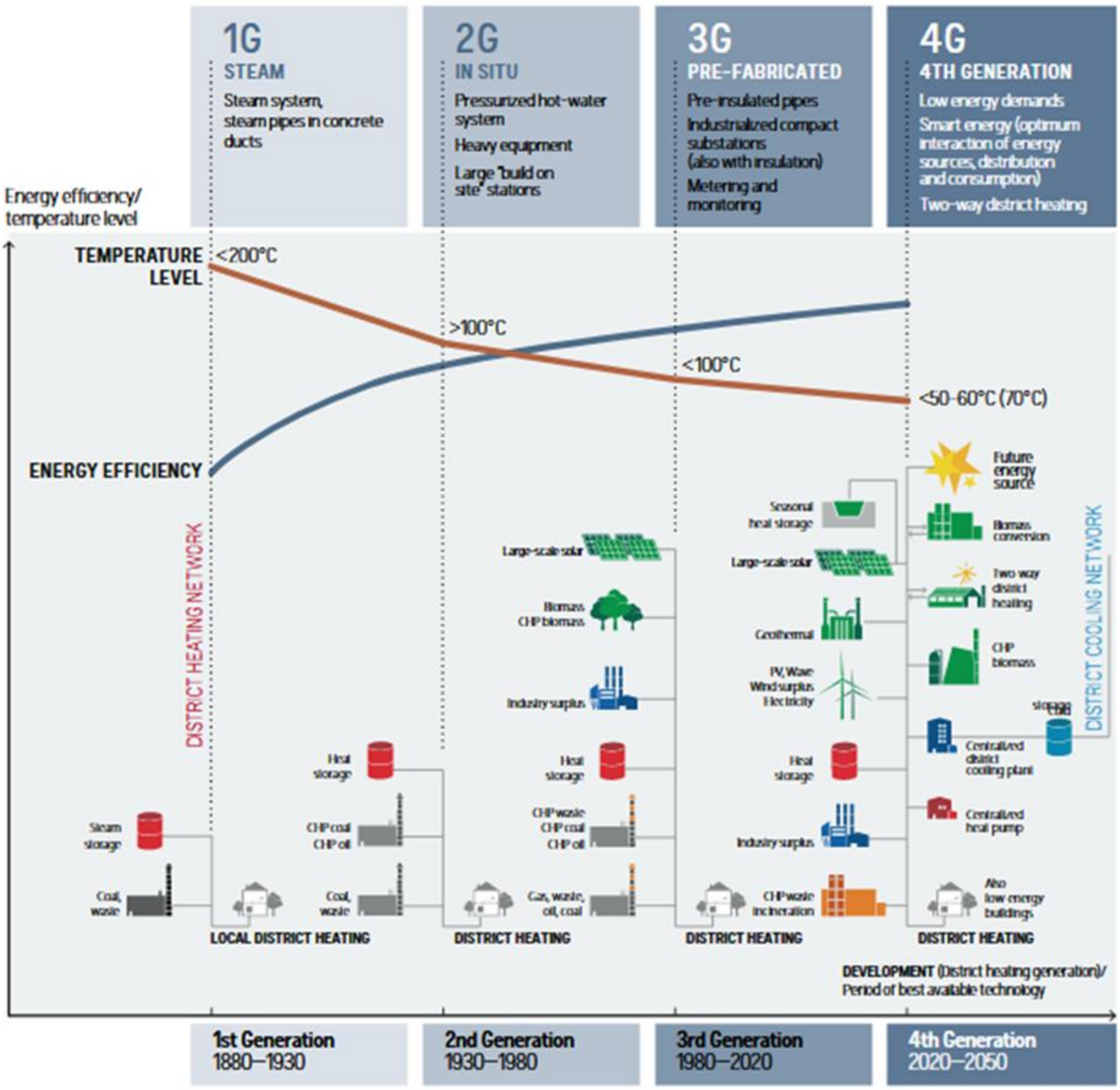


Figure 5:Evolution of district heating systems (Lund et al., 2014).

Fourth generation systems run at lower temperatures, resulting in lower heat losses compared to previous models, enabling connectivity to low-energy density areas such as those with low-energy buildings through the use of low-temperature heat sources integrated with the operation of smart energy systems with intelligent control of the heating of buildings and peak shaving (Lund et al., 2014). Various heat sources such as low-grade waste heat can be used by these systems and can also allow consumers to supply heat. Such systems are a cost-effective solution to build the flexibility required to integrate high share of variable renewable energy into the energy grid through heat storage, smart grids and flexible supply. Fourth-generation systems are closer to loading centres and generating plants than traditional central-stations. Also, the distributive design and scale of these systems make it possible to provide a more nodal and web-like architecture which improves grid access across multiple **points (UNEP, 2016; Lund et al., 2014).**

2.3.1. Heat Distribution

A modern heat network consists of a pair of pipes, flow and return, that are well-insulated. Pre-insulated pipe systems are often used in most situations, with the carrier pipe wrapped in polyurethane foam insulation and an exterior lining used for mechanical safety and to prevent ground water from entering the insulation. Since the 1970s, such pre-insulated pipe systems have been developed and will be manufactured and built-in compliance with European standards. The carrier pipe may be made of steel or plastic, with polybutylene and cross-linked polyethylene being common materials. Since the plastic carrier pipes are flexible, more flexible insulation is used (such as polyethylene foam). Because of their versatility, these pipes are easier to fit around obstructions in the ground or variations in ground level. Plastic pipe systems are typically used for smaller diameters, such as individual house connections (Woods and Overgaard, 2015; Lake, Rezaie and Beyerlein, 2017).

Where steel pre-insulated pipes are used, a monitoring device would be mounted to detect the presence of water in the insulation, which will raise the risk of external corrosion of the steel carrier pipe. The device will allow a fault to be identified and fixed before any damage to the carrier pipe occurs. DH networks are usually buried in the ground, in the same way as other utility services. As a result, regular inspections are not practical, and repairs are often very costly and expensive. This necessitates a very high technical standard of installation, both for the steel welding and the outer casing jointing at each stage where the pipes are connected. The network must be installed by trained and skilled heat network specialists, and inspections must be conducted at each stage of the process (Woods and Overgaard, 2015; Lake, Rezaie and Beyerlein, 2017). Heat is distributed through the network of insulated pipes, typically using hot water between 60°C and 90°C, steam can also be used where the heat is at a high temperature. The lifespan of DH infrastructure ranges between 40 and 70 years (Werner and Frederiksen, 2013).

Transmission pipes are used in large-scale networks to convey heat at high pressure and speed over longer distances, and distribution pipes are used to distribute heat directly to points of demand. Transmission pipes may have a diameter of up to 1.2m and are typically made of steel, depending on the heat demand. Heat loss is reduced in larger pipes due to the smaller surface area of the external pipe per cubic meter of hot water transported. The longest transmission pipeline in Europe spans a direct distance of more than 30 kilometres (Andrews *et al.*, 2012). Heat exchange units are used for transferring heat from transmission pipelines into local distribution networks, where smaller and less expensive pipes (which can be made of plastic for system temperatures that typically remain below 80°C) are used to supply to each point of demand, via another heat exchanger into a building's central heating and hot water system. Heat losses in networks are usually between 10 to 20%, but they can be much lower when the transportation distance is short, where the network supplies a densely populated area, and the heat source is close to the point of demand (Lund *et al.*, 2014; Wiltshire, Williams and Woods, 2014).

2.3.2. Thermal Energy Generating Units

A critical decision when designing a new DH network, is how to generate the thermal energy. The choice of thermal generating unit will impact the cost, reliability, security, and environmental performance of the network. The following sub sections describe the characteristics and considerations for each of the thermal generating units: Boilers, CHP, and heat pumps.

2.3.2.1. Combined Heat and Power and District Heating (CHP-DH) Technology

Combined heat and power (CHP) systems generate useful electricity and heat in the form of steam or hot water simultaneously (co-generation) from a single energy source in the same exothermic process, thereby providing economic, operational and environmental benefits (Ratheal, 2013; Weber, 2014). They are considered established and mature technologies, with the first applications reported at the beginning of the 20th century (Russell, 1986; Kelly and Pollitt, 2010). A key element of the cogeneration process is that it benefits from the collection and recycling of waste heat, which is normally discarded in the conventional cycle of electricity generation to provide additional "useful" energy (Ratheal, 2013).

CHP-DH is an integrated system of CHP plant connected to a DH network. The heat produced in the system is transported and distributed through the district heating network while the electricity is supplied by transmission and distribution to where it is required. It is one of the most cost-effective heat generation methods that has been proven to be successful in several countries (EPA, 2017). A key benefit of CHP is that it saves primary energy without undermining energy supply efficiency and reliability to consumers. Figure 6 provides a schematic diagram of separate and combined (simultaneous) generation of electricity and heat. The CHP system is seen to be less resource intensive, more efficient with an energy efficiency of 75% as opposed to 51% in conventional generation systems, thus providing greater energy security. Also, compared to separate energy systems, CHP-DH systems have stronger interconnections between production and distribution networks (EPA, 2017).

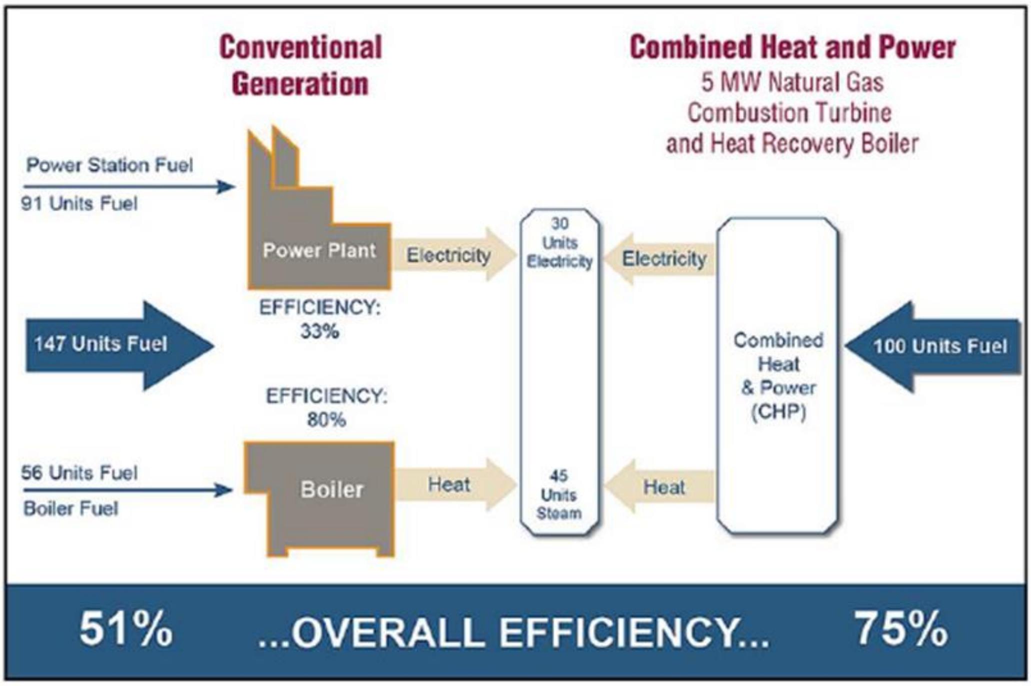


Figure 6: Comparison between the energy efficiency of CHP-DH systems and conventional central power generation systems and on-site boilers (EPA, 2017).

In this example of a typical CHP system, the conventional generation or separate heat and power systems require 147 units of energy to create 75 units of useful energy—91 for electricity production and 56 for heat production—resulting in an overall efficiency of 51%. The CHP system, on the other hand, requires only 100 units of energy to create the 75 units of useful energy from a single fuel source, resulting in a total system efficiency of 75% (EPA, 2017).

CHP is recognised by the European Parliament as a means to improve the efficiency of an energy system and to reduce carbon emissions (European Union, 2004). Energy efficiency can be improved by a well-designed CHP system to more than 80% (U.S. Department of Energy, 2000). The cogeneration plant in Hungary, for example, has an output of 81.5% based on fuel, which means 43.1% of electricity is generated from the fuel and 38.4% heat for district heating (Klimstra, 2008; Rezaie and Rosen, 2012).

Types of CHP Technologies

There are four major types of conventional CHP systems, which are widely recognised to be proven and well-established technologies developed over long periods of time and continually improved through incremental innovation (Kelly and Pollitt, 2010).

- **Steam turbines:** This uses diverse range of fuels to generate high-pressure steam for electricity, using excess steam as a source of heat supply.

- **Gas turbines:** They are often adapted from aerospace engines, where gas-oil or gas is combusted for the generation of electricity while the combustion gas is captured and used for the production of usable steam in the waste heat boiler.
- **Combined cycle systems:** This involves the use of more than one type of prime mover in the system, any combination of gas turbine, steam turbine and/or combustion engine may be used. It is primarily suitable for large installations and is characterised by a higher electrical efficiency and a lower heat-to-power ratio compared to turbine-based systems.
- **Reciprocating engine systems:** They are based on recycled automotive or marine engines that primarily use gas or diesel as a fuel source; they are smaller than the other three major types of CHP systems and are used in settings where hot water can be used for heating purposes rather than steam.

2.3.2.2. Boilers

Industrial, commercial, and institutional boilers are mainly designed to use the chemical energy in fuel to increase the temperature of water for use in process and heating applications. A wide range of fuels such as fossil fuels, biomass, biofuels, and municipal solid waste (MSW) can be used in boilers. Boilers are often used in combination with other thermal energy generating units, serving as a backup and peak load generator. It can be used for peaking (gas, coal, electricity) or base loading (wood chips, pellets, etc.) depending on the fuel source. As a result, boilers are known as peak shaving equipment. Boilers come in a variety of designs, including pulverized, low NOX, fluidized bed, and grate. Boilers can be used in CHP applications as fired heat-recovery systems, which use heat rejected from prime movers and other heat sources to generate more steam with less fuel. When used in this capacity they are referred to as waste heat-recovery boilers (Oland, 2004; Werner and Frederiksen, 2013; Raine, Sharifi and Swithenbank, 2014). Copenhagen, Helsinki and London DH networks all use boilers as a backup when baseload heat sources cannot meet peak demand.

2.3.2.3. Heat Pumps

Heat pumps operate by raising the temperature of heat, allowing for the use of low-temperature heat sources in a wider range of situations. Heat pumps require electricity to increase the temperature of the low-grade heat, so they're best used in areas with low electricity prices and associated CO_2 emissions to provide opportunities for increased energy efficiency, cost-effectiveness and low carbon heat generation (Werner and Frederiksen, 2013; DECC, 2016b). In the context of a low carbon electricity grid, integrating heat pumps into DH networks has the potential to deliver significant carbon savings compared to district heating based on either gas-CHP (for large schemes) or gas boilers (for small schemes). Heat pumps can be integrated into DH networks, the fuel source include ambient air, water, ground source heat, or waste heat from industrial processes. Low- or medium-temperature networks solely dependent on heat pumps have the greatest potential for CO_2 reduction (DECC, 2016b). The Katri Vala heat pump in HELSINKI generates 165,000 GWh of heat from the city's wastewater, making it one of the world's largest heat pump station (Connolly et al., 2014).

2.4. Heat Sources

DH networks can use a wide range of heat sources from industrial processes, geothermal heat recovery from abandoned coal mines, waste to heat energy and ocean or water source heat and they are also technology agnostic (Petersen and Energi, 2017). Making use of available low-carbon heat sources is critical for decarbonizing the heating sector. Unlike the choice of thermal generating units, DH networks may not have the option of selecting any heat source, as this is often determined by the available low carbon heat source in the geographical location. DH networks enable flexibility and security of supply that would not be possible without DH infrastructure. Due to the diversity and number of heat sources (see figure 7) that can be integrated with DH, the need to provide low-carbon heat has increased interest in DH (Connolly *et al.*, 2014; Bush *et al.*, 2017; Millar, Burnside and Yu, 2019).

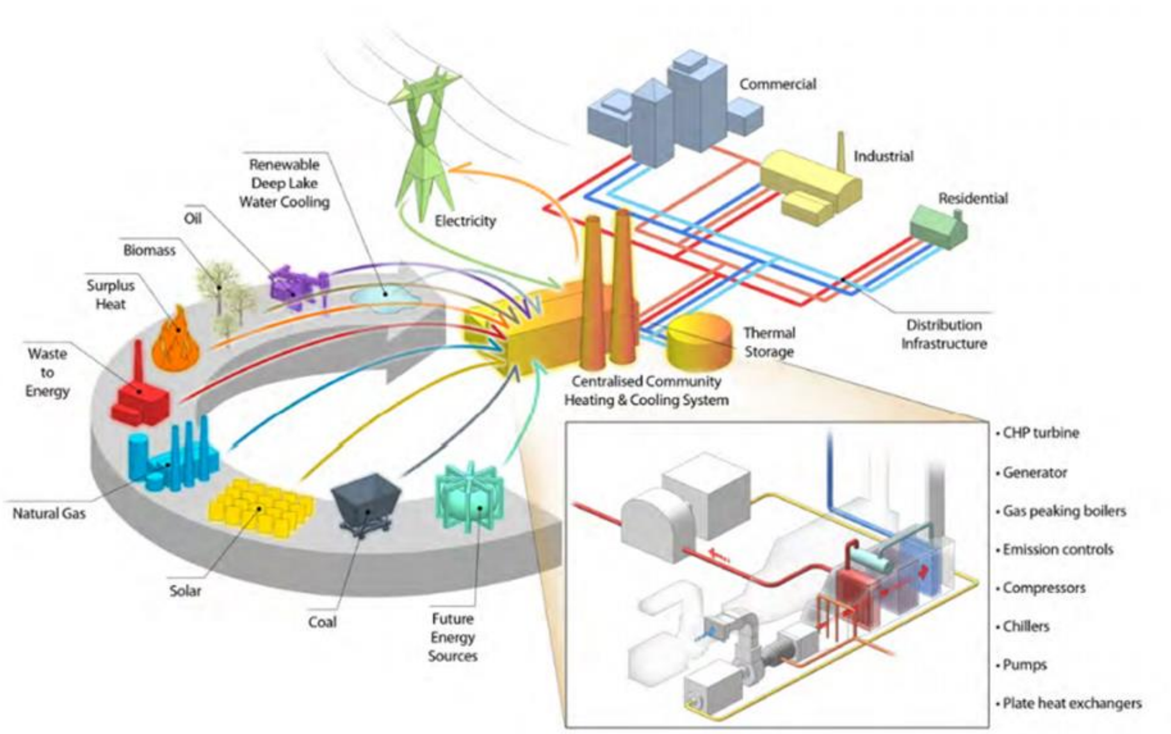


Figure 7:District Heating Heat Sources (DECC, 2015b)

Figure 7 shows the sources of heat that can be integrated with DH which are discussed in the following sub-sections.

2.4.1. Waste Heat Recovery

Waste heat recovery is the use of excess heat from low-grade heat from sewage or waste heat from industrial processes or power generation plants that could otherwise have been wasted or released into the atmosphere. Waste heat is a low carbon heat source that increases the economic and environmental performance of the industry providing the heat and the heat off taker (heat network operator). DH systems are the only low exergy technologies that enables the use of low-exergy waste heat in several cities. Low exergy (or Low Ex) systems are heating or cooling systems that enable the use of low-grade energy supplied by renewable energy sources (Hepbasli, 2012). Why is waste heat important?

- It saves carbon
- It maintains the strategic rationale for DH networks
- It can diversify local supply options
- It minimises the pressure on other decarbonisation pathways
- It maximises efficient use of resources
- It reduces energy system costs
- It enhances the energy performance of assets

Waste energy recycling increases the energy efficiency of a city in line with the concept of a circular economy (Pan et al., 2015; Petersen and Energi, 2017). The circular economy concept seeks to achieve resource-use efficiency through the practices of reduce, reuse, recycle and recovery in order to reduce the demand of fossil fuels (Pan *et al.*, 2015; Zamparas, 2021). Waste heat can be recovered using various technologies at different temperature ranges. The use of waste heat provides benefits such as lower heat costs, lower fuel consumption, and increased energy efficiency. However, it requires consideration of how to price waste heat. There is often a commercial agreement between the industry providing the heat and the off taker known as the "Heat Offtake Agreement" which contains information regarding the heat supply (Hammond and Norman, 2014; NLWA, 2016).

Local industries supply a considerable proportion of heat to several large-scale DH schemes, using heat that would otherwise be wasted. High-temperature processes, such as cement manufacturing and oil refining are common heat providers for example in Aalborg and Gothenburg, respectively.

Although similar opportunities exist on a smaller scale, basing a DH scheme on a single industrial waste heat source may be commercially risky. Back up boilers may be required, as waste heat supply may not guarantee the satisfaction of demand needs. The Southeast False Creek Neighbourhood Energy Utility Demonstration Project in Vancouver provides district heating to about 7,000 residential units, with raw wastewater accounting for 70% of heating energy. In London heat exchangers and a heat pump have been installed to capture waste heat from the underground metro system in Islington, UK to supply excess heat to the local district heating network for 454 homes (Woods and Overgaard, 2015; Galindo Fernández *et al.*, 2016) Other examples of waste heat recovery include; Excess heat from Copenhagen Fur mink coat storage in Copenhagen supplies heat to multiple DH network companies in Greater Copenhagen. Heat extraction from the wastewater treatment plant using heat pumps in Gothenburg, Sweden. Open District Heating in Stockholm, Sweden. See figure 8 for an illustration of open district heating (Petersen and Energi, 2017).

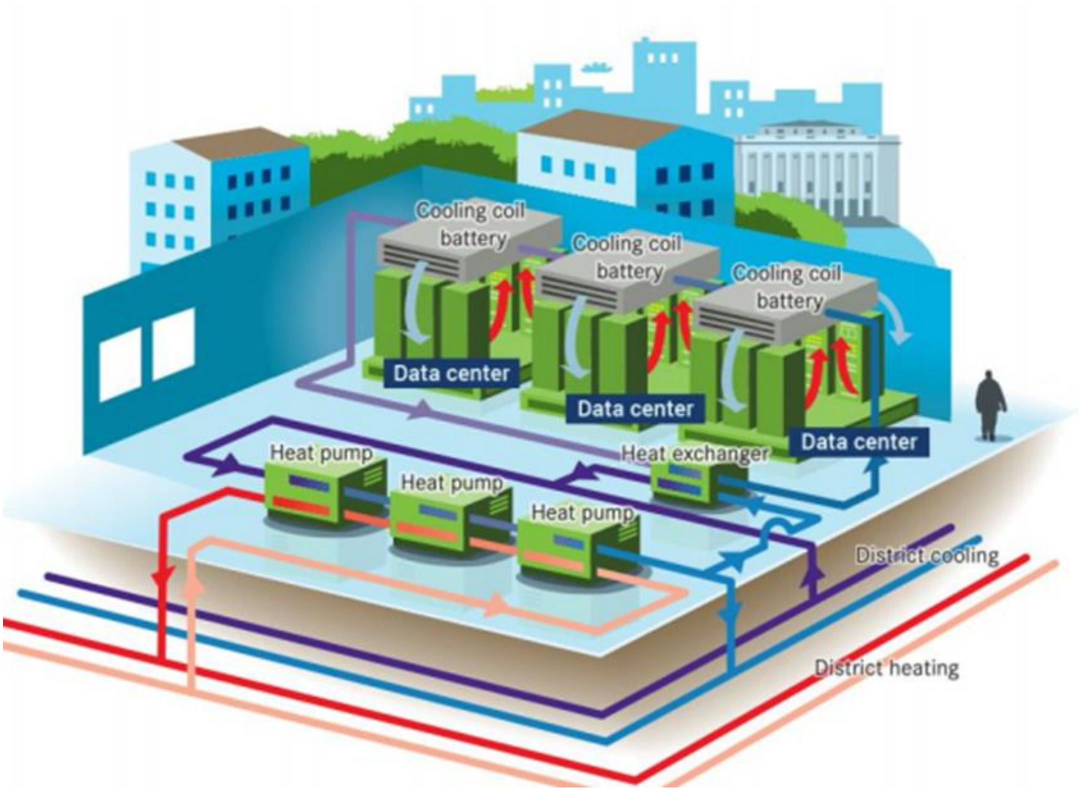


Figure 8:Open district heating (Petersen and Energi, 2017).

Open District heating is a unique model that enables data centres, supermarkets, industries and other businesses to sell their excess heat at an open market. More than 30 data centres in Stockholm are currently connected to the district heating and cooling networks (Petersen and Energi, 2017).

2.4.2. Waste to Energy

Waste-to-energy (WtE) or energy-from-waste (EfW) is the process of converting waste into a useful form of energy fuel source such as electricity, heat or transport fuels (e.g. diesel). This process involves burning waste to generate heat, usually municipal solid waste (MSW) which can be achieved in a variety of ways, the most common method is incineration. WtE is a source of low-carbon, renewable fuel that eliminates the environmental effects of landfilling. As shown in figure 9 the Waste Hierarchy outlines a five-step approach for managing waste and WtE should only be considered in the recovery stage if the waste cannot be reduced, reused, or recycled.

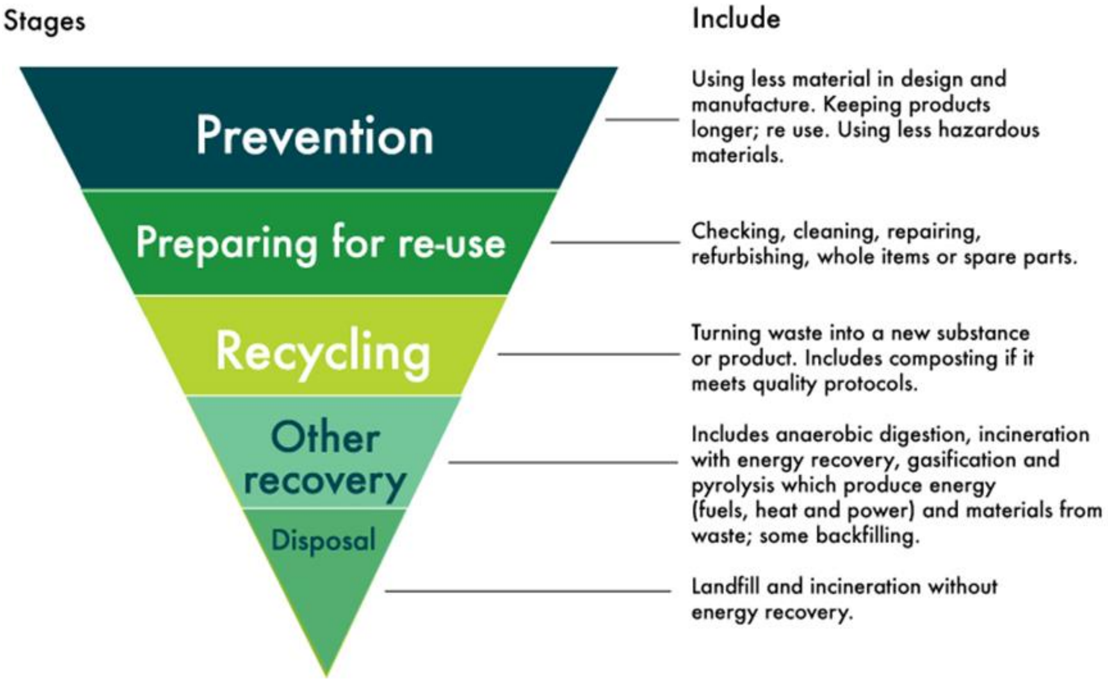


Figure 9:Waste hierarchy (Fox, 2017)

Waste to energy requires strict monitoring and control of the WTE plants due to the emissions of hazardous pollutants and by-products including dioxins. As a result, it may have potential health impacts if it is not properly managed (Finney, Sharifi, *et al.*, 2012; DEFRA, 2014; Zorpas *et al.*, 2015; Lake, Rezaie and Beyerlein, 2017). Due to the high cost of transporting waste, DH schemes are often supplied with energy from waste plants close to cities, for example DH schemes in Vienna, Copenhagen, Sheffield, Nottingham and Coventry). These waste-to-energy plants are designed to provide baseload heat to the network, so they will need to operate continuously throughout the year. Economisers have been used to capture low-grade heat from flue gases in waste-to-energy technology developments. DH economisers are also used in coal-fired combined cycle gas turbine (CCGT) CHP plants (Woods and Overgaard, 2015). Waste incinerators generate very low-cost heat which often contributes to the development of district heating network in cities. Some waste incinerators generate electricity and heat for the DH network. Also, the residual waste (bottom ash / slaughter) can be used for construction purposes, and it will no longer generate methane (Galindo Fernández *et al.*, 2016).

2.4.3. Fossil Fuel

Fossil fuel is a finite energy source, comprising coal, oil and natural gas formed from the remains of decayed plants and animals that were exposed to heat and pressure from geological processes hundreds of million years ago. Fossil fuels have a high calorific value which makes them an efficient fuel source with the capacity to deliver optimum energy (Berner, 2003). The heat sector has the highest share of carbon emissions globally, due to the fact that heat is majorly derived from fossil fuel (IEA, 2017). The use of fossil fuel produces large amounts of carbon emissions responsible for climate change (Seneviratne *et al.*, 2018). Although, fossil fuels have poor environmental performance, they are cheap and simple to combust for energy (Werner and Frederiksen, 2013). Gas CHP has been widely used in several successful DH schemes. While the use of fossil fuels in DH networks produces less carbon emissions and can be more cost effective for customers compared to individual building level alternative solutions (individual gas boilers), DH networks powered by gas will not be regarded as a low carbon solution, as it still contributes to carbon emissions (Raine, Sharifi and Swithenbank, 2014).

2.4.4. Renewable Energy Sources

Renewable energy sources include wind, solar and geothermal energy. The continued interest of the scientific community for research and development towards clean energy technologies to aid the transition to more sustainable forms of energy from renewable energy fuel has led to their increased integration with DH networks. Renewable fuels are carbon free sources of energy (Zecca and Chiari, 2010; Das Gupta, 2013; Werner and Frederiksen, 2013).

Wind and Solar Energy: Wind and solar provide low temperature heat which can be used as an energy input for DH using a heat pump. However, they are weather dependent which may make it unreliable and inefficient in delivering a high-capacity energy supply at all times. Problems arise as a result of the variable generation cycles of wind and solar energy sources. This is one of the reasons why energy storage technology is becoming a critical part of energy systems to ensure the delivery of reliable energy from renewables (Olsthoorn, Haghighat and Mirzaei, 2016; Electricity North West, 2017). Large scale solar thermal DH schemes have been implemented in a number of Danish schemes. It is less expensive to install a large scale solar thermal system than a small one in individual buildings, and it could be a reliable heat supply source for a DH network when integrated with inter-seasonal storage.

However, the cost and land area required to install the collectors is still significant (Woods and Overgaard, 2015).

Geothermal Heat: Geothermal heat can be sourced from saline water (brine) from underground reservoirs or mine water geothermal heat recovery from abandoned coal mines though heat pumps and heat exchangers. Geothermal source mine energy could range from 14^0C to 40^0C, and it is compatible with district DH networks, with no inter-seasonal variation in the source temperature of the mine water. Such that the coefficient of performance of any DH network technology feeding into it remains constant (Adams and Gluyas, 2019; Coal Authority, 2020). The Coefficient of Performance (CoP) is a ratio that defines a system's efficiency. It is based on the relationship between the amount of energy (kW) input to a system and the amount of energy output. CoP is defined as power output / power input. The greater number, the more efficient the system (Dincer and Rosen, 2021). There are cheap and plentiful geothermal sources in some parts of the world that can be extracted with minimal environmental impact, for example Iceland's high percentage of 92% DH supplies to its citizens can be attributed to the abundance of readily available near-surface geothermal resources (Andrews *et al.*, 2012). Geothermal heat is suitable for the supply of baseload heat demand, it has low running cost, and it is a source of free fuel. However, there is a potential uncertainty of available resources until wells have been drilled. While it is a renewable heat source with a low environmental impact, drilling boreholes is expensive and risky, and it may be too expensive to drill the boreholes and finance a heat network. It could, however, be used as a baseload heat supply for existing networks. (Euroheat & Power, 2015; Woods and Overgaard, 2015; Colmenar-Santos *et al.*, 2016).

The UK is looking to explore opportunities to repurpose its abandoned coal mines to recover mine water heat for use in heat network to heat buildings in the surrounding areas. The mine water project in Heerlen, Netherlands, which began operation in October 2008, uses mine water to power a low-temperature DH network, is an example of an operational mine water heat recovery project (Verhoeven *et al.*, 2014).

Biomass: Biomass is a renewable energy source generated from burning organic materials made up of plants, animals, wood, crops and household waste for central heating and hot water boilers. However, the use of biomass fuel raises concerns due to the fuel over food production debate and their transportation. Biomass can be used in boilers to provide renewable and carbon-free energy provided that the biomass is sustainably sourced and the economic, ecological, and social impacts are considered in the fuel chain (Eriksson *et al.*, 2007; Li *et al.*, 2012).

2.5. Heat Demand

The heat demand profile of a DH network is just as important as the heat supply and distribution. Technically, a network is most effective when the heat demand profile is consistent, with few peaks and troughs. This is accomplished by connecting a variety of consumers ranging from residential households to commercial shops and offices, as well as larger and more consistent heat users such as hotel, schools, hospitals and swimming pools (Bush *et al.*, 2017). The location of heat demand is also significant economically. The high capital costs of a network are reduced by connecting to high heat demand density areas. When heat demand becomes less dense, the network's capital costs can prevent heat supply from being financially viable (for example, in rural or suburban detached domestic household areas). The investment risk associated with high upfront capital cost and long payback periods can be minimised by securing long term heat supply contracts with key anchor load customers (preferably 10-20 years as investment recovery relies on long term stability of supply to customers). Anchor load customers are typically large industrial and commercial heat consumers, such as manufacturing companies, universities, shopping malls, or hospitals, but they can also be secured with a large number of domestic connections, such as new-build housing developments. DH consumers are typically paid for their heat supply in two ways: (1) by a set-standing fee that covers the network's capital and maintenance costs, and (2) each unit of heat used by the consumer is measured with a heat meter with a variable price based on the price of heat supply to the network (Bush *et al.*, 2017).

Retrofitting existing buildings to improve energy performance and sustainability includes upgrades to a property to improve energy efficiency, reduce energy demand and the encourages the use of low-carbon technologies (Swan *et al.*, 2013). Energy efficiency is clearly an important advantage in the use of DH, DH systems must be well designed to reduce heat losses from the distribution networks in order to ensure DH continues to be an effective solution for buildings. Similarly, addressing inefficiency in buildings by retrofitting existing buildings is an essential pre-requisite for the deployment of district heating systems. It is important to note that energy efficiency and fabric performance of buildings is outside the scope of this research, as these are addressed through related but different activities.

2.6. District Heating Development and Delivery

DH is made up of many different components. It is unusual for a single organization to be responsible for the design, installation, management, and operation of the DH network, as well as the buildings that will be connected to it and the heat supply sources. An efficient DH network is characterised by the numerous organisations involved having a thorough understanding of all aspects of DH, ensuring that each component of the network is designed and managed to deliver optimum efficiency and performance. This can be accomplished through well-designed implementation plan, contracts, policies, regulations, financial instruments, fair pricing, consumer protection, business model, ownership and management structure and technical standards, but it is more likely to be accomplished through collaboration within a shared culture of expertise, experience, and ideas, which takes time to develop across the different sectors, industries and commercial organizations involved (Lake, Rezaie and Beyerlein, 2017). The implementation of efficient DH networks often requires collaborations between the private and public sector. Therefore, active participation between the following key private and public stakeholders is required-

- DH operators: Heat networks are managed by heat operators, who may engage contractors to undertake operations, maintenance, repair, metering or billing services.
- manufacturing and industrial organisations: They supply surplus/waste heat to local DH schemes
- local authorities: local authorities act as intermediaries, educating local stakeholders about the significance of DH and establishing the social networks necessary for the successful delivery of DH projects.
- Central government: central government establish the overall heat policy, the overarching framework of requirements, and appropriate incentive mechanisms
- Local authorities: local authorities act as intermediaries, educating local stakeholders about the significance of DH and establishing the social networks necessary for the successful delivery of DH projects.
- Planning authorities: play an important role in identifying the potential for new and extended heat networks bringing together potential heat customers of mixed used development, and residential environments at sufficiently high densities to help underpin the viability of networks
- Policy makers: the role of policy makers is to formulate policies that will drive/support the implementation of heat networks.
- Property developers: Property developers can play a key role in including heat network infrastructure in their projects and, where possible, connect to existing networks.

(Lake, Rezaie and Beyerlein, 2017; BEIS, 2019b; ADE, 2020).

They all need to be actively involved in the planning, coordination, leadership, implementation, and management of DH systems. This is important and useful for establishing interdependencies and aligning interests in order to develop effective policy instruments, incentives, energy flows, strategies, processes and structures that will drive the successful implementation, integration and operation of DH networks (Lake, Rezaie and Beyerlein, 2017; BEIS, 2019b; ADE, 2020). The implementation of DH networks requires the consideration of several social, technical, and organisational mechanisms. The analysis of these sociotechnical mechanisms will provide an understanding of (Lake, Rezaie and Beyerlein, 2017):

- How heat planning, technical standards, regulation, and policy intervention can influence the successful implementation of a heat network.
- The role of various stakeholders and how they interact with each other.
- How the DH development decision-making process can influence the design and implementation of DH networks

The following sub sections discusses the functional aspects of DH which are important to consider in the implementation of a heat network.

2.6.1. The Role of Actors

Actors are parties with a vested interest in the success of a DH network and they may be local, regional, or national (Hawkey, Webb and Winskel, 2013). Local actors include local authorities (LAs), customers especially those who can serve as anchor loads, energy companies, developers, and community organisations who may have a specific interest in reducing local emissions, increasing energy efficiency or addressing fuel poverty (Hawkey, 2009, 2012). National actors include the national government, which has the authority to intervene in national policy and investment and energy regulators. There is currently no regulator for the heat sector in UK. However, the Association of Decentralised Energy (ADE) aims to eliminate national barriers to development and implementation of DH networks(BEIS, 2019b; ADE, 2020).

LAs are key local actors in the development of DH networks. LAs have a unique position to foster DH networks in their various capacities as planners, regulators, facilitators of finance, role models, advocates, large energy consumers, and infrastructure and services providers (such as housing, energy, transport, waste collection and wastewater treatment). They have a significant role to play in the delivery of a smarter local energy system for various reasons which could manifest in different ways; good knowledge of the area, facilitating engagement with residents and stakeholders across the city, established network contacts and communication channels, access to information about energy consumption, access to cheap loans, strategic development, and long-term planning as well as reputation, confidence, and trust for local authorities. They can also undertake a wide range of useful functions, which include initial impetus, local data, the planning policy for locating new customers and the use of local authorities' buildings for anchor loads see figure 10 (Webb, 2015).

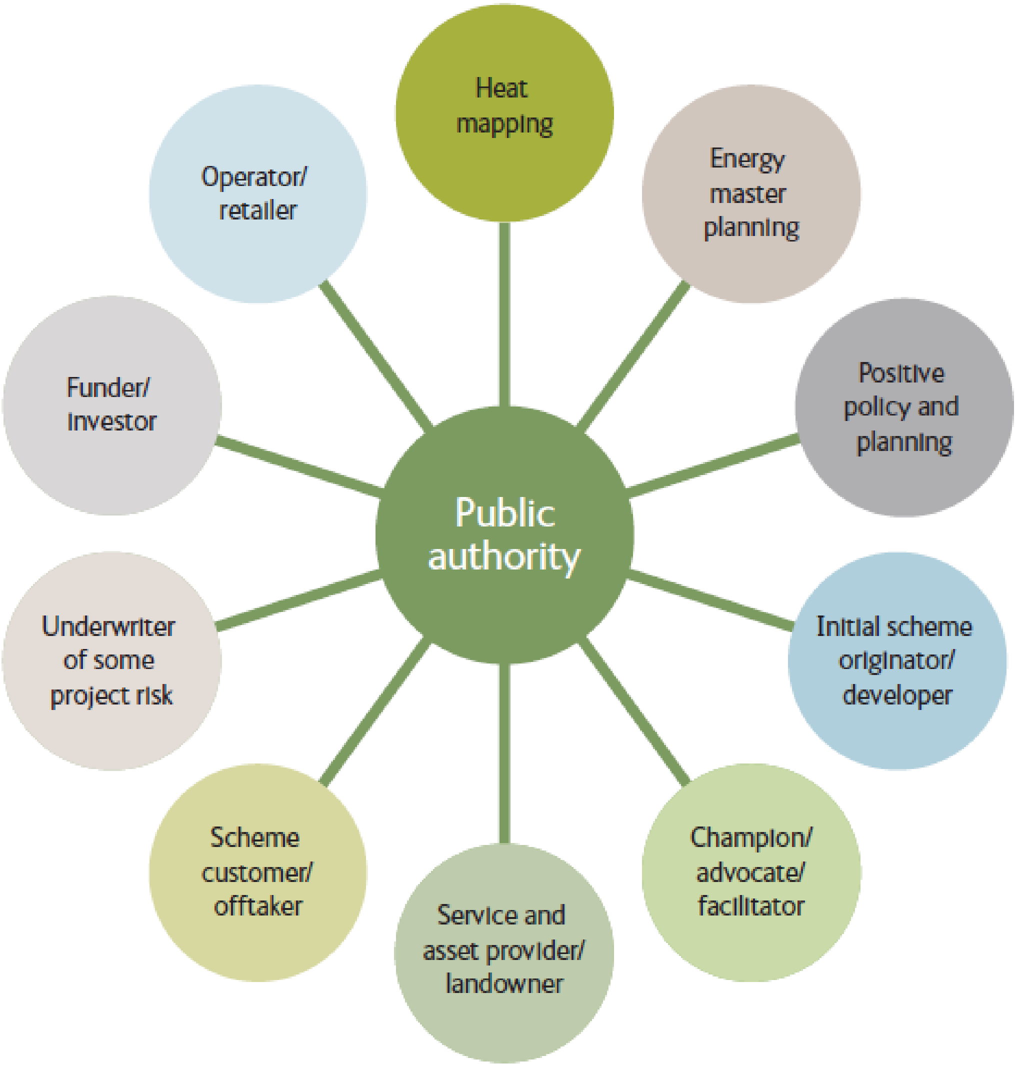


Figure 10: Roles of public authorities (Green Investment Bank, 2015).

Until after the Second World War, local authorities in the UK had their own power generation station, its own gas generating stations. This was nationalised, and many of those skills were lost due to a lack of demand at the local level were re-distributed at the national level. LAs also have limited financial autonomy and have complex relationship with the national government. While local authorities have been pushed away from providing energy services, limiting their ability to plan, and operate a DH network, DH development will need to involve local authorities in some shape or form because they understand the area, they know their plans for development and regeneration, as well as the opportunities that exists and they have their own targets and plans on how they intend to decarbonise their cities (Russell, 1986, 1993; Webb, 2015).

The policy options available to cities are often influenced by the national policy frameworks and the nature and extent of the devolution of power in their energy sector. Cities have the potential to influence planning policy and local regulations to promote and accelerate DH through vision and target setting; integrated energy, land-use and infrastructure planning and mapping; connection policies; and waste-to-energy mandates. The case study cities have specific DH targets, either arising from or related to wider energy targets such as energy efficiency, carbon emissions, fossil fuel usage and energy intensity. Integrated energy planning and mapping is a best practice approach to identify synergies and opportunities for cost-effective DH systems and to develop tailored policies or financial incentives in different areas of the city supported by a designated co-ordination unit or public-private partnerships. Through such policies, the Greater London Authority plans to invest £8 billion in district energy by 2030. In 2012, the city's integrated energy and land-use planning policy resulted in an investment of £133 million in heat network infrastructure (Galindo Fernández *et al.*, 2016).

2.6.2. Customer Relations

Customers will be an important part of any modern DH scheme, as they are in any industry. According to several surveys, utility companies are among the least common groups in terms of customer satisfaction (Finney, Chen, *et al.*, 2012; CIBSE and ADE, 2020). DH could suffer as a result of being perceived as too costly or restrictive. This was especially true of older networks, which were installed with minimal usage monitoring controls and no metering. In these situations, an individual boiler can be seen as a desirable alternative that gives the consumer more control.

A modern DH network can provide customers a high degree of control, including time control and room-by-room temperature setting, as well as individual metering and a selection of payment options. The DH company can provide regular updates on the operation of the network, as well as notice of any scheduled interruptions and a prompt response to any technical issues through a 24/7 customer helpline. Details on the scheme's environmental benefits, often expressed as the carbon content of the heat supplied, as well as details of the environmental performance can be provided (Finney, Chen, *et al.*, 2012; CIBSE and ADE, 2020).

Customers may dispute DH charges for heat, based on a direct comparison to the cost of heat from a gas boiler. This may reveal that DH prices are higher. However, a true comparison would take into account the capital cost of boiler, repairs/replacement and maintenance over a long period of time. DH will usually be found to be more cost-effective on this basis (Finney, Chen, *et al.*, 2012; Woods and Overgaard, 2015; CIBSE and ADE, 2020).

2.6.3. Heat Decarbonisation Policies

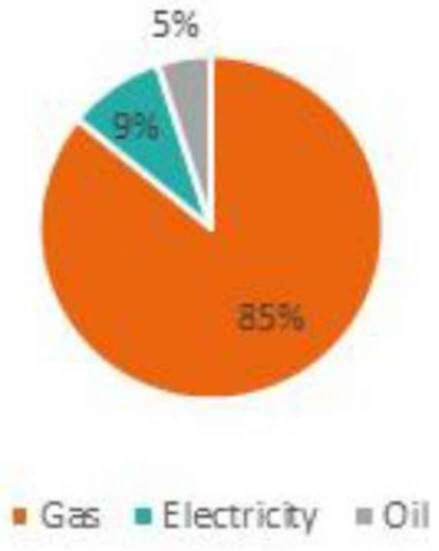
Due to the adoption of various net zero emission reduction targets in several countries, decarbonising the heating of homes, and the broader housing stock, is one of the key challenges confronted by climate change mitigation policy makers (Le Quéré *et al.*, 2018; BEIS, 2018a; Bridge *et al.*, 2013; IEA, 2015, 2017). The scale of the heat decarbonisation challenge in Europe varies greatly, with some countries almost entirely dependent on fossil fuels for heat, such as the UK, the Netherlands, and Germany, and others, such as Norway and Sweden where fossil fuels currently play only a minimal role. In countries that continue to rely on fossil fuel heating, the potential mix of low-carbon technology is often unclear (Le Quéré *et al.*, 2018; BEIS, 2018a; Bridge *et al.*, 2013; IEA, 2015, 2017). However, given the magnitude of the problem, substantial progress toward decarbonisation must be made in the coming years. Decisions about how government policy will best promote the transition must be made, with the policy mechanisms that bring about the change, such as subsidies, energy taxes, and regulations, likely to be subject to public and political scrutiny. It is important to phase out fossil fuel heating which include boilers powered by the mains gas grid, standalone boilers powered by gasoline, liquid petroleum gas, or solid fuels such as coal, and the fossil-fuelled systems in DH networks (Kerr and Winskel, 2021).

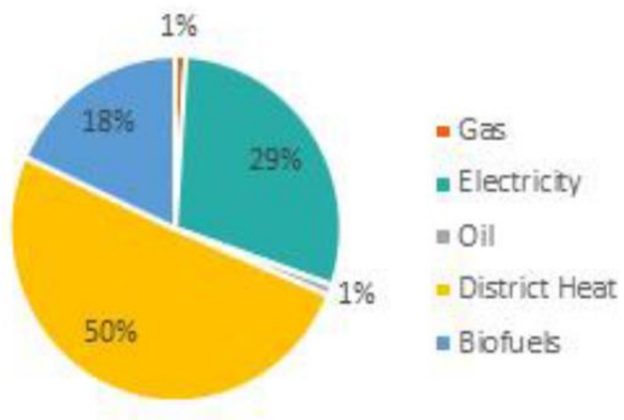
The policy mix in many countries has seen a rise in the ban on the use of fossil alongside more developed incentives for low carbon initiatives. Since the early 2010s, Norway and Denmark have banned oil heating in new buildings, and the prohibitions have since been expanded to include all new fossil fuel heating in new Norwegian buildings, as well as any substitution of oil heating technology in existing buildings in Danish "collective heat zones." Norway has also recently prohibited the use of oil heating. In the Netherlands, Ireland, and the UK, bans on fossil fuel heating in new building is set to be implemented in the early 2020s (Kerr and Winskel, 2021).

Policies are one of the factors that have contributed to the success of DH networks and government policy has been used to change the way heat is delivered. Central government establish the overall heat policy, the overarching framework of requirements, and appropriate incentive mechanisms This can include government support for DH research and development because of its potential to decarbonise heat, as well as high taxes on the use of fossil fuels (Lake, Rezaie and Beyerlein, 2017). Buildings are heated in a variety of ways across Europe, these disparities, which have accumulated over decades, represent specific national resource endowments, economic resources, and technological infrastructures. They also represent various governance strategies and policy instruments (Kerr and Winskel, 2021; Lake, Rezaie and Beyerlein, 2017).

Denmark, Finland and Sweden are three leading countries that have been largely successful in the large scale implementation of DH networks which have contributed in the reduction of carbon emissions in their heating sectors (Kerr and Winskel, 2021; Lake, Rezaie and Beyerlein, 2017; Kelly and Pollitt, 2010; Wissner, 2014). DH accounts for between a third and half of domestic heating in Scandinavian countries, although diminishing, fossil fuels still provide a significant share of DH supply in Finland and Denmark (see figure 11). In countries such as Sweden and Finland, biomass is the main source of low-carbon DH. This is because they have a larger reserve of biomass resources, and there will be much competition to decarbonise heat for countries with limited biomass resources (Kerr and Winskel, 2021; Lake, Rezaie and Beyerlein, 2017).

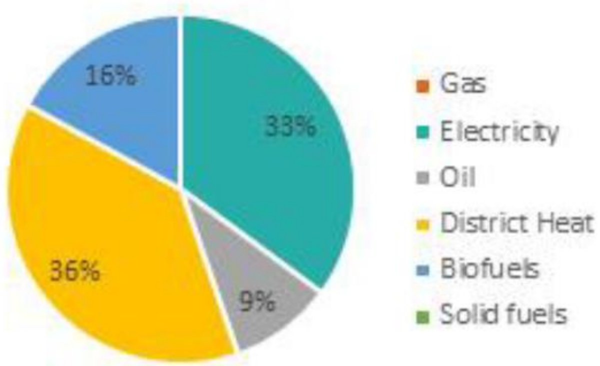
Subsidies such as grants, loans or tax credits are used to incentivise the adoption of low carbon technologies. In Germany, France, and Scotland, low-interest loans for low-carbon heating are available for the purchase of low carbon technologies such as heat pumps, solar thermal and biomass boilers. Prior to the introduction of the Green Homes Grant scheme – the UK was the only country that subsidized the generation of renewable heat rather than the upfront costs of the technology through the Renewable Heat Incentive (RHI) (Kerr and Winskel, 2021). Figure 11 shows the Heating type used in residential buildings in the UK, Sweden, Finland and Denmark.

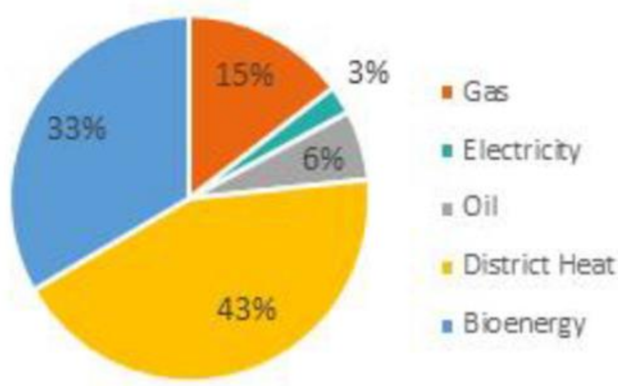




UK (Kerr and Winskel, 2021).

Sweden (Swedish Energy Agency, 2018).





Finland (Fleiter *et al.*, 2017). Denmark (DEA, 2020).

Figure 11:Heating type used in residential buildings in the UK, Sweden, Finland and Denmark

The relative levels of fuel taxation are a critical component of overall heat decarbonisation policy. The UK has one of the lowest tax rates on the use of domestic natural gas (see table 1). While this low level is regarded as a way of address fuel poverty, it has been identified to be a contributory factor to the challenges faced with heat decarbonisation in the UK. The gap between gas and electricity tax levies is becoming increasingly dissimilar in a context where electrification of heating is viewed as a critical means of decarbonising heat in the UK (HM Government, 2021b). Domestic electricity use is taxed at a relatively high rate, which has been linked to high fuel poverty rates in Scottish homes with electric heating. Denmark's targeted approach offers a model that cuts electricity tax by half when used for heating. High tax rates on electricity in comparison to fossil fuels have been identified as a barrier to heat decarbonization in the United Kingdom and Germany (IEA, 2020). In this context, achieving ambitious policy goals for heat decarbonisation and fuel poverty would almost certainly necessitate the reform of energy and fuel direct tax rates, as well as contributions from general taxes such as income tax (Kerr and Winskel, 2021). Table 1 shows the carbon intensity and tax on residential energy use in selected countries.

Table 1:Carbon intensity and taxation of residential heating in selected countries (Kerr and Winskel, 2021).

Country	Carbon intensity of residential heating (2015) (gCO_2/kWh)	Carbon intensity of electricity (2017) (gCO_2/kWh)	Overall tax on residential energy use (%)*			
			Gas	Oil	Electricity	Biomass
UK	185	268	5	24	22	5
Netherlands	200	452	54	63	26	/
Norway	/ **	19	/	45	36	0
Sweden	29	9	45	/	39	/
Finland	95	83	43	45	33	0***
Denmark	118	147	56	50	35****	0
France	100	67	24	34	36	0
Germany	200	419	24	25	54	/
Ireland	254	393	17	29	12	/

Considering the current concerns on energy efficiency, security of supply, sustainability and climate change, policies that support emission reductions should be prioritised along with incentives to intensify DH supply from low carbon heat sources. DH networks offer a potential solution and should be given careful consideration when developing policies (Kelly and Pollitt, 2010; Wissner, 2014).

2.6.4. Heat Planning and Regulation

Since the implementation of a heat network requires significant resources, the economic case is premised on acquiring large heat demand users that will act as key anchor loads for the DH network. A range of regulatory frameworks and strategies have been put forward by various national governments to support DH, such as connection requirements, consent regimes, heat mapping, price regulation, mandating DH planning to local areas, consumer protection, financial instruments regulatory means or market forces such as high taxes on alternative heating legislation (Woods and Overgaard, 2015; Bush *et al.*, 2017). The supply of DH is typically processed through a closed system which involves heat generation, heat distribution through a local network of piped grid, and an end-user heating system. Regulation can either be directed exclusively at the distribution grids or at the entire DH system. DH system have been regulated in various ways in different countries. Figure 11 shows starting points for the regulation of a district heating system (Wissner, 2014).

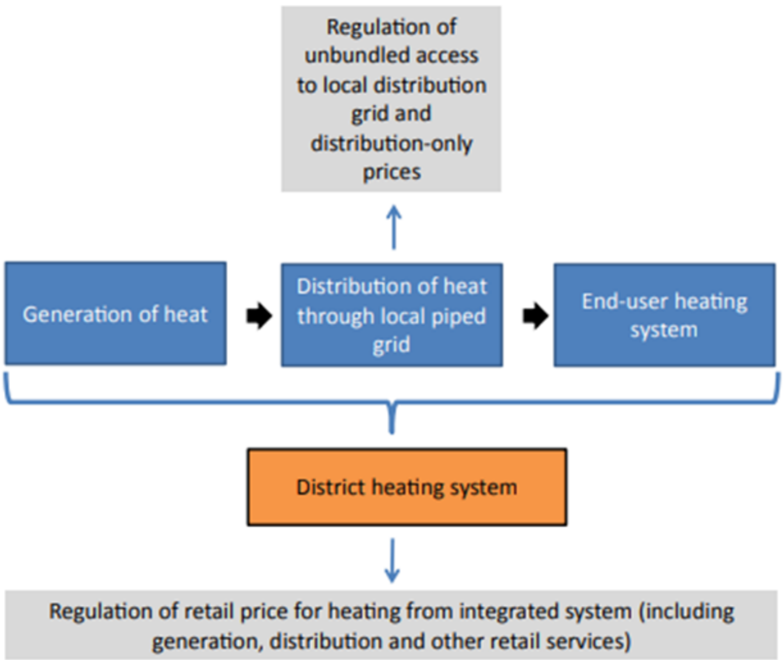


Figure 12: shows starting points for the regulation of a district heating system (Wissner, 2014).

To ensure that DH is implemented in the most appropriate locations, some local authorities conduct heat mapping to identify which parts of the city will be economically viable for DH and which areas will require alternate heating systems. This is the basis of the Danish heat planning legislation (Woods and Overgaard, 2015; Bush *et al.*, 2017). Since its adoption in 1979, Denmark's district heating networks have been largely regulated by the Heat Supply Act which mandates all local authorities to designate DH and natural gas zones. Heat prices were also directly priced to the cost base of developing the infrastructure, rendering it a not-for-profit public-sector operation. The Heat Supply Act places statutory obligations on municipal authorities to develop local energy plans which identified the locations of significant heat demand. Municipalities were also given the power to compel buildings located in DH zones to connect. Several local councils (1980-1995) utilized the power provided by the Act at the beginning, however, it is hardly ever used anymore, as DH has become increasingly competitive. DH companies in Denmark regulated by the Heat Supply Act are not-for-profit. The return on invested capital is limited to 7-8% and only the actual cost of production and delivery to the consumer can be included in the price of heat. The key justification for this is to optimise efficiency in the interests of customers (Bolton and Foxon, 2013; Galindo Fernández *et al.*, 2016). However, the zoning system which mandates DH connection and supply in a given area is often criticized, because it restricts the choice of heating systems and may occasionally result in inefficient energy use (Yoon, Ma and Rhodes, 2015).

Sweden has implemented a comprehensive collection of policy instruments and incentives to promote a sustainable and market-based heat supply. The DH Act was introduced by the Swedish Government to protect consumers and improve transparency in the DH sector. Key elements of the Act are summarised as follows (Galindo Fernández *et al.*, 2016)**:**

- It outlines the general framework for DH contracts, such as the content, compensation, termination, etc.
- It mandates DH companies to provide pricing information to their customers and the public.
- It requires DH companies to negotiate changes in prices and terms of heat supply with their consumers. In the event of any discrepancy, customers may notify the National District Heating Board for mediation.
- It regulates arbitrary modifications to the DH contract as well as the discontinuation of district heat supply.
- It requires DH companies to notify the supervisory authority which is the Swedish Energy Markets Inspectorate (SEMI) of its activities and operations on an annual basis in order to ensure compliance with the DH Act.

The DH Act was amended in 2011 to incorporate additional metering and billing requirements. The amendment required DH companies to monitor the energy use of their customers using measuring meters and to report the results on a monthly basis. It also established that, unless otherwise agreed between the parties, the billing must be made at least four times a year. In August 2014, the DH Act was amended to introduce a set of rules aimed at facilitating the supply of surplus heat to the DH network under certain conditions.

While there is no separate district heating act in Finland, the Competition Authority has identified that district heating operators are in a dominant market position relative to their current district heating customers. The exploitation of the dominant market position is prohibited, which sets out certain conditions for district heating operators, as regards their pricing and cost elements including new capacity investments. Typically, the requirements relate to prohibitive prices, terms and price discrimination. The price of district heating is not regulated, but the dominant position of the market demands fair pricing on equal terms for all similar customer groups. The Finnish Competition and Consumer Authority (FCCA) may initiate investigations if it suspects that prices are being abused by unreasonably high prices, as a result of the dominant market position of district heating (City of Helsinki, 2019b; FCCA, 2020).

Generally, there is no obligation to connect to a district heating network. However, in most cases connection has been required locally as municipalities have imposed DH connection in their city plans.

The nationalisation of the UK's energy system followed by privatisation and liberalisation, has resulted in a highly centralised system and a market-led approach to implementing new low-carbon technologies (Bolton and Foxon, 2013). Russell (1986; 1993) presents the most detailed historical account of why the CHP/DH never had a foothold in the UK throughout the nationalised period. Russell's research identifies a number of issues, including the dominance of centralised producer interests, the erosion of local authority power in the energy sector following wartime nationalisation, and a general lack of emphasis on the potential for end-use savings. Despite a number of initiatives to jumpstart the industry, government efforts were haphazard, and DH lacked the necessary policy framework to compete with existing gas and electricity suppliers. Russell also mentions the prioritisation of commercial interests in the energy sector, which has prevented the development of energy infrastructure to fulfil a broader set of socially oriented aims at the local level (Bolton and Foxon, 2013).

A number of UK local authorities have attempted to implement DH in recent years, not only because of the benefits in terms of energy efficiency and carbon reductions, but also because of its inherent local character, which can aid the realisation of local decarbonisation targets, as well as economic growth and development it can bring to the community. Despite the potential benefits, DH implementation in the UK has remained low, accounting for only 2% of total heat demand (Galindo Fernández *et al.*, 2016; City of Helsinki, 2019b). The degree of expansion, market penetration and the proportion of households supplied by district heating varies from country to country. Figure 13, shows the percentage of citizens that have their energy supplied from DH systems which vary from 92% in Iceland to 2% in the United Kingdom (Euroheat & Power, 2015; Colmenar-Santos *et al.*, 2016).

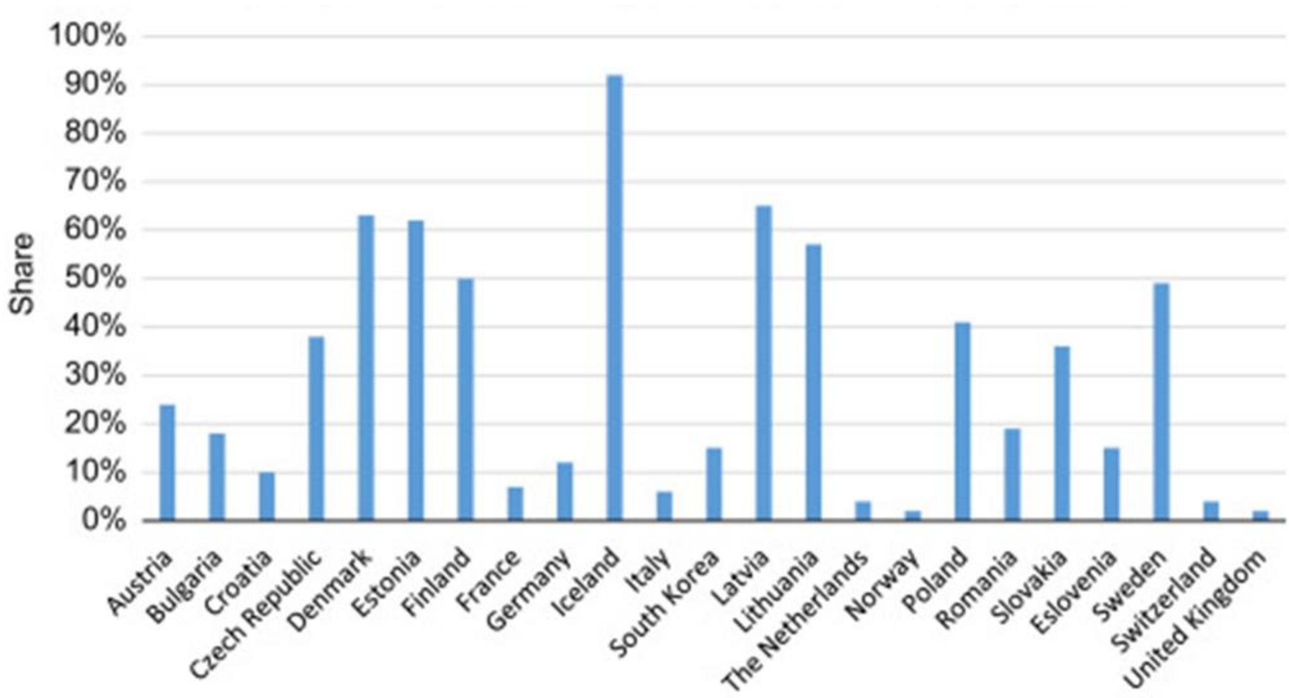


Figure 13:The percentage of citizens served by district heating systems (Euroheat & Power, 2015).

Bolton and Foxon (2013) posit that the structure and nature of the regulatory institutions that govern the liberalised energy sector in the UK have particularly been an influential factor in the development of DH. This continues to limit its development, as the governance framework centred on cost reduction and incumbent infrastructures will be inadequate for the needs of low-carbon niches which do not readily align with the incumbent regime, which will be explained in more details in chapter 3. Despite the interest of many local authorities who see DH as a means of achieving both climate targets and local economic development, it is argued that regulation needs to move away from a one-dimensional focus on markets, to begin to govern the system in a way that empowers local actors and does not close down opportunities for the development of alternative low carbon pathways. Due to the UK's strong emphasis on energy market regulation and the regulator's strategic role in achieving energy policy objectives, it is clear that the alignment between national energy policy and local initiatives will be a critical component of the development of the DH niche in the UK (Bolton and Foxon, 2013; Galindo Fernández *et al.*, 2016).

While many of the specific decisions and actions associated with the implementation of DH systems need to be taken at the local level, support at the national level for DH can significantly strengthen initiatives at the sub-national or local level as national policies are crucial to achieving optimum results

(Galindo Fernández *et al.*, 2016). Four of the most significant national policies with major impacts include: **national regulation on tariffs, incorporation of DH into building efficiency standards and labels, incentives for CHP and renewables, and tax regimes, as well as clear planning guidance and regulations that provide local authorities with a mandate to act.** For example, European Union (EU) energy efficiency legislation requires national and local authorities to implement heating and cooling infrastructure plans that use all the available renewable energy sources and CHP in their region (Galindo Fernández *et al.*, 2016). The national licensing framework in Norway supports local implementation of DH by requiring prospective providers to design comprehensive development plans that provide evidence of the socio-economic and environmental benefits of district heating compared to other alternatives. In Nordic countries such as Sweden, Finland and Denmark, the use of polluter tax is a key best practice in achieving high levels of DH use due to the energy efficiency and, and capacity to decarbonise heat, through the use of heat from a range of energy sources, and integration of renewable energy technologies, results in lower carbon emissions than fossil fuel-based systems . The modernization of DH systems in China has also been driven by taxes and other penalties, such that the national-level regulation empowers the local authorities to fine cities with high levels of pollutants air pollutants (Bolton and Foxon, 2013; Galindo Fernández *et al.*, 2016).

Due to the nature of DH as a local infrastructure technology, it is particularly prone to challenges such as high capital costs and investor risk perceptions, as well as a lack of institutional support or strategic coordination. Anshan (China) is expected to have a payback period of only three years for investments in a transmission line to integrate the city's isolated boilers to enable the use of surplus heat that could have been lost or wasted contributing to higher energy efficiency, emission reduction and cost-effectiveness, thereby avoiding pollution fines and reducing the purchase of coal. In the absence of taxes, national governments can provide subsidies and grants to support DH and to establish a level playing field. For example, Rotterdam obtained a grant of €27 million from the Dutch government which is equivalent to the avoided “costs” of CO_2 and NO_x emissions; this is a cost benefit analysis approach which puts a putative price on environmental harm and can be subjective. Cities are increasingly involved in the design and implementation of "vertically integrated" state and national policies in order to promote the effective alignment and implementation of policies at national and local levels. Climate finance is a viable means of promoting low- carbon DH systems through Vertically Integrated Nationally Appropriate Mitigation Actions (V-NAMAs). These are actions that contribute to combating climate change (Galindo Fernández *et al.*, 2016). In contrast to the electricity and gas suppliers, DH suppliers do not directly compete with one other because DH networks are designed to be isolated systems that are unconnected to one another. As a result, customers do not have the option to select between various DH suppliers. (Wissner, 2014). The issue of monopolized supply in district heating is often debated; opt-out existence has been shown to result in higher prices for the remaining customers connected to the network and as the cost increases, more customers may opt-out, resulting in a chain reaction (Yoon, Ma and Rhodes, 2015). According to Wissner (2014), the regulation of pricing and distribution grids is necessary to prevent customer exploitation due to DH potential for monopoly abuse. However, this should be achieved without discrimination against alternative heating sources and the mandatory connection to district heating should be modified to reduce the risk of monopoly power abuse.

Wissner's (2014) study on the regulation DH networks addresses the question of regulation through the application of microeconomic theory and likens the results with the reality of the DH sector. The significance of the study stems from the fact that it provides a holistic view of possible regulatory starting points and the problems associated with them. Figure 14 provides an illustration of the course of the analysis.

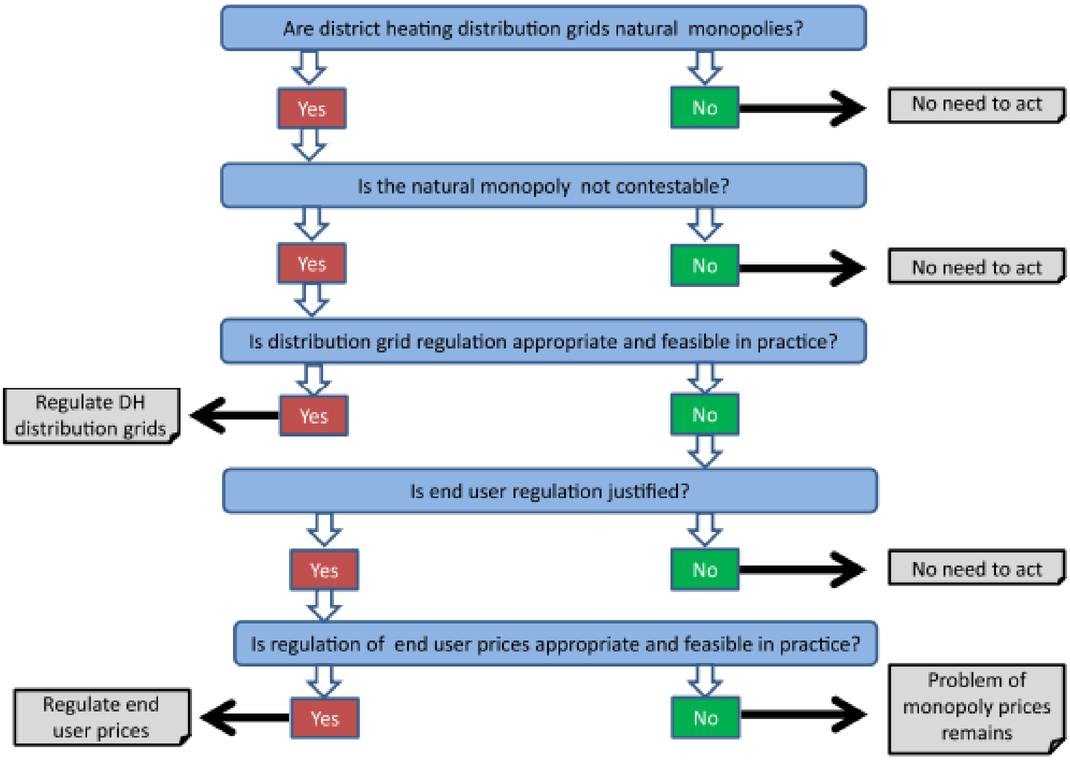


Figure 14:Course of the analysis (Wissner, 2014).

The analysis begins by determining if district-heating distribution grids are natural monopolies. The next question seeks to determine if they need to be regulated. If district-heating distribution grids are not contestable, such that, the market entry is not free and/or market exit is costly, the response is yes. If district-heating distribution grids are not contestable, such that, the market entry is not free and/or market exit is costly, the response is yes. As a result, if district-heating distribution grids are inherent monopolies that are not contestable, they should be subject to economic regulation. But, in practice, is such a regulation feasible and appropriate? In the next step, this issue will be addressed, and potential solutions will be discussed. Alternatives must be sought if distribution grid regulation is not feasible in practice (Wissner, 2014; Rezaie and Beyerlein, 2017; Donnellan *et al.*, 2018).

The regulation of end-user prices is one option. However, the absence of competition on the heating market is a precondition for price regulation which is why it is included as part of the analysis. Finally, if price control is justified, what are the concerns and challenges associated with implementing it? This methodical approach to research assists in the detection of issues and the formulation of policy recommendations (Wissner, 2014; Rezaie and Beyerlein, 2017; Donnellan *et al.*, 2018).

2.6.5. District Heating Development Process

DH Networks work best when implemented appropriately and will only succeed in areas of high heat density. A planned strategic approach to development is required to demonstrate that DH is the lowest cost option, which should foster the acceptance of the overall DH policy and implementation of DH in a given area, heat mapping is used to estimate the heat demand in a given area, to display a possible DH path, and to identify potential anchor loads. Figure 14 provides an outline of the three stages of the DH development process.

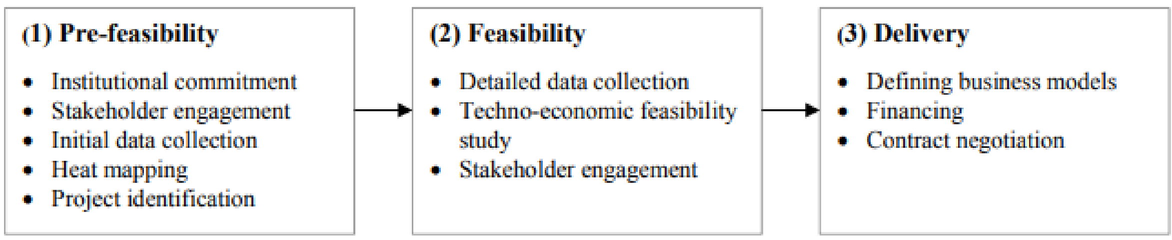


Figure 15: Outline of the three stages of the DH development process (Bush *et al.*, 2017).

2.6.5.1. Pre-feasibility Study

The pre-feasibility study seeks to provide a view of areas within a local authority where DH may be viable and heat mapping is often an output of this stage (Bush *et al.*, 2017). The outputs of a pre-feasibility study are outlined below.

Outputs of the pre-feasibility study include:

- Support from senior officers
- Map showing potential specific areas to support DH schemes including
- Potential consumer buildings such as hospitals, leisure centres, high density housing and universities

- Future developments and regeneration zones
- Sources of low carbon heat
- Details of building ownership and occupancy patterns
- Input from DH stakeholders, indicating level of interest in the scheme and any expectations around its high-level viability.

Given that the aim of the pre-feasibility stage is to identify opportunities, it makes sense to minimise costs and to keep as much of the activities in-house as much as possible. This can be enabled using freely available resources, such as the national heat map, as well as identifying where in-house personnel have appropriate skill sets which could be used at this stage. However, it can be more effective to commission specialist external providers for some elements of the pre-feasibility work, particularly for the detailed mapping exercises with greater speed and accuracy. It is important to be clear about the goals of heat mapping, otherwise it could be carried out without delivering any real benefits. High-level heat mapping is likely to be most beneficial for local authorities, as part of a wider strategic planning across their entire geographical area. Areas can be divided into broad sections with differing patterns of usage for example Industrial, commercial, and residential. The heat density is overlaid in a map of these areas, usually represented by colour shading rather than the actual numerals. Heat density is effectively an indication of annual energy consumption. It is estimated using a combination of published energy benchmarks and estimates of the treated floor area. For example (Bush *et al.*, 2017; Werner, 2017a; UKDEA, 2020c):

Heat density (kWh/m2) = Energy benchmark (kWh/m2) x Floor area ratio

Empirical research and metrics should be used to ascertain if a DH is viable, and if it is beneficial to proceed with more extensive feasibility work. The main output of the pre-feasibility stage is to point towards areas where DH could provide significant benefits and to demonstrate that further development work is worthwhile. Figure 15 provides an outline of the three stages of the DH development process. The pre-feasibility stage should provide a strategic overview of the potential for DH. Consequently, developers need to consider what their main drivers are, at this early stage. Local authorities may be driven by fuel poverty targets of low carbon aspirations, whereas commercial developers may be predominantly concerned with meeting carbon emissions obligations. In any case, a list of the drivers and their relative importance to the developer can help inform the process and serve as a checklist against which the project can be assessed, as it progresses. In addition to the consideration of the aims and objectives, the strategic overview also considers the local setting and assets. Where are the relatively high-density areas? Does the developer have controlling interests in large buildings that can act as anchor loads? Are there existing DH assets that can be expanded, upgraded, or decarbonised? Some potential Drivers for Delivering a DH Network include (Fudge, Peters and Woodman, 2016; Bush *et al.*, 2017; Werner, 2017a; UKDEA, 2020c):

- Carbon emission targets
- Decentralised generation targets
- Planning requirements
- Operational cost savings
- Fuel poverty goals
- Economic development
- Utilisation of available low carbon heat sources
- Existing plant reaching the end of its useful life
- Redevelopment plans offering a window for installation with minimal disruption

Aside from heat mapping, the pre-feasibility stage is the right time to begin discussions with existing DH stakeholders. Particularly, to seek advice from several organisations that have successfully delivered DH schemes. Local authorities should seek to engage with other local authorities that own and operate their own DH network, as well as those that have contracted an energy service partner to deliver a scheme. While it can be more challenging for commercial developers to seek the advice of other commercial developers there are still good case studies available regarding lessons learnt from delivering DH schemes. There are also useful forums available, where commercial developers are able to share experience of less familiar green technologies. Also commercial developers of DH schemes which are called Energy Service Companies (ESCOs) can be contacted to carry out an assessment of the potential of the DH project (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020c).

2.6.5.2. Feasibility Study

A comprehensive feasibility study expands on the preliminary work to provide a more accurate view of the prospects for DH in each region. Because of the specialized knowledge needed, it is common practice to hire a third-party consultant to conduct the feasibility study. The feasibility study focuses on areas where the potential for DH was found during the pre-feasibility stage, as well as making recommendations on the consumer buildings that will be required to connect to the network. It is important to avoid wasting time on areas with no DH potential.

The cost of a feasibility study may vary significantly depending on the area's size and scope, as well as the customers being considered. A well-conducted pre-feasibility study can significantly reduce the cost of a feasibility study by providing a valuable starting point, while a poorly conducted pre-feasibility study can hinder the progress of a feasibility study by providing unreliable information (Schleussner *et al.*, 2016; Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b).

2.6.5.2.1. Data Gathering

Accurate data is the foundation of a feasibility study and therefore significant data collection efforts are often required from the consultants and the owners of the buildings involved in the study. Collated data forms the basis of an operational and financial model, which is used to assess the viability of the network. A range of data needs to be gathered for potential consumer buildings. It is not necessary to gather fully detailed information for every single building in an area. Rather, the study needs to focus on potential anchor load customers. The list below covers some of the data that is collected to inform a feasibility study (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b).

- Data outputs from pre-feasibility work
- Details of potential anchor load customers including:
- Building ownership and the relationship with the developer
- Building use and occupancy patterns
- Floor areas
- Arrangement, capacity, condition and expected lifetime of existing energy plant and plant room on site.
- Details of the internal heating system of the building
- Historic and/or projected annual energy consumption (from bills or modelled projections
- Historic and/or projected energy peak demands
- Current energy purchasing arrangements and prices

Details of any existing potential heat sources such as waste heat from industries or energy from waste facilities, including:

- Plant ownership and the relationship with the developer.
- Any obligations or plans to utilise the heat generated
- Likely size of potential heat supply (for example peak output)
- Any loss in performance that would result from heat off-take
- Expected availability of the heat and likelihood of supply guarantees
- Price expectations for heat.

- The developer's drivers for conducting the DH network feasibility study

The developer and building owners have a responsibility to provide accurate and well sourced data, of existing heating systems and buildings from gas and electricity bills or projections of heat consumption for new buildings. In addition to the building services data that will be shared, it is important to be aware of significant development plans which could affect the outcome of a feasibility study. The feasibility study needs to identify potential locations for an energy centre, whether existing plant space within a consumer building or maybe the need for a new dedicated energy centre building and potential sites for this. Existing energy systems such as gas fired boilers can where possible be adopted as back-up and top-up plant to reduce the capital cost of the scheme. A new low carbon plant will require its own space to be installed. The feasibility study should also consider any potential local heat sources as well as existing sources of heat identified during the pre-feasibility study with details of the benefits and challenges to assess the viability of the network. Three issues to be considered with third party sources of heat include (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b):

- Projected availability across the year
- Long term plans for the heat supply
- Price of heat
- Quality of the heat supply such as temperature, variability, and pressure
- Supply guarantees

Potential Network Routes

The feasibility study should also identify potential routes for the connection of pipes for the heat network. The routes may not be detailed at this stage but should include:

- Consideration of any existing thermal works and if upgrade work may be required
- The most efficient routes with minimised length of buried pipe work.
- Existing tunnels, ducts or basement area through which pipes could be installed, reducing the likely cost of installing the network.
- The ground type to be dug through and re-instated (e.g roads, verges etc)
- Potential route restrictions arising from private land ownership along likely pipe routes
- Required right of access
- In-principle solution to challenges relating to infrastructure crossings such as waterways and rail.

Although pre-feasibility studies are important, extensive heat mapping and feasibility studies may not lead to project development, let alone long-term strategic planning of DH systems, unless challenges such as staff resources and access to experts with the required DH implementation skills and expertise are addressed.

2.6.5.2.2. Operational and Financial Model

The operational and financial is a key element of the feasibility study, it enables the analysis of an array of potential DH scheme options, based on the range of source data from the developer, building operators, published site survey benchmarks and in-house resources. The model analyses the performance of various energy plant solutions, such as biomass boilers, energy from waste and gas fired CHP against various consumer connection scenarios. This process is often computerised to enable fast optimisation of the plant solution against each scenario. Low carbon plant is optimised to run for as many hours in a year, while back up plants is intended to meet peak loads, with a certain level of redundancy in case of unexpected plant failures. Annual energy consumption and the shape of the demand profiles have a greater influence on the design of the low carbon solution than the peak demands (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b).

Buildings consume different volumes of energy every year, depending on changes in building use, occupancy patterns, and the weather. Degree day correction adjusts for the weather in the month and year the data was collected. This enables the model to use standardised heat consumption profiles that are closer to a long-term average. Degree days measure how often and how far the temperature falls below a certain threshold and are taken to be proportional to the amount of energy required to heat a building (Werner, 2017b). Degree days only affects the amount of heat consumed for space heating, and not the use of hot water services. Each potential energy plant solution will have different capital and operational costs, depending on the type and scale of the energy plant. The operational and financial model analyses the predicted costs and revenues of each plant solution in each scenario over a typical year. This yields an expected financial performance of the DH scheme, regardless of the actual delivery business model selected. However, it should consider the level of whole life cycle cost savings available to the consumers, when compared to conventional energy supplies (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017b; UKDEA, 2020b).

The model will typically focus on overall costs, rather than give particular energy tariffs at this stage. It can be useful to provide indicative tariffs in the feasibility report, with detailed analysis of how it is calculated. Beyond the analysis of a typical annual operation, most operational and financial model also consider the long-term performance of the energy solution, with project lifetime of at least 20 years or longer, considering the 50-year plus lifetime of best practice DH networks. The long-term performance is important in terms of financial viability, long timescales are usually required to achieve sufficient payback on the large capital investment required, regardless of the business model. The high level of initial investment requires long term energy supply contracts of at least 20 years, in order to avoid any operational over-cost to customers in comparison to conventional energy solutions. Recovering the initial investment requires a long-term process, it will therefore, not be generally feasible to fund new DH projects on the back of short-term supply agreements. The model also enables sensitivity analysis to be undertaken, judging the resilience of an energy solution against potential future changes such as changes in fuel prices or consumers (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017b; UKDEA, 2020b).

2.6.5.2.3. Outputs of a Feasibility Study

The main output of a feasibility study is to provide an options appraisal, which sets out a range of options and low carbon plant solutions, highlighting the comparative merits of each. Also, a key output of the study is the carbon savings projected to be achieved by the scheme. It is useful to provide the total carbon emissions saving in comparison to alternative conventional forms of energy supply, this is usually expressed in tonnes per annum. It may also be useful to understand the carbon intensity of the energy supplies, in gCO_2 emitted per kWh (gCO_2/kWh) of energy consumed. This is often useful to customers to understand their emission savings as well as for developers in terms of setting an emission reduction targets. Table 2 provides a summary of some of the outputs from a feasibility study (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b).

Table 2:Summary of outputs from a feasibility study

Strategic development, and long-term planning	**Operational and financial modelling including**	**Potential frameworks for delivering the scheme including considerations of:**
A descriptive outline of DH and its potential benefits to the area	Outline of capital costs	Available methods of procurement
A descriptive outline of the potential low carbon technologies to be integrated	Any available financial incentives or grant funding	Outsourcing and transfer of risk
The initial building to be connected to the scheme as anchor loads as well as new	Projected whole life cost savings to the consumer	Outline of the scope of the project deliverables

developments that could be connected in the future		
Summary of the network operation, temperature and potential location of the energy centre	Any available gap funding	Options for financing

It is important to note that the feasibility study should provide a strong indication of potential solutions, to avoid restricting the development of the scheme to one solution. Also, it should not include any detailed technical design work as this is excessive detail which could incur unnecessary cost and can limit the potential of the scheme during delivery (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b).

2.6.5.3. Delivery Stage

Irrespective of the mix of public or private money that is used to deliver a DH network, there should always be a viable business case that justifies the investment. The DN network needs to be financially viable in the long-term, requiring no ongoing public subsidy, with the exception of any financial incentive it is entitled to (such as the Renewable Heat Incentive-RHI in the UK). Careful consideration should be given to the ratio between the annual energy sales and capital cost to ensure the scheme is financially viable. A DH network should not only be low carbon ensuring environmental sustainability, it should be socially sustainable in the sense that it should provide energy that is not more expensive for its consumers when compared to the conventional alternative and it should also be economically sustainable, being self-supporting (Bush *et al.*, 2017; Werner, 2017a; Buffa *et al.*, 2019; UKDEA, 2020a).

2.6.5.3.1. Heat Network Business Case

A business case identifies various sources of funding, to deliver the capital cost of the scheme and how those investments are recovered over the life cycle of the project. It should also provide an analysis of the risks involved and where these risks are allocated. The ultimate decision to select a business case outline lies with the developer, provided that any required service providers are willing to engage in it. The business case option of the developer may be restricted for a number of reasons: the availability of capital funds and the requirement to achieve a certain Internal Rates of Return (IRR) (Bush *et al.*, 2017; Rao *et al.*, 2017; UKDEA, 2020a).

Available Business Models

DH networks operate under various business models globally (UNEP, 2015). Business models vary from wholly owned systems to private public partnerships and cooperative models, to wholly owned private systems. Three factors largely determine the relative involvement of the public or private sector: 1) the level of control that each partner seeks to possess 2) the degree and nature of risk that project partners are willing to take on and 3) the financial profile of a project that involves mechanisms that are negotiated in the context of complex actors' networks; (Homes and Communities Agency, 2011; Rao et al., 2017). Also, country-specific public and private sectors requirements can have a direct impact on the choice of business models (UNEP, 2015).

In contrast to the electricity and gas networks, the bulk of the cost for a DH network is in the network itself, with relatively low operating costs. The heat is reasonably priced, and the network itself requires little maintenance. As a result, securing low-interest funding and patient capital for network investment and long-term financing is critical. If the conditions are favourable for attracting long-term investors, the cost of the heat supplied will be more competitive, and the scheme's long-term viability will be more assured (Woods and Overgaard, 2015). According to an analysis of heat network business models, the wholly public business model is the most widely adopted globally (UNEP, 2015).

Wholly public business model in this model, local authorities or public utilities retain full ownership and management of the DH network to achieve social, environmental and economic objectives. This has largely been the model in Scandinavian countries. The public sector bears the burden of the risk and finances the project through investments or loans. Depending on the returns and financial responsibility approach, projects can be developed through a local authority agency or through a special purpose vehicle (SPV). Due to lower risks and a lower cost of capital, public business models that use public funds will generate higher rates of return (UNEP, 2015; Woods and Overgaard, 2015).

A hybrid model incorporates public and private sector participation with ownership, risk, and returns negotiated between partners is an alternative to fully public ownership. It includes (UNEP, 2015; Rao *et al.*, 2017):

- Public and private joint ventures in which both parties finance the construction of the network construction are examples of hybrid models. The joint-venture model generally involves the establishment of a Special Project Vehicle (SPV) with both partners providing equity, and possibly debt finance, as well as the creation of a board of directors that represents the ownership distribution.

- Concession contracts in which the public sector is responsible for the development of a project but then hires a private sector company to design, build, operate and maintain (DBOM) the network on a long-term basis under a concession contract. The risks associated with designing, building, operating and maintaining the DH network is borne by the concession holder, but benefits from risk mitigation due to the local authority's involvement in the initial development and the provision of public sector anchor loads. Agreements may include billing structures or profit sharing, but the local authority has limited control over the concession (Rao et al., 2017).
- Cooperative or community-owned business models in which networks are developed by the community with limited local authority involvement. The local authority involvement tends to be in the early stages of development and possibly financial underwriting.

Wholly private business models this is typically undertaken when minimal public sector collaboration is required, and the rate of return is sufficient to attract private investment, but they are usually governed by a regulatory authority. This model is more likely to be used in new designs than in retrofit projects, where pipework construction costs are lower (UNEP, 2015; Woods and Overgaard, 2015). In a study of district heating opportunities in the UK, it was identified that implementing DH networks poses a considerable risk for private companies due to initial costs and the uncertainty of government policies. High installation costs continue to impede DH delivery, it will be useful for policy makers to implement policies to reduce cost barriers to DH implementation (Kelly and Pollitt, 2010; Yoon, Ma and Rhodes, 2015). Table 3 shows a broad classification of heat network business models as wholly public, hybrid public-private, and wholly private.

Table 3:Classification of business models for DH networks (UNEP, 2015).

Financial Return on Investment	Degree of Control and Risk Appetite of Public Sector	Type of Business Model	Examples
Low	High	Wholly Public	To deliver social objectives related to housing or fuel poverty
Medium / Low	High	Wholly Public	To demonstrate the business case of DH networks

			To develop projects to generate revenue To lower the Internal rate of return (IRR) by enabling cheaper energy tariffs than the private sector
Medium / High	Medium	Public / Private Hybrid	Public / Private Joint Venture Concession Contracts Community-owned not-for-profit or Cooperative
High	Medium / Low	Private with Public Facilitation	Privately owned project with some local authority support, possibly through strategic partnerships

There are two heat network models for heat generation, distribution, and supply namely (Werner, 2017a):

Bundled model: In this model one company is responsible for the management and operation generation, distribution, and supply of heat. This is the dominant heat network model used in most heat network schemes in various countries.

Unbundled model: This is where different companies are responsible for the management and operation generation, distribution and supply of heat. The unbundled model was rejected in Sweden on the grounds that it could likely increase costs. Existing networks in the UK and Germany operate the bundled model. Also, the electricity and gas sector in the UK operate the unbundled model as different companies are responsible for the generation, distribution and supply of electricity and gas (Werner, 2017a).

2.6.5.3.2. Heat Price, Metering and Billing

It is important to understand how the heat price will be determined and set out a strategy for the recovery of the revenue. In the UK, most successful DH schemes calculate their pricing on what is referred to as an ‘’avoided cost’’ basis. This involves the estimation of the total cost of operating the network, which includes (UKDEA, 2020a):

- Fuel consumption
- Repairs and maintenance costs of the network

- Sinking fund for long term replacement of the network

The estimated total cost is divided by the expected annual energy consumption to give an average price for the conventional alternative or counterfactual scenario. The heat price is then set to be equal to or a certain percentage lower that the overall average price of the conventional alternative (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b). Each consumer may be provided with their own individual price using this method. This guarantees that each customer saves money compared to their conventional alternative heating system. It is often calculated for sets of similar buildings rather than individual buildings. Contrary to the avoided cost model, some DH operators may set their heat price on a cost recovery basis, which ensures the recovery of their investment irrespective of the conventional alternative heat price. The cost recovery method almost always results in heat prices that are higher than the conventional option, which can be difficult to justify and not often recommended. Likewise, fixed charging with no reference to the actual energy consumed often leads to high heating prices. The cost savings that can be achieved should be transparently expressed through a cost benefit analysis that provides a list of the conventional alternative costs in comparison to the DH pricing structure. This may be provided over the duration of the contract for commercial consumers known as whole life cycle analysis (Bush *et al.*, 2017; Lake, Rezaie and Beyerlein, 2017; Werner, 2017a; UKDEA, 2020b).

2.6.5.3.2.1. Investment Structure and Finance Options

A range of investment structures and funding options are available for DH projects, but not all will be suitable in all circumstances. Project teams must evaluate projects from the perspective of an investor, whether public or private. While investments structures can vary significantly across a spectrum, two business models are detailed below see figure 16.

Projects could be set up so that they appear on the DH network developer's balance sheet and are financed with corporate finance loans or reserves. To differentiate the district heating business unit, a separate completely owned company could be created – the developer (scheme owner) essentially provides 100% equity of the project, with risk transfer achieved through the contractual agreement.

In a project finance structure, the developer would invest in a separate entity through a SPV. This structure can attract other equity co-investors and project senior debt with minimal recourse to the developer's own balance sheet; as a result, risk transfer is achieved through the contractual and finance structure (Green Investment Bank, 2015).

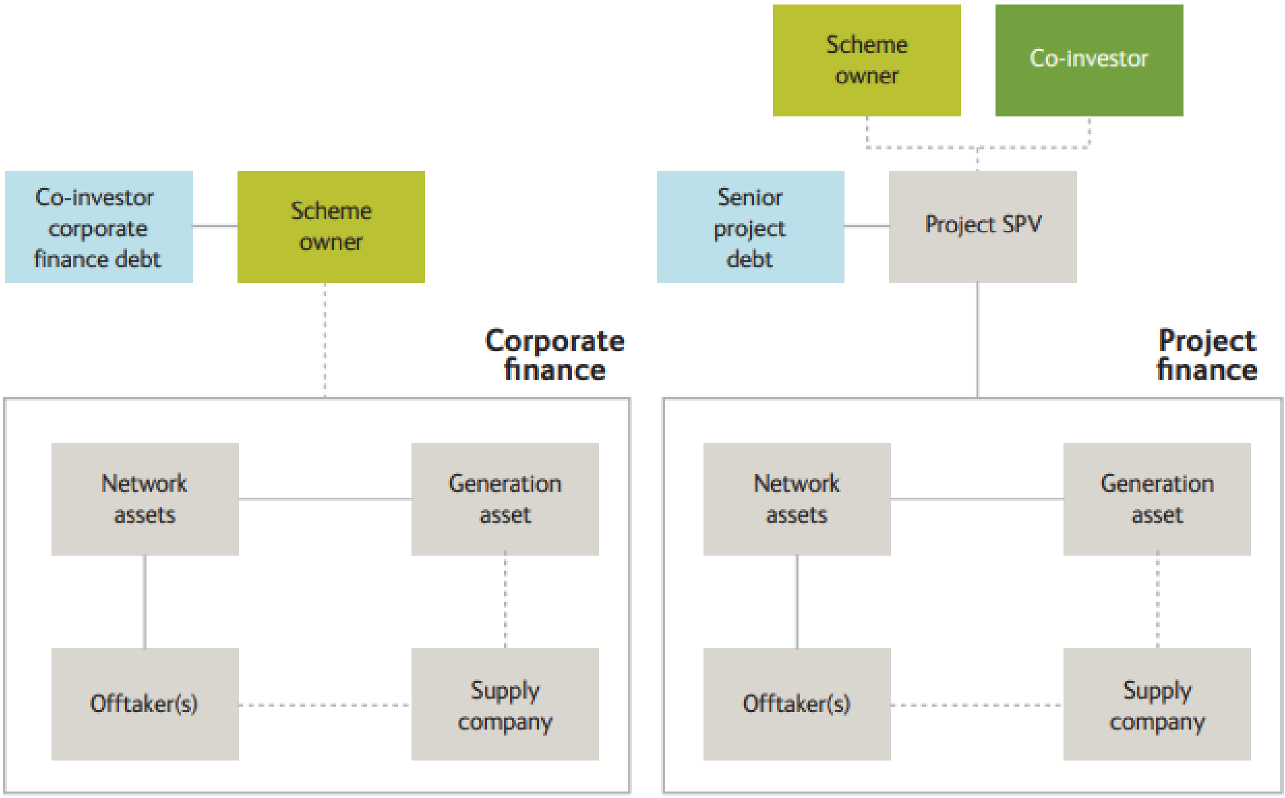


Figure 16:Investment structures (Green Investment Bank, 2015).

2.6.5.3.2.2. Finance Options

In general, the capital funding for DH network comes from a range of sources, depending on the chosen business model. These sources include (DECC, 2016b; Woods and Overgaard, 2016; UKDEA, 2020a):

Grants and incentives have been successful at incentivising the development of new DH network and the expansion of existing DH network which may be able to fully fund, or part fund a DH scheme. It includes, low or zero interest loan programmes which helps to meet the capital cost of projects. It will however need to be re-paid from the revenue generated from the DH network, at a reduced capital cost compared to a typical bank funding. It may also include the provision of specific technical assistance. Access to some funding streams may only be available to specific stakeholders. To this end, developers and partners need to be proactive in identifying available funding streams within and outside their organisations. In the UK, the Department of Business, Energy, and Industrial Strategy (BEIS) established a Heat Network Delivery Unit (HNDU), which provides funding and support to local authorities to develop DH schemes up to the feasibility (DECC, 2016b; Woods and Overgaard, 2016) stage.

Long-term revenue incentive programmes like the Renewable Heat Incentive (RH) could help improve the viability of renewable energy-based DH schemes. While it does not provide capital funding, the incentive scheme's secure long-term revenue can open up opportunities for increased capital investment (DECC, 2016b; Woods and Overgaard, 2016; UKDEA, 2020a).

Energy Service Company (ESCO) Funding is the investment in a scheme in exchange for a long-term stake in operating the DH network, with the investment recovered by revenue from heat sales over a long period of time, usually more than 20 years. In certain cases, the ESCO can own the network or lease it from a developer, securing the exclusive right to operate and maintain the asset for the purpose of selling heat. However, certain local authority developers may wish to exclusively own the DH scheme; in circumstances where local government budgets are under considerable pressure, it is regarded as a source of revenue while acknowledging the risk of sole ownership. Private developers may not want to bear the long-term risk burden of such substantial investment in some cases. The ESCO model has several advantages beyond contracting the design, construction, operation, and maintenance of the scheme separately (DECC, 2016b; Woods and Overgaard, 2016; UKDEA, 2020a). Since the ESCO invests significant capital into the project and bears the development risk, the ESCO is driven to ensure the project runs smoothly for the duration of the project. While the transfer of risk may be beneficial for the developer's financial liabilities, the developer is unlikely to want to relinquish control of the project. As a result, the developer must be clear about the deliverables required of the energy service provider, which are communicated via the contractual agreement (DECC, 2016b; Woods and Overgaard, 2016; Nurcahyanto and Urmee, 2018; UKDEA, 2020a).

Bank Funding in cases where bank funding is used, the bank will normally need significant input into the contractual arrangements to ensure that project risks are addressed appropriately. Banks would normally require long-term fuel purchase contracts, as well as extensive due diligence on the chosen technology and construction methods. This can significantly increase the administrative burden of the project and its development cost, but it usually results in a well-thought-out project that is potentially less risky (DECC, 2016b; Woods and Overgaard, 2016; UKDEA, 2020a).

Developer Capital Contributions some developers may choose to own an equity stake in DH projects, while there is no reason to avoid this, it should be noted that itis a powerful instrument for control, and the contractual relationship remains fundamentally important. To be clear, a well-drafted energy service contract would allow for 100% private sector funding and ownership, as well as risk transfer, while the developer retains significant control over the project's development. In situations where the developer does not fully finance the DH scheme, a capital contribution is usually used to make up the difference. Depending on how they are utilized, developer capital contributions can enable the DH scheme to offer greater operational cost savings. In this way, a trade-off between the scale of development contributions and the achievable operational cost savings can be considered.

A profit-sharing agreement in which any profit above a certain level is shared between the energy service provider and the developer will provide financial reward for the developer's investment. This can be especially appealing to a developer if the scheme is expected to expand significantly over the course of the project (DECC, 2016b; Woods and Overgaard, 2016; UKDEA, 2020a).

2.6.5.3.3. Procurement

Due to the long contract periods, procuring the required energy services can be one of the most difficult aspects of delivering a DH scheme. As a result, it is important to employ experts with a successful track record. Developers must make all feasibility study details accessible to tendering parties (bidders). Failure to do so will lead to significant uncertainty and an increased risk of making irrational assumptions. This in turn can lead to the tender process not providing a level playing field and potentially key objectives may be overlooked. In the worst-case scenario, there is the possibility of major delays in the procurement process or significant adjustments to previously agreed-upon deliverables after the procurement process has concluded. Developers must be clear about the services that are being procured such as design, construction substations and metering, heat supplies, or maintenance services and why they are being procured. The specifics should be included in the descriptive document. The output specification is also important in the tender phase because it informs bidders about the developer's priorities and what they plan to accomplish through the delivery of a DH network (Hodson *et al.*, 2012; Bush *et al.*, 2017; Rao *et al.*, 2017; UKDEA, 2020d).

2.6.5.3.4. Project Agreement

The project agreement governs the relationship between the developer and energy services provider(s), setting out each party’s obligations. The agreement is important long before the approach of the contract award and is in fact central to the procurement process, with a draft contract or heads of terms usually included alongside the descriptive document. The contract terms are effectively subject to negotiation throughout the tender process, and it is essentially the project agreement at the heart of each bidder’s best and final offer (BAFO) that represents the actual offer against which the bidder is judged by the developer. The winning bidder is referred to as the Service Provider (Hodson *et al.*, 2012; Bush *et al.*, 2017; Rao *et al.*, 2017; UKDEA, 2020d).

2.7. Chapter Summary

This chapter drew on relevant parts of the existing theoretical literature on DH development and delivery to shape an analytical framework. The technical/management literature review provided insights into the historical development, the social issues, technological advancements, regulatory policies, and features of a modern large-scale district heating scheme as well as the implementation strategies that have been useful in the successful implementation of DH networks. Important aspects to consider in the implementation of DH networks were also highlighted such as the technical, economic, and environmental analysis of DH, the role of actors as well as non-technical organisational aspects which are critical to the delivery of successful DH schemes. According to the literature review, DH technologies have clearly improved in the market, playing an essential role in decarbonising the heat sector and helping to reduce fuel poverty in many countries. However, a critical aspect in the context of the current research has been the development of policies and strategies to aid the widespread use of DH. This research focuses on the implementation of large-scale DH networks that provide numerous decarbonisation and sustainability benefits to the energy system. The following chapter will outline the theoretical underpinnings in the socio-technical transitions literature, exploring key discussions in the field and how it relates to the research. It conducts a critical review of the existing socio-technical transitions literature and identifies gaps in the body of knowledge. Finally, it outlines the theoretical framework upon which the thesis's analysis is based and highlights areas of theoretical contribution provided by the thesis.

3. CHAPTER THREE URBAN ENERGY SYSTEMS AND THE MULTILEVEL PERSPECTIVE ON SOCIO-TECHNICAL TRANSITIONS

3.1. Introduction

The growing awareness and urgency of climate change mitigation have led to increased research interest in how the transition to a more sustainable low carbon economy can be accomplished. Urban infrastructure studies and its dynamics has become an increasingly significant part of sustainability and low-carbon discourses. The energy system is a complex sociotechnical system that is shaped by a number of social, technical and non-technical factors such as institutions, business strategies, technological innovations, ecosystems, and user practices (Foxon, 2011; Bolton and Foxon, 2013). Researchers in the field of sustainability-oriented innovation and technological transition studies have become increasingly concerned about the changes that occur within socio-technical processes during transitions. This chapter explores key discussions in the field and how they relate to energy system transitions to low carbon technologies with a specific focus on DH.

Several underpinning theories have emerged that use similar concepts but apply different lenses to the transition process. There are four main theoretical frameworks which include: strategic niche management (Rip and Kemp, 1998; Smith, 2007; Schot and Geels, 2008; Raven and F W Geels, 2010), the multi-level perspective (Geels, 2002; Geels and Kemp, 2007; Geels and Schot, 2007), technological innovation system (Bergek *et al.*, 2008; Markard and Truffer, 2008; Markard, Hekkert and Jacobsson, 2015) and transition management (Rotmans, Kemp and Van Asselt, 2001; Loorbach and Rotmans, 2006; Kern and Smith, 2008). These theoretical frameworks, collectively referred to as transitions theory, use different terms to explain the theoretical approaches in the analysis of socio-technical transition processes. However, many of these approaches examine the interrelationship between socio-technical change stability and dynamics with reference to the multilevel perspective of technological change (MLP) (Geels, 2002; Geels and Kemp, 2007; Geels and Schot, 2007).

Sociotechnical transitions study provides a comprehensive analysis of the interactions between multiple elements within the socio-technical system and its context. The study is situated within the broader context of the literature on sociotechnical transitions, which seeks to explore the coevolution of actors, institutions, and technologies in the reconfiguration and transformation of large infrastructure systems such as energy supply (Verbong and Geels, 2010; Bolton and Foxon, 2013). It draws on the sociotechnical transitions literature using the multi-level perspective on sociotechnical transitions to analyse the case studies to gain insights into how to steer the transformational shift to low carbon technologies. It presents the theoretical perspectives to understand the socio-technical transition processes in the energy system with a critical review of some of the key parts of the MLP literature on transitions. It is important to note that this section does not attempt to provide details of all literature on transition studies rather it explains the theoretical framework of the study which is the multilevel perspective on socio-technical transitions and provides justification for it.

3.2. Urban Energy Transitions

Energy systems are socio-technical configurations in which technologies, institutional arrangements (such as regulation and norms), social practices, and actor constellations (such as user–producer relations and interactions, intermediary organisations, public authorities, and so on) are mutually dependent and co-evolve. As a result of interactions between a wide range of individuals from multiple organizations and regions, innovation processes are becoming more distributed and complex (Verbong and Geels, 2007; Kern, 2012; Köhler *et al.*, 2019). Urban energy systems are complex, adaptive systems made up of organisations, policies, technological components and applications which involve dynamic interactions between various actors with diverse roles and interests (Berkhout and Westerhoff, 2013). Socio-technical change is dependent on mechanisms of societal and technological co-evolution. This research examines how change occurs in socio-technical systems: the patterns and dynamics that give rise to transitions, and structural transformations of these systems (Unruh, 2000b; Geels, 2002; F. W. Geels, 2005; F.W. Geels, 2005). Geels proposed that a multi-level perspective (MLP) can be useful in understanding such processes based on a number of historical case studies and prior work by Rip and Kemp (Geels, 2004). The MLP has been used to describe and analyse sustainability transitions in various systems, such as the energy system, transportation system, and the heat and cooling system (Geels, 2005a; Geels, 2011).

Cities, as entities that consume an increasing amount of energy, are viewed as both a significant target of energy transition and a critical ‘instrument' in implementing it (Rutherford and Coutard, 2014). The significance of place (especially cities) in socio-technical transitions literature has been criticized in the sustainable transitions literature (Eames *et al.*, 2006; Coutard and Rutherford, 2010; Hodson and Marvin, 2010a, 2010b, 2012; Bridge *et al.*, 2013). Although transition theories acknowledge the interaction and interpenetration of various landscape (macro), regime (meso), and niche (micro) levels, the role of the city and regional scale in transition processes has received little attention. According to Markard, Raven and Truffer (2012), studies on socio-technical transitions often focus on national-level systems with little attention on geographical scales of urban or regional contexts. A “spatial turn” in sustainable transition studies has addressed this to some extent in recent years (Coenen and Truffer, 2012b; Coenen, Benneworth and Truffer, 2012; Hansen and Coenen, 2015; Sengers and Raven, 2015; Wolfram and Frantzeskaki, 2016; Sengers, Wieczorek and Raven, 2019).

However, more extensive analysis of how cities contribute to sustainable transitions is still necessary (Karvonen and Guy, 2018). This requires a detailed examination of the dynamics of socio-technical interactions across the levels of niches, regimes and landscapes as well as multilevel systems of governance to develop a more geographically nuanced understanding of niche development (Rohracher and Späth, 2014). Urban energy transition studies provide the opportunity to gain a deeper understanding of the role of cities in socio-technical transitions (Rutherford and Coutard, 2014).

The analysis of DH implementation in the cities of Copenhagen, Stockholm, Helsinki and GM to contribute to a growing body of research that emphasizes the importance of spatial perspectives and the crucial role of cities and regions in transition processes. Using the multi-level perspective on socio-technical transitions, it focuses on the specific local dynamics of DH implementation: what instruments and strategies have been employed by the case study cities in the implementation of efficient DH networks for sustainable heat production and consumption? What motivations, visions, logic of actions, and actor coalitions shape these place-related strategies? How are local actions and change capacity interconnected with and dependent on multi-scalar relations such as international regimes and national frameworks? A parallel aim of this research is to acknowledge the critical role of cities and regions in energy transitions through the multilevel perspective on socio-technical transitions: Are cities merely testing grounds for niche experiments? Are local actions a bridge between the niche and the regime? Do they play a unique role in enabling and stabilizing change processes? Or are they essential for entrenching transitions in broader socio-political dynamics that extend beyond the energy system?

3.2.1. Key concepts in Socio-technical Transitions

The key concepts in socio-technical transitions are discussed in the following subsections:

3.2.1.1. Socio-technical Systems

Socio-technical systems consist of an array of elements which include people, technology, infrastructure, regulation, practices, market culture, production systems, maintenance networks, and goals integrated to achieve functionality with multi-level perspectives on transitions (see figure 17) (Geels, 2005a; Kern, 2012; Papachristos, 2014). This is because of the varied agendas values, priorities, views, strategies and resources (finance, skills, knowledge and networks) of multiple social groups and actors which occur at various levels. It operates across a range of scales, that can overlap and interlock in different ways from organisations to local, regional, and central governments. The socio-technical system concept reflects on the relationship and interaction between social and technical dynamics which form the unit of functional analysis of artefacts and knowledge (Geels, 2005a; Papachristos, 2014).

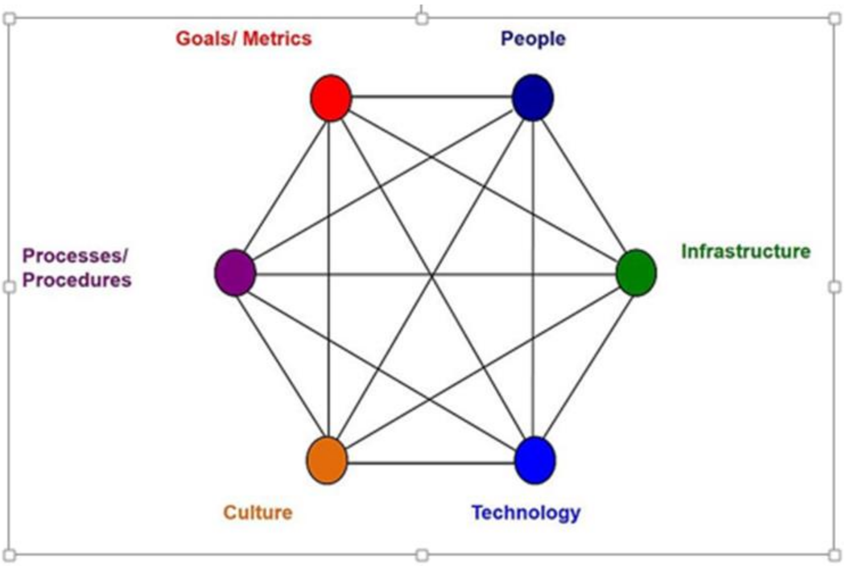


Figure 17:The Socio-technical System

The socio-technical system is an analytical concept, that can be applied to empirical cases of diverse scopes and geographical scales. Numerous researchers have investigated this concept in order to gain a deeper understanding of the complex transition process that occurs when a technological innovation emerges and becomes widely used (Kemp et al., 1998; Geels, 2004; Bergek et al., 2008; Foxon, 2011).

Social and technical systems cannot achieve functionality in isolation which means societal functions cannot be fulfilled by technology or social structures, but by a combination of the two systems. For example, ships and cars necessary for transportation cannot fulfil societal functions without people and social structures. Hence, the combination of social and technical systems known as socio-technical systems which are diverse and yet intertwined forms the unit of functional analysis of artefacts and knowledge in technological transitions and system innovations (Geels, 2005a). In the same vein, energy transitions and system innovations such as DH networks, involve changes in energy sources, stores of energy as well as the transmission and distribution networks to where the energy is needed would also require socio-technical systems to achieve societal functions. Figure 18 highlights the cluster of elements involved in socio-technical systems for energy supply.

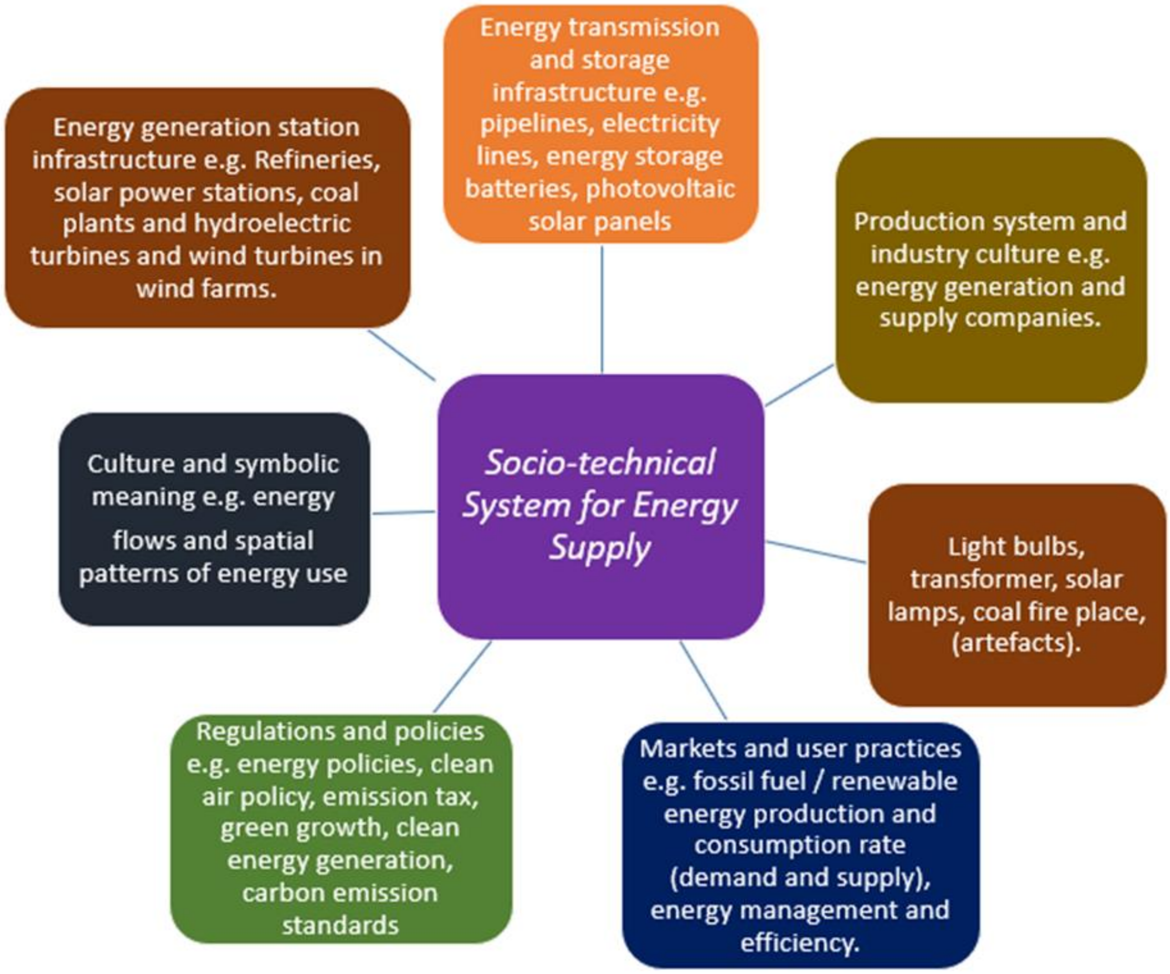


Figure 18:Socio-technical system for energy supply adapted from (Geels, 2005a).

A socio-technical system concept explores the interaction and relationship between social and technical dynamics. Socio-technical change is dependent on mechanisms of societal and technological co-evolution. This literature examines how change occurs in socio-technical systems: the patterns and dynamics that give rise to transitions, and structural transformations of these systems (Unruh, 2000b; Geels, 2002; F. W. Geels, 2005; F.W. Geels, 2005). Geels proposed that a multi-level perspective (MLP) can be useful in understanding such processes based on a number of historical case studies and prior work by Rip and Kemp (Geels, 2004).

3.2.1.2. Socio-technical Regimes

The sociotechnical regime is another key theoretical concept that is relevant to this research. It is drawn from the socio-technical transitions literature (Rip and Kemp, 1998; Geels, 2004) (Rip and Kemp, 1998; Geels, 2004), and it provides an understanding of the dynamics of socio-technical systems over time, as well as an analytical distinction between socio-technical systems, and the actors, rules, and institutions within them. The actors, rules and institutions provide a form of coordination for activities. Rule-regimes are made up of interconnected rules and institutions, such as those for policy, consumers and markets, politics, or science. Socio-technical regimes are autonomous, each with their own set of rules, but they are often interdependent and influenced by one another. Within a given socio-technical system, these elements combine to form sub-regimes of an overall "socio-technical regime." In the context of this research the socio-technical regime are the policies, markets users, institutions, and actors involved in the DH network implementation process.

The meta-coordination through socio-technical regimes led to the need for the analytical framework of three interrelated dimensions. As previously stated, socio-technical systems are created, managed and reproduced by human actors in social groups. Similarly, human actions and activities are governed by rules and institutions. Hence, the interrelationship between socio-technical systems, actors as well as regimes rules and institutions can be analytically differentiated see figure 19.

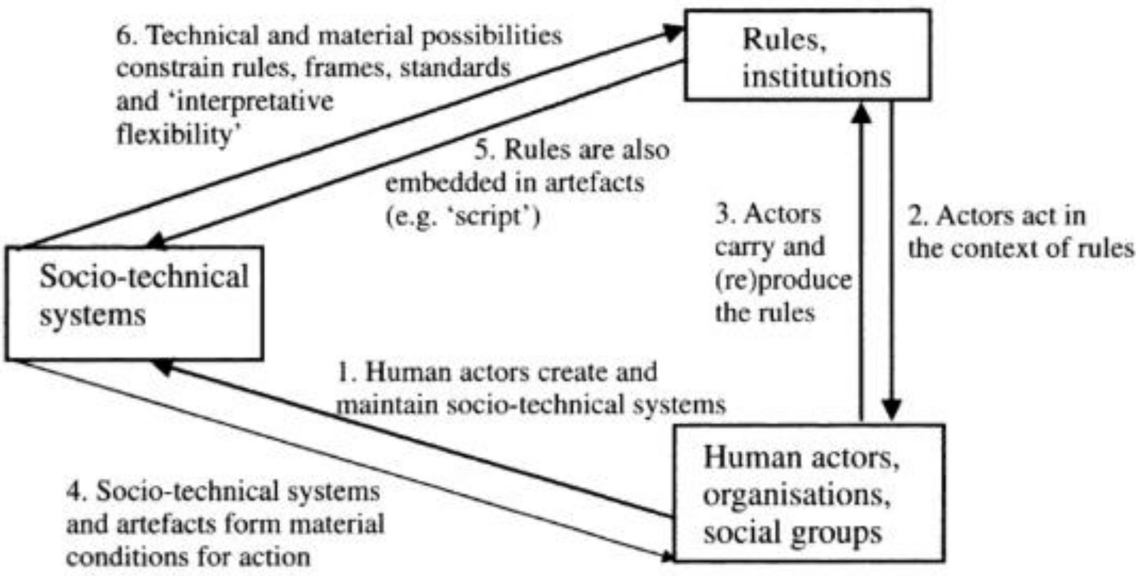


Figure 19:Three Interrelated Analytical Dimensions (Geels, 2004).

The concept of the socio-technical regime as proposed by Geels (2005) provides an in-depth understanding of the meta-coordination between regimes. Socio-technical regimes cut across other regimes with a mutually dependent relationship with other regimes, but they do not involve the entirety of other regimes, as each regime is relatively autonomous (see figure 20). However, they share rules that are in alignment with one another thus making them interdependent on each other. A regime consists of a set of rules (institutions), routines and practices responsible for stabilising and locking in the existing system into the incumbent regime. It can be described as a partially consistent set of rules connected to each other making it extremely difficult to change a rule without modifying the others (Unruh, 2000a; Geels, 2002). A regime can only be changed if it is necessary, practical, and beneficial and it is widely endorsed by a wide range of actors and institutions. This implies that evolving socio-technical regimes have far-reaching effects that can alter and standardise certain forms of social activities with implications for the pattern, practices, market culture, production systems, and maintenance networks (Geels, 2004).

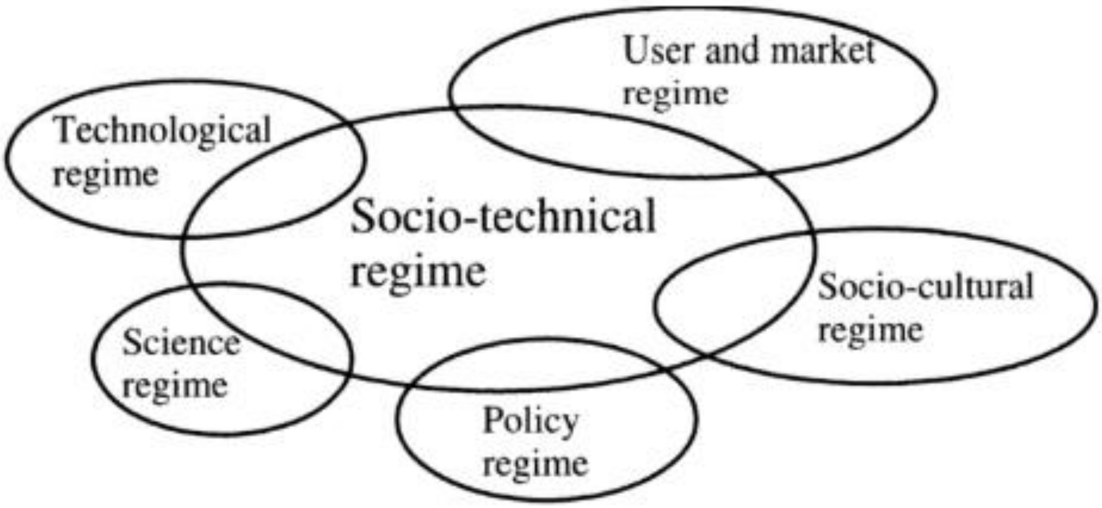


Figure 20: Meta-coordination through socio-technical regimes (Geels, 2004).

This conceptual perspective finds its roots in evolutionary economics, it aims to give a detailed account of the paths and trajectories of technologies. The cognitive routines common to both engineers and designers in various companies are referred to as technological regimes (Rip and Kemp, 1998; Geels, 2004). These linkages between heterogeneous elements aid in ensuring stable socio-technical configurations which emanate from the coordinated activities of the social groups that produced/reproduced them. Search heuristics is an example of routines that influences innovation in specific directions, it often leads to the optimal improvement of existing technologies (Rip and Kemp, 1998; Geels, 2004). Consequently, engineers are not solely responsible for influencing trajectories, trajectories are often influenced by the collective network of multi-actors involved in socio-technical regimes which include policymakers, societal groups, scientists, capital banks and so on (Geels, 2002).

According to Rip and Kemp, (1998), technological regimes are predetermined set of rules that provide guidelines for product process technologies, complex engineering practices, skills and procedures, how to handle relevant artefacts and persons and the methods of defining problems in institutions and organisations. Since the regimes (rules) are deeply rooted in corporate governance structures, manufacturing procedures and product characteristics, they are often difficult to change. Consequently, technological regimes give rise to incremental innovations which modify the dominant design along the path of the technical trajectories without altering the basic design rules within the socio-technical system (Geels, 2005a). Genus and Coles (2008), argued that incremental innovations could easily pass for radical innovations due to performance improvement developments over a long period of time such that it has completely evolved into a different technology, as it is the case for telephones.

Technological regimes govern the activities of communities and social groups which account for the stability and coordination that exists in socio-technical configurations leading to stable technological developments (Geels, 2002; Geels, 2005a). Therefore, technological regimes are responsible for selections and deeply structured retention mechanisms, which do not give room for radical innovation due to the multiple path dependencies that exist between the various socio-technical regimes; user and market regimes technological or product regimes, science regimes, socio-cultural regimes, policy regimes see figure 20 above. Although the rules in a socio-technical regime are often aligned with one another which provides stability and coordination (Geels, 2002; Geels, 2005a; Geels and Schot, 2007). However, the rules which make up the socio-technical regime are regarded as a semi-coherent set of rules (cognitive, normative and regulative) with the potential to cause tension and misalignments thus leading to instability of the regime which could create a ‘window of opportunity’ for successful niche innovations such as low carbon technologies (DH) to emerge (Geels, 2002; Geels, 2005a). The MLP recognises that resource availability such as knowledge, capacity and the extent of resource deployment are essential ingredients for transitions (Geels and Schot, 2007). Also, Smith, Stirling and Berkhout, (2005), as well as other researchers (Geels and Schot, 2007; Smith, Voß and Grin, 2010a), posit that, in order to change socio-technical regimes, internal niche-regime interactions and external landscape pressures are necessary. It could also result from changes in the landscape or interaction with another regime which causes a strain in the configurations of the existing regime. Smith's research acknowledges the potential for more deliberate policy initiatives to foster socio-technical transitions (such as the transition to low carbon technologies such as DH towards an environmentally sustainable future).

3.2.1.3. Sociotechnical Transitions

The complex process of deep structural change to a socio-technical system is referred to as "transition." It includes changes in the configurations of policy, infrastructure, markets, scientific knowledge, technology, cultural context, and consumer practices (Geels, 2011). With increased awareness of global sustainability challenges, there has been growing interest in understanding sociotechnical transitions. Solving 'wicked' problems (problems that are challenging and difficult to solve due to interdependent factors) like climate change, depletion of natural resources, and environmental degradation require radical changes in socio-technical systems (Markard, Raven and Truffer, 2012). The urgent need to transition to more sustainable systems has sparked research and discussion about how socio-technical systems can be actively governed by policy instruments or broader actions (Kemp, Schot and Hoogma, 1998; Kemp, Loorbach and Rotmans, 2007). Socio-technical transitions involve the conversion from one socio-technical system to another through an active process of refinement and reconfigurations fulfilled by sociotechnical systems which include a combination of urban pathways, modes of governance, practices, networks, people, culture, technology, infrastructure, and goals that enable transformational change (Geels, 2005b). It involves the shift, substitution, and reworking of assemblages of coordinated elements such that the substitution of one element can induce changes in other elements of the socio-technical system (Geels, 2005a).

The activities of social groups such as academic institutions, organizations, public authorities, focus groups and users play an important role in transitions and are responsible for the change in elements and linkages in sociotechnical transitions (Geels, 2005b). An understanding of the dynamics of socio-technical transitions will give insights into the technological and social changes that enable or inhibit socio-technical transitions in order to proffer solutions that foster successful transitions (Papachristos, 2014). Research on sociotechnical transitions encounter two major interrelated challenges centred on (i) generating a detailed chronological analysis of historical and up-to-date socio-technical system transitions in order to develop and propose effective modes of governance and system transitions towards sustainable trajectories with less impact on the environment and (ii) advancing and refining the analytical frameworks and tools used in analysis (Papachristos, 2014).

3.2.1.4. Niches

Niches are key concepts in socio-technical transition processes, they are "protected spaces" within a socio-technical system where innovations can emerge free of the selection pressures of the incumbent regime. Since the stability and path dependencies that exist within socio-technical systems inhibit the creation of radical innovation and only bring about incremental innovation within socio-technical systems, how then do radical innovations emerge? Radical innovations often emerge as ‘’hopeful monstrosities’’ (Mokyr, 1990). While they have the potential to perform specific functions they are referred to as ‘’ monstrous’’ because of their initially unrefined and relatively low technical performance, high costs and complicated nature. Thus radical innovations are a lot more difficult to change within socio-technical systems and are developed in niches (Geels, 2002). In the context of this research DH can be said to be a radical innovation in a niche that needs to be protected in order to emerge.

Niches provide the needed shelter and protection to aid the development/improvement of radical innovations which prevents them from being available for mainstream market selection until they have been tested for high performance. Strategic niche management provides extensive analysis and description of internal niche operational processes in the emergence of radical innovations. Several strategic niche management scholars (Schot, Hoogma and Elzen, 1994; Kemp, Schot and Hoogma, 1998; Hoogma, 2000; Kemp *et al.*, 2001) posit that three processes are pivotal to the construction and development of niches which are:

i. A social network structure that can support novelties.
ii. Learning and development processes that can foster increased price/performance ratio of radical technologies as well as their alignment with wider socio-technical systems. Learning processes are multi-dimensional in nature they occur on both the user side and the supply side. The user side involves regulation, symbolic meaning, user preferences, infrastructure, symbolic meaning and polices while the supply side involves technology, production networks and policies.
iii. The creation of clear goals and expectations designed to achieve the desired outcomes. This aids in providing direction and structure to the learning processes as well as to expand the social network by attracting more actors.

   (Schot, Hoogma and Elzen, 1994; Kemp, Schot and Hoogma, 1998; Hoogma, 2000; Kemp *et al.*, 2001).

   The three interrelated analytical dimensions which are rules, actors and socio-technical systems are also applicable to niches. Niches differ from socio-technical systems in that they do not have as much stability. Furthermore, niches have some degree of protection which may give rise to uncertainties around the most suitable design heuristics, user preferences, social network, and public policies that will be ideal for the real world. The experimental projects that take place in niches are often based on certain conditional circumstances, as not all actors are involved in some projects (Rip and Kemp, 1998; Geels, 2002, 2011; Geels and Schot, 2007). Also, there are no concrete rules, clear role relationships, interdependencies and normative rules which often leads to unstructured activities. The socio-technical configurations that obtain in niches are also not fixed. They are constantly changing due to the speculations around the suitable architectural arrangement, the component elements in the technical system and the arrangement with regards to infrastructure, the supply of tools and components. Though niches give room for exploring varieties of experimental tests, the more uncertain the rules are the more unstructured the activities become (Kemp, Schot and Hoogma, 1998; Hoogma, 2000; Kemp *et al.*, 2001). However, in due course the rules and social networks may stabilise as a result of various successive learning processes which can increase the technical performance, thus attracting more actors to get involved, consequently aligning the socio-technical configuration and making the niche more stable. It is therefore important that actors ensure that well-articulated rules and concrete social networks are established in order to provide the needed structure and support to sustain the niche (Geels, 2004). According to García-Olivares (2015), new technologies and energy systems do not diffuse all through the economy rapidly, it takes approximately 50 years. This suggests that the technologies and system innovations that are currently being tested in niches will be the ones to substitute fossil fuel 50 years from now. While niches are agents of change created to provide solutions to the problems of the existing regimes, it is often difficult to break through the stability created by the existing regime because radical innovations are often incompatible with the existing regime which often leads to the failure of the niche innovations see figure 21.

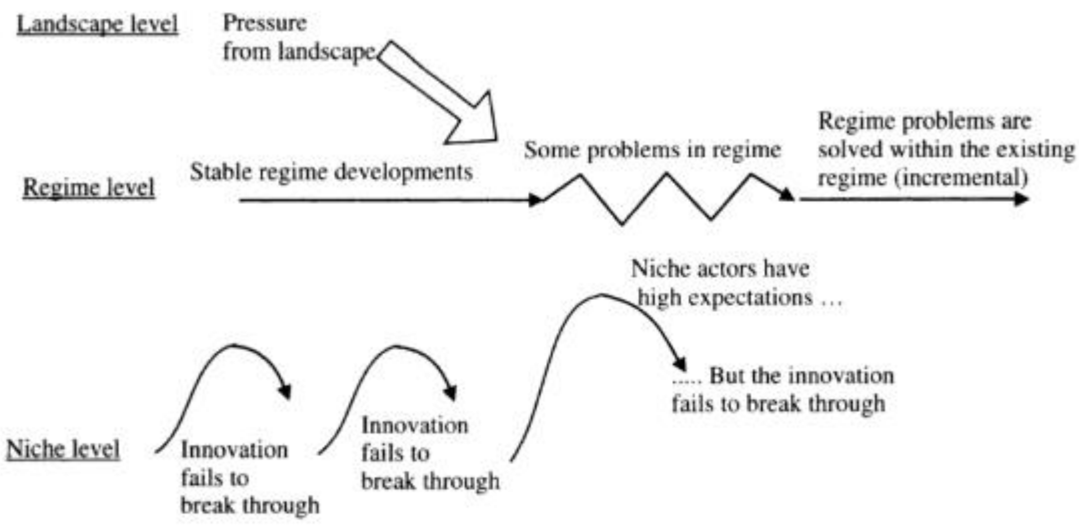


Figure 21: Failures of Niche Innovations (Geels, 2005a).

While niches processes provide an understanding of transitions, the literature acknowledges that niche processes are not able to independently instigate regime changes (Smith, Stirling and Berkhout, 2005; Kemp, Loorbach and Rotmans, 2007). In this study DH development processes are not able to independently enable the changes in policies, user preferences, market, technology, culture as they do not have existing markets and user preferences in place. Niche innovations are nascent social or technological innovations that are radically different from the existing socio-technical system and regime, but are capable of establishing improvements in specific applications or geographical areas through focused policy support (Kemp, Schot and Hoogma, 1998).

The MLP thus provides a detailed analysis of the socio-technical system of niche, regime, and landscape levels, while conceptualizing the dynamic processes of socio-technical transitions (Rip and Kemp, 1998; Geels, 2002, 2011; Geels and Schot, 2007).

3.3. Governing Innovation and Technological Change for Social-Technical Transitions

Owing to the configuration and alignment between the elements of a socio-technical system, such transition processes do not easily occur. Transitions to new technologies can be an uphill task due to the array of elements such as user practices, maintenance networks, infrastructure, and regulations aligned and coordinated to operate with the existing technology (Geels, 2002). However, evidence has shown that it is possible to undo socio-technical configurations to allow for the transition to new technologies. The big question is how do technological transitions occur and how can the barriers and limitations be overcome? Socio-technical transitions involve the shift, substitution, and reworking of assemblages of coordinated elements. The substitution of one element can induce changes in other elements of the socio-technical system (Geels, 2005a). However, radically new technologies do not have existing markets and user preferences in place, these simultaneously evolve with the new technology (Geels, 2002).

Socio-technical transitions in the energy system calls for innovation and technological changes which are deeply rooted in broader social and economic contexts at the system level (Geels, 2005a). The focus is on the innovation capabilities to deliver low-carbon technologies within social structures and institutional settings, with a view to securing sustainable solutions that fulfil societal functions (Kern, 2012). The practical definition of technology put forward by Rip and Kemp (1998) defines technology as ''configurations that work''. ''Configurations'' in this case is the coordination and alignment that exists between heterogeneous elements ''that work'' to fulfil a function. This definition lays emphasis on two integral aspects which are the configurations and functionalities. All technologies must possess the appropriate conceptualisations of the configurations between the social and technical elements in order to fulfil a function. The conceptualisation of technology as a heterogeneous configuration of elements that work is a productive way of analysing system innovation at different levels (from firms to socio-technical systems). This is because it highlights the functions of the technical and social aspects and the links that exist between them (Geels, 2005a).

Technology is heterogeneous and linkages between component elements are required for the functioning of technologies. The term ''seamless web'' is a metaphor coined by Hughes (1987) to describe the way tangible artefacts, natural resources, legislative artefacts (laws), organisations (investment banks, manufacturing industries, research and development (R&D) laboratories) and scientific elements (books, articles) are integrated to achieve functionalities. The linkages between elements are regarded as basic ontology in Actor-Network Theory, where it is believed that elements do not exist without linkages as links between social and technical changes are created during transformational processes (Latour, 1991; Law and Callon, 1992; Geels, 2005a).

The analytic focus in this research needs to be broadened to the whole socio-technical system to provide a broad analysis of the interplay between the elements. Studies on sustainable development tend to focus on how to incorporate 'incremental change' with the existing technology within a system to deliver on sustainability goals (Kemp, 1994; Berkhout, 2002; Unruh, 2002). While, studies on transitions to a low carbon economy pertains to the investigation of changes in institutions by addressing policy-making processes in a wider social, economic and political context (Scrase *et al.*, 2009).

The transition to low carbon technologies requires the widespread deployment and diffusion of low carbon technologies and adjustments in institutional frameworks and policies. Studies on socio-technical transitions seek to understand technological and social change through the analysis of the factors that enable or inhibit them. A huge part of the studies on socio-technical transitions involves proposing policy recommendations and strategic direction that can drive socio-technical transitions (Papachristos, 2014). However, the major challenge is how to leverage policies to support sociotechnical transitions and what policy instruments can effectively support low carbon transitions as policies must address the need to support the widespread deployment and high diffusion of low carbon technologies throughout the entire energy system (Berkhout, 2002).

The component elements of socio-technical systems are created and managed by human actors entrenched in social groups. Socio-technical systems cannot function or achieve functionality without human actors. The social groups in modern societies are often designed to interact with the elements of socio-technical systems. Social groups influence the stability and trajectory of socio-technical systems by adhering to specific sets of rules referred to as sociotechnical regimes. Regimes can be described as a partially consistent set of rules connected to each other making it extremely difficult to change a rule without modifying the others. Socio-technical systems often take several years to develop, establishing coordination, stability and path dependencies that become resistant to change (Papachristos, 2014; Geels, 2018).

Existing socio-technical systems and regimes often serve as barriers to technological change owing to the lock-in and path dependencies to unsustainable mechanisms which cannot meet the challenge of climate change. As such, energy transitions will involve adjustments in the established order and changes in technology, consumer habits, markets, business models, policies, infrastructure and cultural significance. This will include embedding strategies that can foster structural changes in technology, institutions and practices all through the economic sector while aligning policies to address issues such as resource scarcity and depletion, accessibility, affordability, climate change reliability and quality of energy services, and energy supply security to drive the transition to a low carbon economy in order to tackle the climate change challenge (Geels, 2011, 2018; Geels *et al.*, 2017).

While innovations and technological change are vital elements for socio-technical transitions, the social aspects are also integral to the transition process. Developing an understanding of transition processes which co-evolve and are interlinked (Geels, 2005a) will, therefore, require the analysis of the social (non-technical) aspects of the socio-technical system. The primary concern is to include the constructive role of social actors in institutionalizing policies and shaping technology and practices which have not been fully explored in the literature in order to provide a broad understanding of the transition processes and to contribute to the social aspects of socio-technical transition.

Since technological and social change which co-evolve are intertwined and are both essential for socio-technical transitions an in-depth understanding of the social groups will provide a broad analysis of the co-evolution, alignment and multidimensionality of the whole system which has not been fully developed in the literature. This integrated approach is an existing gap in the literature that requires further research which will be beneficial for future references.

In the energy system, landscape pressures (such as climate change) influence energy policies and have led to the advent of ambitious goals setting and carbon reduction commitments in the pursuit to mitigate climate change and for sustainable low carbon growth and development. However, these targets are challenged by lock-in to existing systems and technologies, which can lead to incremental technological innovation, rather than a whole system structural change in the energy system. A key objective in this research on the socio-technical analysis of large-scale DH implementation in urban environments is to provide more understanding of the enablers and barriers of low carbon transitions in their wider political, social and economic contexts to foster innovation and technological change.

3.4. Development of Transition Studies

In the last 20 years, several development trajectories have been observed in studies of sustainable transitions, system innovation, and socio-technical regime change. Transitions research has branched out into several distinct analytical approaches and research strands, (See figure 22) each focusing on distinct components of the transition process and using a variety of different analytical constructs, drawing on knowledge from innovation studies, evolutionary economics, the concept of technical paradigms, and innovation systems research (Nelson and Winter, 1982).

In the field of transition studies, there are increasing concerns surrounding the changes that take place within socio-technical systems during transition processes. There are a number of frameworks and approaches that have been applied as a theoretical basis for case study research on socio-technical transitions, to contribute to the understanding of how socio-technical transitions might be governed. However, four main approaches have attained prominence these include:

a) Transition Management (Rotmans, Kemp and Van Asselt, 2001; Kern and Smith, 2008; Loorbach, 2010):The policy and application based approach transition management approach posits that different forms of governance are required to resolve complex sustainability challenges in order for the required transitions to occur.
b) The Strategic Niche Management (Rip and Kemp, 1998; Smith, 2007; Raven and F W Geels, 2010): Strategic niche management emphases on the function of niches in driving transitions, it provides extensive analysis and description of internal niche operational processes in the emergence of radical innovations (Rip and Kemp, 1998). Niches can be likened to ''incubator rooms'' that serve as locations of testing, learning, and development as well as the creation of market and social networks that support the development of radical innovations and novelties (Geels, 2002).
c) Technological innovation systems (Jacobsson and Johnson, 2000; Hekkert *et al.*, 2007; Bergek *et al.*, 2008): This approach assesses the performance of specific innovation systems by identifying the key processes that enable the development, penetration and use of the new technology. It also identifies the factors that affect performance as well as the main policy issues in order to inform future policy decisions (Bergek *et al.*, 2008).
d) The Multi-Level Perspective (Geels, 2002; Geels and Schot, 2007; Smith, Voß and Grin, 2010a): It is formulated on the theory that transitions occur as a result of the interactions between multiple levels which influence one another (Geels, 2005a; Geels, 2011).

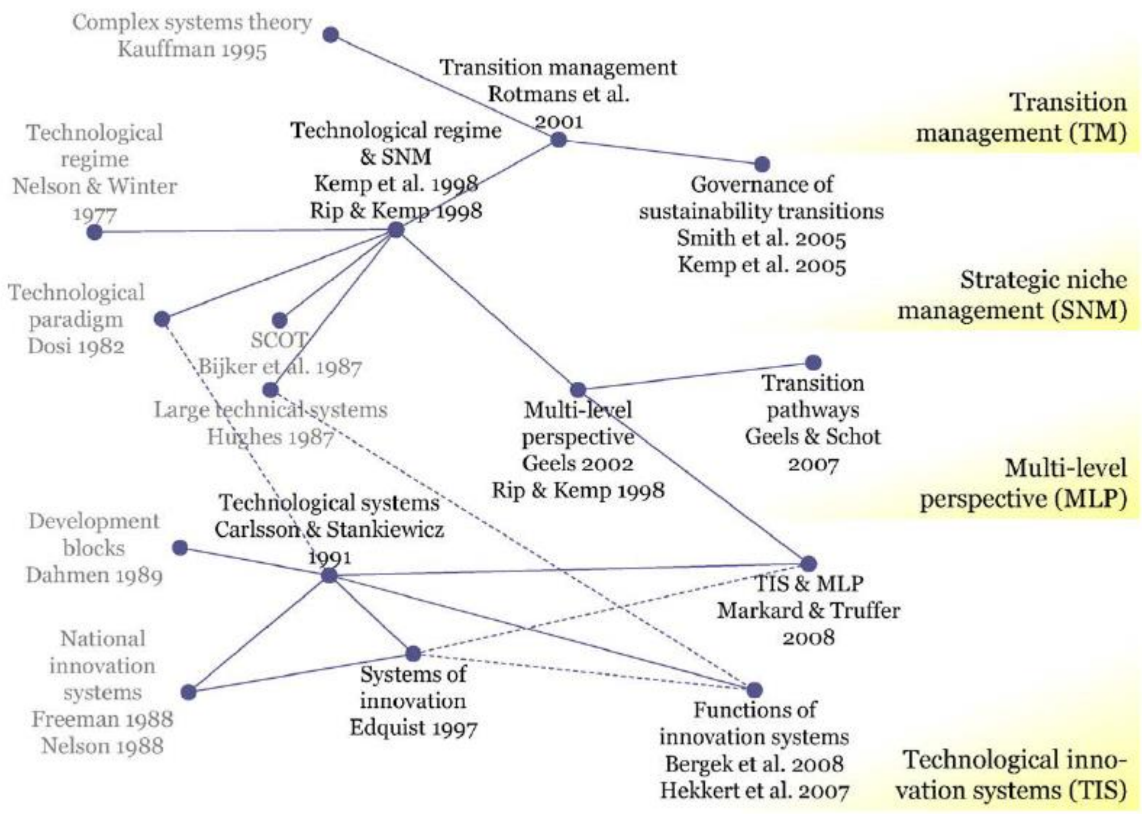


Figure 22:Map of key contributions and research strands in the field of sustainability transition studies (Markard, Raven and Truffer, 2012)

A number of other relevant theoretical system approaches have also been utilized in transition studies such as actor-network theory (ANT) (Callon, 1986; Law and Hassard, 1999), the social construction of technology (SCOT) (Bijker *et al.*, 1989), large technical systems theory (LTS) (Hughes, 1987; Mayntz and Hughes, 1988; Coutard, 1999) and constructive technology approaches (Rip, Misa and Schot, 1995). The various theories on governing transitions are widely debated. Key aspects of such debates centre around the causes of regime change; the capacity of various actors to affect change, the actors responsible for governing transitions and the role of policies in pivoting transitions. Given that the actors seeking to govern change operate within the system and are constrained by the incumbent regime, some scholars question the possibility of governing transition in a complex socio-technical system (Shove and Walker, 2007).

The four main research strands are at least partially and conceptually related and often used in conjunction with each other with more explicit conceptual and analytical connections between the concepts and analytical constructs. The rest of this chapter presents and discusses key aspects of the MLP on socio-technical transitions in relation to their relevance in answering the research questions.

3.4.1. The Multilevel Perspective (MLP)

Dutch scholars who merged studies from sociology of technology, evolutionary economics and institutional theory, to apply hierarchical levels of innovation from a multi-level perspective to understand the past and future dynamics of socio-technical change were the early proponents of the MLP (Rip and Kemp, 1998; Rotmans, Kemp and Van Asselt, 2001; Elzen, Geels and Green, 2004; Geels and Schot, 2007). Subsequently, the MLP was further developed by Geels (2002b, 2004, 2005b, 2006b, 2006a, 2007), and it is now widely used to describe long-term transition processes as a set of actor network and institutional dynamics occurring at the micro level niches, meso level socio-technical regimes and macro level socio-technical landscapes (Geels, 2002).

The MLP is an analytical framework that builds a conceptual perspective on system innovations and socio-technical transitions based on the findings derived from various works of literature integrated to form different multiple levels. It is formulated on the theory that transition processes occur as a result of the interactions happening in a multi-layered system which influence one another (Geels, 2005a; Geels, 2011). It is a concept that has been used to describe and analyse sustainability transitions in various systems, such as the energy system, transportation system, and the heat and cooling system. The MLP posits that socio-technical transitions emerge by the interaction and alignment between three levels of structuration, the current regime, radical niche innovations and the socio-technical landscape (Rip and Kemp, 1998; Geels, 2002). As shown in figure 23- a level of confined technological niches within a socio-technical system that serve as "protected spaces" and a testing ground for new technologies where innovations can emerge free of the selection pressures of the incumbent regime; a level of socio-technical regimes (for example, the energy system) that provide stable structures and a selection environment for innovations; and, thirdly the socio-technical landscape, which includes cultural norms, values, and relatively stable broader social structures that influence niche and regime dynamics, as well as the socio-technical system structures (Rip and Kemp, 1998; Geels, 2002). These three levels are applicable to all major socio-technical systems. (Rip and Kemp, 1998; Geels, 2002), however all definitions and descriptions in this study are focused on energy system transitions. According to Geels, (2002) the three levels where originally described to form a nested hierarchy where niches were created within regimes (see figure 23) in relation to local practices..

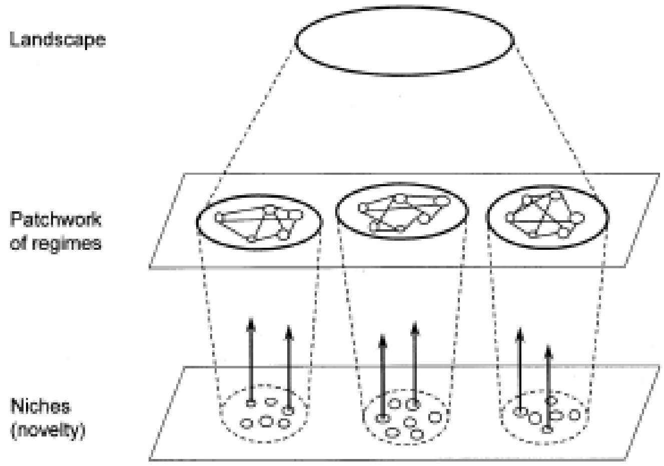


Figure 23:The MLP as a nested hierarchy (Geels, 2002).

However, in response to criticisms from Shove and Walker (2010), about the use of a nested hierarchy to describe processes which might be happening in a flat plane Geels adjusted this. It was refined to be understood that higher levels are more stable than lower levels with regards to the number of actors and the degree of alignment between the elements and niches are not necessary in a spatial manner. These levels are not meant to be hierarchical representations of reality, but rather to serve as analytical concepts. Transitions occur when micro-level innovation evolves and is introduced to modify the mix of regimes, eventually transforming the macro-level landscape (Geels, 2011).

Using the heat system as an example, at the landscape level, external factors such as environmental problems caused by climate change influence the development/transition of the heat system but are beyond the control of individual actors. In this instance, growing environmental concerns and awareness campaigns on climate change is responsible for the development of technical trajectories in certain directions as opposed to other directions, giving rise to the increasing demand for low-carbon technologies such as DH. The existing fossil-fuel-based energy regime is marked by the dominance of certain technological artifacts, networks, cultural meanings, user practices, institutions, market structures, cultural meanings, scientific knowledge, and regulatory frameworks. In order to reduce carbon emissions, significant adjustments to current energy systems are required. Consequently, transitions require disruptions in the established order and a whole system reconfiguration with transformational changes not only in technologies, but also in consumer behaviours, policies, infrastructure, production networks, business models and market culture referred to as socio-technical transitions (Geels, 2011, 2018; Geels *et al.*, 2017).

The MLP, defines transitions as shifts from one sociotechnical regime to another. They occur as a result of the interaction processes at the niche-regime-landscape interface; niche-innovations build up internal momentum for change, while landscape changes create pressure that destabilises the socio-technical regime, which creates opportunities for niche-innovations to emerge in the socio-technical system and replace the existing regime as shown in figure 24. The MLP posits that niche-regime-landscape processes must be aligned for a transition to occur (Rip and Kemp, 1998; Geels, 2002).

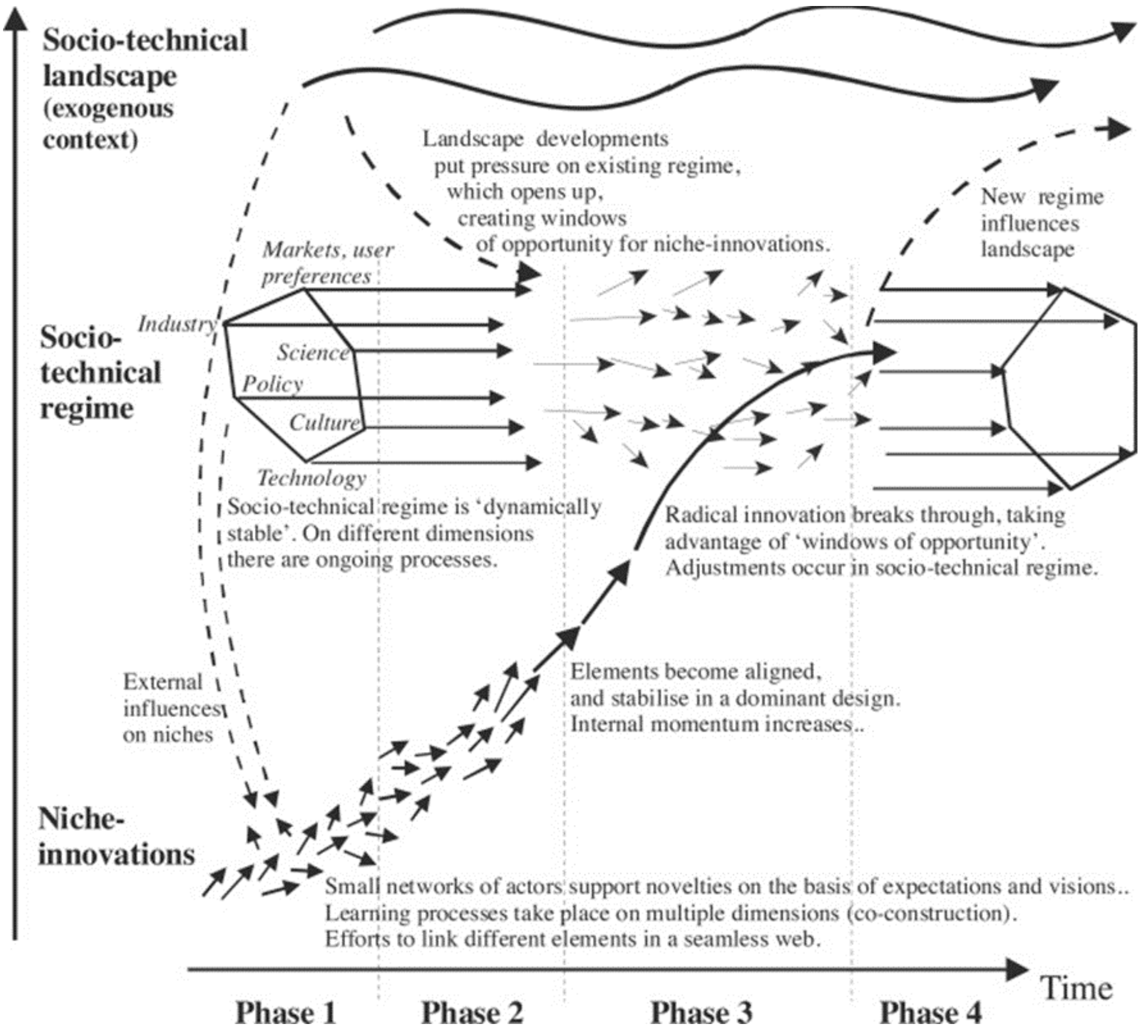


Figure 24:Multi-level perspective on socio-technical transitions (Geels *et al.*, 2017).

The multi-level concept implies that transition paths are generally non-linear and involve the transition of different phases from one dynamic equilibrium to another. As a result, the evolving pathway scenarios can be further subdivided into four transition phases, with each transition pathway comprising of four transition phases (Loorbach & Rotmans, 2006; Rotmans et al., 2001):

- A predevelopment phase characterised by a dynamic equilibrium in which there are numerous actions at the stakeholder level but few changes at the system level.
- The take-off phase where the system-level change process occurs.

- The breakthrough or acceleration phase characterised by observable structural changes at the system level.
- The stabilisation phase that marks the conclusion of a transition, where the rate of change slows, and a new dynamic equilibrium is attained.

The strength of the MLP lies in the dynamic nature of its multi-dimensional (non-linear) processes that occur through the interactions of the three analytical and heuristic levels for system innovation (Rip and Kemp, 1998; Geels, 2002), which are discussed in more details in subsequent subsections.

3.4.1.1. Micro Level Niches

Potential new technologies are developed at the micro level in technological niches with small, shielded spaces. Niches serve as incubators for technological maturation, the emergence of shared trajectories, and the development of supporting structures (Schot and Geels, 2008). It is considered to be the birthplace of radical innovation, which is mostly carried out by small networks of dedicated actors who are usually outside or fringe actors, such as environmental activists (Geels and Schot, 2007). Technological projects and emerging technologies are initially unstable and low-performing niches provide protected spaces for experimentation against market selection pressures to enable radical innovations for new technologies and social practices to emerge (Kemp, Schot and Hoogma, 1998). The network of actors provide protection through investment in the development of new technologies that create spaces for vital internal processes, such as learning by doing, learning by using, and learning by interaction, as well as the formation of social networks (Verbong and Geels, 2007).

When niches and niche actors reach a sufficiently advanced stage of development, they enter a co-evolutionary process with incumbent regimes, the nature of these processes are often dependent on both niche and regime stability, as well as the intensity of top-down landscape pressure. The regime may undergo an internal transformation process or engage in a broader process with the developing niche. Transitions do not only occur at this level, other elements of the socio-technical systems, such as infrastructure, networks, and regulation, evolve alongside the transition of technology and market share (Greenacre, Gross and Speirs, 2012). As a result, niche accumulation occurs, allowing diffusion to increase market share and, eventually, competing with and overthrowing the incumbent (Geels and Schot, 2007). Internal tensions within the overall sociotechnical regime are sometimes generated by the internal dynamics of sub-regimes, which provide opportunities for transition (Geels, 2002). The transition process can take several different forms. Geels and Schot (2007), proposed a potential typology based on the timing and existence of niche regime interactions. Although they are described as four transition pathways, in reality, they are unlikely to adhere strictly to a single pathway, a series of different sub-transitions may take place (Geels and Schot, 2007). Geels *et al.*, (2016) refined this typology, resulting in the following proposed pathways.

Transformation Pathway : In this pathway, pressures from the external landscape-level cause tension in the regime while the niche innovation is not sufficiently developed to emerge. The dynamics of the regime is therefore redefined by modifying the internal processes of the regime.
De-alignment and re-alignment Pathway: Pressures from the external landscape-level cause the regimes to first disintegrate, multiple niche innovations make use of the space created to emerge. These innovations compete for a long time until the realignment processes take place around a single innovation resulting in a stable new regime.

Reconfiguration Pathway: This occurs when ' symbiotic ' innovations are implemented as auxiliaries by existing actors to address local problems within the current regime due to external landscape pressures. Over time, their involvement causes changes to the entire structure of the regime.

Technological Substitution Pathway: This occurs when the niche-innovations are well established, and landscape changes create pressure in the regimes. The instability in the regime provides a window of opportunity for the niche innovation to emerge thus replacing the regime. Alternatively, niche-innovations can attain high internal support (due to capital investments consumer demand, social interest, political support, etc.) such that they can substitute the existing regime without the intervention of landscape pressures.

According to the literature on socio-technical transitions, niches play an important role in enabling a wider transition (Kemp et al., 1998; Geels, 2004; Smith and Raven, 2012). In theory, they allow for the development of an innovation until it reaches a stage where it can be diffused within the larger regime. As a result, they have received a lot of attention in the literature on governing socio-technical transitions – especially in the case of sustainable transitions, where many innovations are still in the early stages of implementation and diffusion (Smith and Raven, 2012).

3.4.1.2. Meso Level Socio-Technical Regimes

Regimes are existing dominant frameworks that govern the interaction of actors, institutions and other elements of the sociotechnical system to ensure stability is maintained and to strengthen the system. Regimes are identified by path dependency and regime lock-in (see table 4), which are the result of stabilising mechanisms such as organisational capital, sunk investments, vested interests, and strong beliefs (Verbong and Geels, 2007). However, organizations do not share identical cognitive routines, such as technological pursuit, problem definitions, belief systems, and guiding principles, which may lead to the misalignment of technological transition trajectories, causing instability in the regime (Geels, 2004; Greenacre, Gross and Speirs, 2012).

Regimes are often viewed as more than just a set of laws and institutions; they are often viewed as coordinated actors in the political arena (Hess 2014). Incremental innovation is usually activated to provide stability due to the alignment of activities and interactions between elements that span the production and consumption divide, such as scientists, engineers, policymakers, investors, normative patterns and customers (Geels and Schot, 2007). Consequently, optimization rather than transformation is emphasized at the regime level, resulting in incremental innovation because of the locking mechanisms.

Table 4:An overview of industry regime lock-in by source, adapted from (Unruh, 2002; Geels, 2004).

Lock-in	**Examples**
Technological	Dominant design, standard technological architectures and components, compatibility
Shared mindsets, cognitive frames	Routines, preferences, blinding actors to development outside their focus, cognitive schemas
Industry	Industry standards
Regulatory institutions	Government policy, legal frameworks, departments

Established regimes only change in response to micro-level pressure (bottom-up developments), internal tensions within the system, and external pressures. They may vary from being self-protective and attempting to limit other actors to only adopt reactive approaches to improve their system, or on the other end of the continuum, they can find ways to actively contribute to transitions (Rotmans, Kemp and Van Asselt, 2001). Socio-technical regimes generally comprise of three interconnected elements: (a) a network of actors and social groups, (b) rules that govern interaction (regulations, standards, laws), normative (value and norms pattern), cognitive, and (c) tangible elements - physical infrastructures (Geels and Schot, 2007). The reliance on fossil fuel transmission and distribution systems, and energy-intensive activities characterises the dominant energy production system globally. Sunk investment costs, regulation, the stability of existing infrastructure, cognitive and normative rules, and interdependency between actors and material networks act as barriers to the expansion of innovation alternatives to address pressing sustainability development goals such as greener and cleaner energy production and sustainable consumption patterns (Schot and Geels, 2008; Geels *et al.*, 2016; Kanger and Schot, 2019).

3.4.1.3. Macro Level Socio-technical Landscape

The socio-technical landscape which is the macro-level influences the niche and regime dynamics, and the socio-technical system structures. It includes deep structural trends such as macro-political developments, macro-economic and socio-cultural patterns (Verbong and Geels, 2007). Technological trajectories occur within a socio-technical landscape, it is regarded as the prevalent situations and structural trends that take place in large-scale societal contexts such as factories, cities, energy systems, and highways. The metaphor ‘’landscape’’ connotes the relative hardness of the material contexts of the society in which it operates. Socio-technical landscapes involve groups of heterogeneous factors that provide the external structure and contextual situations for the interaction of social actors which are often exogenous. Examples of socio-technical landscapes include oil prices, political coalitions, wars, environmental problems (climate change) scarcity of resources, cultural and normative values and economic issues (Rip and Kemp, 1998). They are responsible for providing the basis for the development of technical trajectories in certain directions as opposed to other directions.

Socio-technical landscapes refer to broader technology-independent contexts that influence the regime but cannot be easily influenced by regime actors as a result of the symbols and values, collective cultural beliefs, and the relative material hardness which form a ‘’gradient’’ for actions often difficult to depart see figure 25. Consequently, a socio-technical landscape is often much more difficult to change in comparison with socio-technical regimes. The landscape is an external context that cannot be easily influenced by the regime actors in the immediate term, examples include climate change, oil prices, conflicts or war. Pressures from the external landscape shape the sociotechnical regime. Landscape conditions do not influence the regime directly, however, the regime actors analyse and address the situation by taken actions (Geels and Schot, 2007).

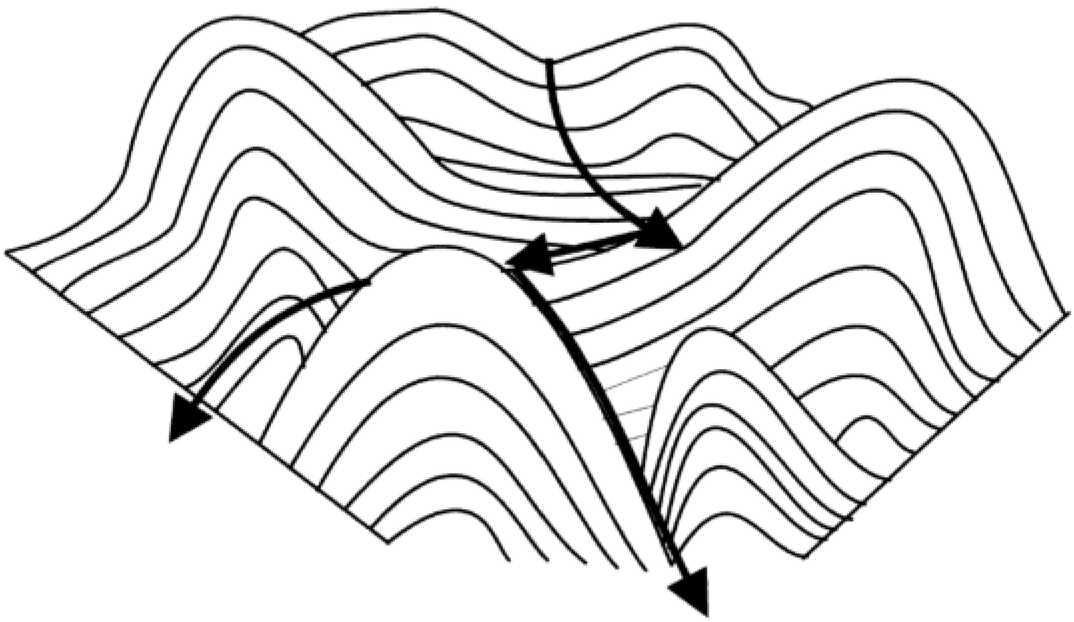


Figure 25: Landscape as a Context for Technological Trajectories (Sahal, 1985, p. 79).

Two types of changes occur in landscapes which could either be relatively slow changes or relatively fast developmental changes. Examples of relatively slow changes include political cultures and ideologies, as well as cultural and demographic changes (environmental conditions: rainfall, climate change, and soil), which form deep structures that cannot be changed at will forming the Longue durée (which are deep structures formed in the macro level) (Braudel, 1958). Examples of relatively fast developmental changes include economic issues, war, and oil prices (Geels, 2005a).

In the history of, the MLP and its core analytical constructs, the niche, regime, and landscape have been used to analyse several transition studies that focused on historical processes in the early stages of its development (Geels, 2002, 2006b, 2006a; Van Driel and Schot, 2005). This approach, however, has been used to describe more recent and ongoing developments, though the focus of these studies was more on niche-regime and inter-regime interaction (Raven, 2006). Table 5 provides an overview of the transition studies that have made use of the MLP, with details of the the technology, sector, the author and year of publication.

Table 5: An overview of the transition studies that have made use of the MLP

Observed *(transitioning)* technology	Sector	Author	Year of publication
Steam ships	Transport	Geels	2002
Grain elevators	Logistics/transport	Van Driel and Schot	2005
Sewer systems	Waste management	Geels	2006
Turbojet aircraft engines	Transport	Geels	2006
Waste management	Waste management	Geels and Kemp	2007
Rock'n'roll	Performing arts	Geels	2007
Biomass	Waste management, Energy generation	Raven	2007
Nuclear energy	Energy generation	Geels and Verhees	2011
UK electricity system	Energy generation	Geels	2014
German and UK low-carbon electricity transitions	Energy generation	Geels, Kern, Fuchs, Hinderer, Kungl, Mylan, Neukirch, Wassermann	2016

While every transition is unique it is often distinguished by the interaction between processes at various levels: (a) the niche developments, (b) the landscape changes create pressure on the regime. For example, climate change pressures may act as a destabilizer which instigates the development and deployment of low-carbon technologies thus restructuring the regime (c) destabilisation of the regime gives rise to ''windows of opportunity'' for niche- innovations. (Geels, 2011).

3.4.2. The Role of Intermediaries in Socio-technical Transitions

Intermediaries are actors and institutions that range from trade associations, non-governmental organisations (NGOs), public bodies, or consultants which serve as connectors and mediators, that play a critical enabling role in the delivery of niche nurturing processes (Kivimaa, 2014; Küçüksayraç, Keskin and Brezet, 2015). Intermediaries have been identified as critical catalysts for accelerating the transition to more sustainable socio-technical systems. In the literature on sustainability transitions, there has been a recent increase in the number of articles on intermediaries, emphasising the critical role of intermediaries in transition processes. This include connecting both new and incumbent actors and their associated activities, exchange of knowledge, development of skills and standards to support innovation processes, and resources in order to generate momentum for change, establish new collaborations around niche technologies, ideas, and markets, and disrupt existing socio-technical configurations (Geels and Deuten, 2006; White and Stirling, 2013; Fischer and Newig, 2016; Kivimaa *et al.*, 2019).

The literature on the role of intermediaries in socio-technical transitions provides a conceptualization of how intermediaries can facilitate and support socio-technical transitions. Shifts in the relationships between actors, infrastructures, and technologies and application contexts characterise the transition of sociotechnical systems. The need for intermediary action is exacerbated by the changes in contexts as well as changes in positions and interconnections between actors which would benefit policy-makers, academia and other stakeholders in the energy system towards the development of a clean energy future (Kivimaa and Kern, 2016; Kivimaa *et al.*, 2019). Since 2009, there has been a steady increase in interest in this topic, but progress has been slowed by a lack of agreement on the definition of intermediaries and the activities they perform or should perform during transitions. Numerous studies have addressed intermediary-like functions using concepts such as "middle actors" (Parag and Janda, 2014), "hybrid actors" (Elzen, Van Mierlo and Leeuwis, 2012), and "boundary spanners" (Franks, 2010; Smink *et al.*, 2015; Tisenkopfs *et al.*, 2015). Additionally, several terms relating to mediating space, like "user assemblages" (Nielsen, 2016) and "interaction arena," refer to intermediation in transition processes without specifically stating intermediaries (Hyysalo and Usenyuk, 2015; Hyysalo, Johnson and Juntunen, 2017). This research will provide more clarity to the definition and role of intermediaries in transitions by providing a typology of transition intermediaries that are sensitive to issues such as emergence, neutrality, and the goals of intermediary actors in transition processes using the MLP on socio-technical transitions, which is one of the most explicit strands of literature in its treatment of intermediaries.

3.4.2.1. Intermediaries and their role in supporting niche nurturing processes

To date, studies have concentrated on demonstrating the function of intermediaries in delivering niche nurturing activities and knowledge sharing between local niches (Hamann and April, 2013; Hargreaves *et al.*, 2013; Hodson, Marvin and Bulkeley, 2013; Kivimaa, 2014). As demonstrated by Hamann and April (2013) in a study of organisations in Cape Town, South Africa, intermediaries played a role in building a shared vision among actors for sustainable innovation, allowing collaboration between heterogeneous communities. Hodson and Marvin (2010c) and Hodson, Marvin and Bulkeley (2013) investigate the role of 'energy' intermediaries in enabling cities to play a role in transitions by building local actors' capacities and capabilities to act, as well as establishing a shared understanding of an innovation among multiple local actors, in two studies. Kivimaa (2014) reviews the literature on intermediaries in socio-technical transitions, highlighting the various roles that intermediaries can play, especially in supporting niche processes that allow actors to develop and learn about an innovation. There are several empirical studies of how intermediaries face common challenges as a result of their limited resources and capabilities, as well as a lack of devolved powers and the ability to restructure governance systems for actions at local levels (Hawkey, Webb and Winskel, 2013; Küçüksayraç, Keskin and Brezet, 2015).

3.4.2.2. Intermediaries and their role in enabling niche empowerment processes

While the majority of the existing literature on intermediaries focuses on nurturing activities occurring within niches, studies have begun to recognise the relevance of intermediaries in supporting niche empowerment processes. According to Geels and Deuten (2006), the establishment of a 'global' niche is a crucial aspect of this process, allowing an innovation to diffuse and be embedded into the regime. The collection of experiences and learning from a variety of 'local' niches which create an accumulated knowledge about the innovation is referred to as the global niche. The combined strength of the global niche has the potential to create a space within the existing socio-technical regime where an innovation can continue to expand. Geels and Deuten (2006), recognise the important role of intermediaries in facilitating knowledge exchange and aggregation across local niches. Intermediaries can also establish communication channels among regime and local niche actors in order to share experiences and communicate the values of niche innovations, as well as to convey regime perspectives into niches (Hodson and Marvin, 2010c; Hargreaves *et al.*, 2013; Kivimaa, 2014).

The activities that contribute to a transition by promoting niche empowerment processes are not currently examined in detail in the empirical literature on intermediaries. Rather than that, research has concentrated on how intermediaries foster innovation within niche areas. The initial research on the role of intermediaries in supporting systemic shift focused on the role of intermediaries in cities (Hodson and Marvin, 2010c; Hargreaves *et al.*, 2013; Kivimaa, 2014).

Hodson and Marvin (2010b) highlight how global cities such as London, New York, and Tokyo are developing and implementing their own urban transition ideas, rather than focusing on national-scale transmission of technologies (as is sometimes assumed by much of the transitions literature). This research posits that the role of intermediaries in transition processes require an understanding of the geographical scale and the actors' perceptions of the socio-technical system. Similarly, Hodson and Marvin (2013) also emphasise the significant role of the context and agency of intermediary actors in determining their potential to influence systemic socio-technical changes with a conceptual framework for examining the roles of intermediary activities.

The primary case study analysis in this research employs an analytical framework created by Kivimaa (2014) to identify intermediary activities that support niche processes within the case study. The framework is categorised based on the different roles that intermediaries can play in supporting niche nurturing processes. Kivimaa (2014) identified practical intermediary activities in these categories through a series of empirical examples. These serve as a guide in the primary case study (see chapter 7) to identify examples of intermediary activities in the DH development process. These categories are summarised in Table 6 below.

Table 6; An analytical framework for categorising the various types of intermediary activities according to their roles in sustainable transitions (1Kivimaa (2014) and 2Hargreaves et al. (2013)).

Expression of values and visions	**Establishment of social networks**	**Knowledge exchange and the facilitation of learning processes**
Strategy development	Alignment of interests	Knowledge acquisition, processing and combination
Raise awareness of technology benefits	Development and facilitation of new networks for learning and project delivery	Communication and knowledge dissemination
Acceleration of new technology use and commercialization	Identifying sources of funding to support initiatives.	Support and advice

An additional consideration is the role played by intermediaries in supporting empowerment processes. Brokering and coordination of partnerships beyond the niche was first identified as an intermediary role by Hargreaves *et al.* (2013) The following outlines practical examples of intermediary activities that support empowering processes for widespread adoption of a technology and the transition to a supportive regime, as identified by Hargreaves *et al.* (2013).

intermediary activities that support the brokering and coordination of partnerships beyond the niche

- Standardisation and accreditation
- Policy consultation
- Policy communication and implementation

Based on the findings from the initial analysis, a second framework is utilised to examine the characteristics of actors who deliver empowerment processes in the case study (Figure 26). Hodson et al. (2013) developed the framework to emphasise the various modes of urban energy intermediaries, taking into consideration the interest/priorities pursued by energy intermediaries and how they are translated into programmes and projects (Hodson, Marvin and Bulkeley, 2013).

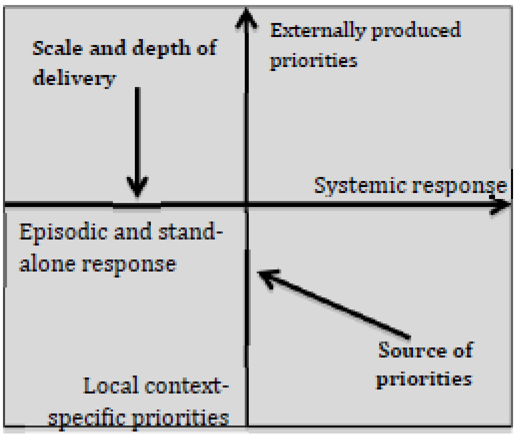


Figure 26: Modes of urban energy intermediation (Hodson et al., 2013).

The x-axis represents the scope and depth of intermediary activity delivery, while the y-axis represents the scale at which intermediary activity priorities are defined.

The study examines the two framework dimensions to determine if there are essential characteristics of intermediaries that contribute to empowerment processes. The two dimensions of the framework are discussed below (Hodson, Marvin and Bulkeley, 2013).

- The scale and extent to which intermediaries and their functions are embedded in institutional practice: Intermediary activities can be carried out as a standalone response or as part of a systemic response, such as by embedding themselves in the long-term functioning of existing organisations. They can be delivered to a local niche or across various niches. According to Hodson, Marvin and Bulkeley (2013), intermediaries who take a longer-term and more sustained approach, are better able to bridge the gap and facilitate interactions between multiple actors. Local, stand-alone responses, on the other hand, can adapt to specific circumstances and opportunities, allowing for successful delivery of an innovation at local level.

- The source of the priorities that drive intermediaries' activities: Local priorities may influence intermediary priorities, which in turn may influence a top-down national policy objective. The underlying priorities of an intermediary have an effect on their ability to effectively communicate and empathise with the diverse range of actors operating across regime and niche spaces. For example, an intermediary motivated by the interests of regime-embedded actors may be constrained in their activities and unable to disrupt incumbent regime practices. However, intermediary activities driven by the interests of niche-based actors may be better suited to challenge regime practices (Hodson and Marvin, 2010c; Hargreaves *et al.*, 2013; Kivimaa, 2014).

3.4.3. The Multi-level Perspective: Criticisms and Developments

The MLP has been widely used as a framework for analysing the processes and drivers of socio-technical transitions. It has been applied in empirical studies of historical cases so that a full transition process is taken into account (e.g. The transition in aviation from piston-engine aircraft to jetliners in American aviation 1926-1975 (Geels, 2005a) reconstructing the transition from town gas to natural gas 1948 to 1977 and market-led transformation of the manufactured gas regime from 1877 to 1914 (Arapostathis *et al.*, 2013)). In spite of its broad use, it has been confronted with a number of criticisms, which has established some areas in need of improvements. This chapter addresses various parts of these debates and examines the developments that have emerged to address the criticisms.

Most critiques of the MLP reflect on how researchers have interpreted and applied the core concepts of niches, regimes and landscapes in case study analysis. The arbitrary creation of socio-technical regime boundaries within the context of empirical studies could potentially lead to the omission of important elements as a result of the arbitrary boundaries created around the system (Smith, Stirling and Berkhout, 2005; Markard, Raven and Truffer, 2012). Within an empirical study, one could argue that the heat supply system in the UK has its own sociotechnical regime. It could also be considered as a sub-regime of a broader UK energy regime, or as part of wider European or global energy regime. Therefore, it is useful to consider the implications of the chosen regime boundary in the empirical application of the MLP. For example, it could be argued in an empirical study, that Greater

Manchester's energy system has its own socio-technical regime. On the other hand, it could be seen as a sub-regime of the wider United Kingdom energy regime or as part of the large scale European or global energy regime, however, this study considers the UK energy regime as the sociotechnical regime for DH implementation.

The MLP has also been criticised for not providing clarity on how the landscape and regime interact with niches and each other to shape a transition path as it is often applied to historical cases to examine the complete transition process. The potential validity of the data for long term historical transitions as well as the researcher's interpretation of the data considering the actors, nature of the transitions and the start and end point of the process, were also criticised (Genus and Coles, 2008). In response, Geels (2011), highlighted the illustration and exploration focus of MLP studies, while acknowledging that it might not be suitable for systematic analysis. After initial attempts to broaden the scope of the MLP in order to develop a "grand theory" was criticized by several actors, the MLP was classified as a "middle range theory (Geels, 2007b, 2010, 2011). The MLP has been used in transition studies that have covered a wide range of sectors and have mostly focused on long-term transition processes. Some studies indicate that it can take anywhere from 15 to 20 years to several decades (Raven, 2006). Geels (2011), reaffirms the primary objective of the analytical approach as the analysis of relatively rare, long-term macro transitions. This research considers the secondary case study cities as examples of a complete transition to the delivery and operation of DH networks, while the primary case study represents the early-stage development of a DH implementation strategy, which is useful for understanding the DH implementation process on how the landscape and regime interact with niches and each other to shape a transition path at the start of the journey.

In addition to the debates on the use of the MLP and the scope of the proposed analytical approach, the MLP was criticised for its lack of agency (Genus and Coles, 2008), the delineation and use of the regime concept, especially when combined with the system concept, lack of dynamics in the conceptualisation of the landscape (Van Driel and Schot, 2005; Geels, 2011), and the use of the MLP to analyse processes that might have occurred in a flat plane (Shove and Walker, 2010).

Although the MLP aims to give greater consideration to the influence of regime and landscape dynamics in transitions, the framework received numerous criticisms for its perceived bias towards bottom-up transition processes, which is centred on niche innovations (Berkhout, Smith and Stirling, 2004; Geels, 2011). Smith, Stirling and Berkhout (2005) also emphasized that little attention was paid to the detailed characteristics of regimes in empirical examples, which contributed to a perception of the regime as a "monolithic" or "homogeneous'' entity, thereby disregarding significant differences in contexts. In an effort to overcome the bottom-up niche bias, Geels and Schot (2007) presented the four transition pathways to add clarity and detail to the dynamic nature of the multi-level interactions.

De-alignment and re-alignment transitions occur when there is no clear, adequately developed niche innovation, however tensions within the regime are powerful enough to prevent re-alignment of the regime by existing regime actors. This enables multiple underdeveloped innovations to compete and begin to diffuse until a new regime stability that incorporates the successful innovations is established.

Technological substitution transitions occur when a niche invention is sufficiently developed to displace the incumbent regime when a window of opportunity presents itself (often as a result of a "shock" to the landscape).

Reconfiguration transitions occur in situations where 'symbiotic' innovations are adopted to address local issues on a small scale within the existing regime. Over time, their existence gradually alters the overall structure of the regime.

Transformation transitions occur only as a result of landscape-level influences. The niche innovations are not sufficiently developed to maximize the window of opportunity. Consequently, the dynamics of the regime are reconfigured by the adaptation of its internal processes.

Although these are presented as separate typologies, Geels and Schot (2007) acknowledge that pathways rarely conform to a single form in practice. For instance, they may occur during a series of sub-transitions (Geels and Schot, 2007).

Resistant Regimes

Further research developments on the multi-level perspective have emphasised the explicit consideration of politics and power in the incumbent regime and how this might contribute to active resistance to sustainable transitions. The MLP has been criticised for not taking into account the politics and agency of actors seeking to support shielding, nurturing and niche empowerment processes to displace the incumbent regime (Smith et al., 2005; Smith and Raven, 2012; Shove and Walker, 2007). Several low-carbon transition studies analysed by the MLP have majorly concentrated on niche innovations, without considering the power and politics that form the basis for the development and implementation of focused policies. Specifically for analyses that take a normative approach to socio-technical transitions, there has been an overestimation that supporting sustainable innovation alone is sufficient to bring about a sustainable transition, without taking into account the agency of niche actors and the resistance posed by the incumbent regime. Consequently, the MLP has been criticised for lacking a clear focus on power and politics as well as the role of existing regimes and the influence of incumbent actors in resisting transitions (Geels, 2014). More work on understanding politics and power in the existing regime and how this can actively resist sustainable transitions have been explored. Regime actors can wield power and influence to enable or hinder a niche innovation from diffusing into the regime (Späth and Rohracher, 2012).

Geels (2014), builds on the concepts of the regime "lock-in," and identifies four transition pathways in which existing regimes actors (mostly incumbent firms and policymakers) can wield power and politics to resist transitions (towards low carbon technologies) in order to take account of politics and power in the MLP.

a) **The use of instrumental forms of power**: In this situation, actors make use of resources which include money, access to media, capabilities, and personnel in their interactions with other actors in order to achieve their own interests and goals. Regimes actors generally have more access to resources than niche actors as a result of the availability of resources in regimes which is used to promote regime reproduction and incremental adaptation (Avelino and Rotmans, 2009).
b) **The use of discursive strategies**: In this case, regime actors use their powers to shape the narratives of what is being discussed (which is used as a strategy to set their agendas), how it is discussed, what is important and the most suitable solutions to challenges.
c) **The use of broader institutional powers**: This pertains to broader institutional powers ingrained in the frameworks of political cultures ideologies and government structures which enable the agendas of incumbent actors.
d) **The use of material strategies:** Regime actors leverage their technical expertise and economic resources to improve the technical performance of socio-technical regimes in order to make the need for radical innovations appear less necessary. Such technical innovation actions are often associated with discussions and possibilities of effective solutions (Van Lente, 1993), which can be used to attract attention, funding opportunities and resources to steer clear of opposing regulations. Notable examples include supercritical pulverized coal technologies and carbon capture and storage (CCS).

(Geels, 2014)**.**

This research investigates the resistance of the existing fossil-fuel-based energy regime, which is characterised by the dominance of certain technological artefacts, networks, cultural meanings, institutions, market structures, scientific knowledge, and regulatory frameworks to the transition to low carbon technologies. It considers the influence of politics and agency affecting actors seeking to support shielding, nurturing and niche empowerment processes to displace the incumbent regime, and aid the large-scale implementation of DH networks at scale in urban environments.

Geographical scale and Geographical Unevenness of Transitions

Studies on geographical spaces have identified the impact of geographical location on transitions (Smith, Voß and Grin, 2010). The MLP focuses on analysing the transformation of societal functions within socio-technical systems and does not put into consideration the role of the geographical location in relation to the availability of resources which is important for sustainable innovation in transition processes (Smith et al., 2010). For example, in reality, some locations possess abundant reserve of natural resources that can be used to generate sustainable forms of energy in their locations (Smith, Voß and Grin, 2010). Lock-in to existing fossil fuel-driven developmental path creates resistance to new technology markets and policy failures which inhibit the widespread deployment and diffusion of low carbon technologies in spite of the evident environmental and economic benefits of low carbon development (Unruh, 2000a).

Also, it has been recognized that the influence of the socio-technical regime may differ significantly across different geographical scales (international, national, regional or urban) due to varying economic structure, varying economic activities and impact of urban areas as opposed to rural areas (Coenen and Truffer, 2012; Bridge et al., 2013). In line with the debates to broaden socio-technical transition, demands have also been made for more detailed studies on the role of geographical scale in transitions for increased understanding of how geographical locations shape transitions (Coenen and Truffer, 2012a; Bridge *et al.*, 2013).

Studies on the role of geographical scales in the MLP framework have tried to get past considering the geographical context of transitions as a mere “passive background variable” by pointing out the varying influence of local contexts on transitions (Coenen and Truffer, 2012a). In the MLP the implicit assumption is that actors are able to interact, irrespective of the geographical scales in which they operate. Coenen, Benneworth and Truffer, (2012) posit that, in reality, actors at different geographical scales (international, national, regional or urban) may differ significantly in their access to resources. It was discovered that there is a connection between the spatial embeddedness of institutions and the approaches used by actors in the development and deployment of innovations. Building upon this concept Bridge *et al.*, (2013) defines embeddedness as the sunk costs which include the built environment and energy infrastructure networks as well as the place-based consumption cultures associated with certain energy technologies. Spatial embeddedness act as barriers to transitions by becoming resistant to the widespread deployment of radical innovations. The "geographical unevenness of transitions" is another aspect of the geographical scale to be considered in the MLP framework (Coenen, Benneworth and Truffer, 2012). While some areas are suitable for niche creation some other areas can be resistant to niche creation as a result of the differences in their physical, political and institutional attributes which give rise to unequal development and penetration of new innovations (Coenen, Benneworth and Truffer, 2012; Bridge *et al.*, 2013). Based on the discussions it is therefore important to consider the geographical contexts in socio-technical transitions.

Despite all the criticisms linked to the MLP, it has continued to draw the attention of scholars as they untangle issues pertaining to the interactions between niches and regimes, relations between conceptual levels, the definitions of boundaries, and the empirical operationalization of concepts (Geels 2012). As global concern for sustainable development grows, so does the demand for innovations to achieve specific sustainable transitions – making it a top priority to transition from lock-in, path dependence, and to shift socio-technical regimes (Smith et al. 2010). The MLP provides a framework that enables social actors to comprehend socio-technical constituents and deliver instruments to potentially identify innovation-induced change. The MLP is a powerful instrument for policymakers to drive transitions effectively and efficiently by focusing on niches and regimes (Geels 2012). This research takes into consideration the above criticisms and therefore focuses on both technological and social elements, utilising the MLP to gain a deeper understanding of the role of cities in socio-technical transitions to contribute to a growing body of research that emphasises the importance of spatial perspectives and the crucial role of cities and regions in transition processes.

3.5. Theoretical approach used in this research: MLP

Transitions are intrinsically complex phenomena to study because they include multiple actors across multiple dimensions (markets, regulations, cultural, social movements, infrastructure, and social legitimacy) over time (Geels and Schot, 2010). This research explores how cities implement large scale DH network from a socio-technical perspective with a view to identify key success factors and effective governing measures that can overcome the main barriers limiting the uptake and delivery of DH network at scale. The MLP has been widely used as a framework for analysing the processes and drivers of socio-technical transitions. It is concerned with the identification of structures, processes, patterns and underlying mechanisms that may unlock regime resistance and path dependency.

The criteria for selecting an underlying theory were as follows: to be able to identify how the network of actors interact with the DH system, how events outside the DH system may affect a transition and to provide an understanding of how sociotechnical transitions occur. The following was required of a theory that will help capture the transition to DH systems:

- It should be capable of analysing transition processes within a technical system
- It should be able to incorporate both technical and social aspects of the system

- It must be capable of providing an in-depth understanding of the transitioning process in the system and context under analysis.
- It should be capable of capturing the actors and their decision-making processes (actors, institutions, institutional structures, influence, and lock-in processes)
- It should be able to describe the transition process.

The multi-level perspective is an analytical framework which has been applied to gain understanding of socio-technical transitions as well as to conceptualise the influence of the wider system context on transitions. Socio-technical transitions do not only involve changes in technology, but also changes in consumer practises, legislation, cultural meanings, infrastructures, and business models. The MLP is particularly appealing for sustainability research because it examines the dynamics of large-scale socio-technical systems, which reveal the sustainability challenges faced by the current energy system (Rip and Kemp, 1998; Rotmans, Kemp and Van Asselt, 2001; Elzen, Geels and Green, 2004; Geels and Schot, 2007).

Through the application of the multilevel perspective on socio-technical transitions to analyse the case study cities, this research examined the salience and influence of five sociotechnical elements: (1) the implementation strategy; (2) technical solutions and heat sources; (3) policy instruments and regulatory framework; (4) pricing and consumer protection (5) financial instruments and incentives. Investigating these five factors provides insights into the key success factors that aid the implementation of large-scale city based DH networks as well as the barriers to DH implementation.

DH technology merges three functional aspects of the energy system which are important to consider within DH functionality these include: heat supply, heat distribution and heat demand. It is therefore regarded as a complex system to implement, requiring the consideration of several factors, the collective network of multi-actors involved and the interaction between various elements of the socio-technical system. The analytical construct and heuristic levels for system innovation of the MLP makes it a suitable lens to capture a detailed account of the processes in the development and implementation of large-scale DH networks. Lessons will be drawn from the case studies with regards to how intermediary activities can support the development of DH in areas with little previous history of DH networks. There are primarily three main reasons why the MLP is best suited to achieve the aims and objectives in this research:

- The MLP recognizes the co-evolutionary nature of socio-technical transition, it draws on a wide range of theoretical foundations (technical, economic, environmental, cultural and social considerations) to trace patterns and regularities over time (Rip and Kemp, 1998; Rotmans, Kemp and Van Asselt, 2001; Elzen, Geels and Green, 2004; Geels and Schot, 2007).

- the MLP employs a narrative explanation in which outcomes are described as "event sequences, timing, and conjunctures of event-chains," which aids in "capturing dynamic interactions between agency, changing context and identities" (Geels, 2011).
- The cause and effect of a narrative description is considered to be based on probability and there is a need to explain the 'twists and turns' of events (Geels and Schot, 2010). The MLP's strength in this area is that it aids in the organisation of case studies as they are structured according to landscape, regime, and niches. However, it is recognized that specific patterns or pace at which transitions occur are shaped by local contexts. As a result, the extent to which the MLP is applicable in different local contexts determines its applicability (Geels and Schot, 2010).

The greater the applicability to different empirical cases, the greater the possibility of improving the exploratory potential of the MLP's concepts. This is only possible if multiple local cases are studied, investigated, and analysed. This research on the socio-technical analysis of DH implementation in three case study cities seeks to contribute to this call. The secondary case studies represent a well-established DH sector while the primary case study in this thesis is an example of a small community of practice in the early stages of a potential transition with limited DH knowledge, experience and expertise. Where available successful schemes have been driven by local actors who have created supportive local conditions for project delivery. As a result, the DH development process is conceptualised as a series of local niche spaces, and the analysis is based on theories about the role of niches and the capacities of niche actors to govern transitions. The theory of the MLP which posits that socio-technical transitions emerge by the interaction and alignment between three levels of structuration (the niche, socio-technical regime and socio-technical landscape) are used to form the theoretical foundation for structuring the analysis.

3.6. Chapter Summary

Following the review of existing theoretical literature on DH in Chapter 2, which outlined the role of actors, key aspects, and DH implementation challenges, this chapter explored the application of theoretical socio-technical transitions literature with specific reference to district heating. Considering the existing theoretical and applied research on socio-technical transitions, it highlighted the complexities of low-carbon transitions and the challenge of integrating low-carbon technologies into a socio-technical regime that was not designed to support them. In this chapter, the author provided an overview of key concepts analytical approaches used in the field of transition studies and the theoretical positioning of the study. The MLP approach and its core analytical constructs, the niche, regime, and landscape were described in detail and their application in transition studies, as well as the current gaps in in the MLP literature relating to regime stability and socio-technical transitions.

It ends with the criteria for selecting the MLP the highlighting the need for an approach that will capture the transition process in a logical manner. In the context of the overarching research question which is how cities implement large scale heat networks from a socio-technical perspective, DH networks can be considered as a niche in itself which requires protection. The pressures in the sociotechnical landscape due climate change and environmental sustainability are creating pressures in the regime and DH needs a window of opportunity to overcome the incumbent fossil fuel regime in order to become an established technology.

In order to draw lessons for how to govern a low-carbon transition, it is important to have a detailed understanding of how different governing measures can shape social and technical change in different contexts. In addition, each technology has unique characteristics which require various forms of actor involvement and support to aid their development and implementation. Contextual differences could also influence the type of governance approach required. The focus of this study on DH development and implementation in different contexts, allowed for the level of depth and detail required for analysing governance approach in complex socio-technical systems. The thesis findings on how cities implement large-scale DH networks in the various case study contexts are explored and discussed in further detail in chapters 5,6,7, and 8. The next chapter, chapter 4, discusses the research design and methods used to answer the research questions, in order to extract meaning and analytical comprehension on how cities implement DH networks from a socio-technical perspective.

4. CHAPTER FOUR RESEARCH METHODOLOGY

4.1. Introduction

The purpose of this chapter is to present, justify and discuss the research methods applied in this study to attain the aim of this research. The aim of this research is to explore how cities implement large scale DH networks from a socio-technical perspective. It seeks to find key success factors and effective governing measures that can overcome the main barriers limiting the uptake and delivery of DH at scale. The main purpose of data collection in this study is to identify the processes that must take place for a successful DH implementation and transition to occur. It seeks to explore key aspects of DH implementation to draw lessons from the case study cities with regards to how key actors and intermediary activities can support the development of DH in areas with little or no history of DH network uptake.

As discussed in Chapter 3, the theoretical framework employed is the MLP of Sociotechnical Transitions. Transition is required across a wide range of social networks, with decisions made by a diverse group of actors from various institutions. According to Hodgson (2006), the term "institutions" identifies a wide variety of structured activities, and institutional change which occurs within the institutional structuration. The successful implementation of DH schemes has been attributed to the social capital of key local actors', which enabled the coordination of local circumstances for the benefit of the project (Hawkey, Webb and Winskel, 2013; Webb, 2015). As a result, aspects of the socio-technical literature on governing niche processes are particularly relevant to this study.

A detailed explanation of the adopted research design, methodology and data collection processes employed to gather data on the DH implementation process in the case study cities is provided in this chapter. The methodological process is in line with the research onion (Saunders, Lewis and Thornhill, 2016) in that it begins with understanding where this research fits into the various available research philosophies, it identifies what data collection techniques are available, it identifies which methods are available to analyse the data, and it identifies a method to present the data. An outline of the research philosophy and the philosophical stance underlying the methodological decisions applied in this study is presented in the first section. These include introduction to research paradigms, explanation of the philosophical assumptions and theory development. It then moves on to the proposed research problem methodology, data collection processes, data analysis and concludes with ethical considerations and validation providing an intrinsic logic to the research process.

4.2. Philosophical Framework

There are several schools of thought on which approach to take when conducting research in various academic disciplines. All agree, however, that a well-defined and prescribed research pathway is required for success. As a result, research must be conducted within a clearly defined philosophical framework, and the appropriate methodological approach. The "research onion" brings together various philosophical and analytical approaches (Saunders, Lewis and Thornhill, 2009). Figure 27 shows the different research philosophies and approaches in the research onion.

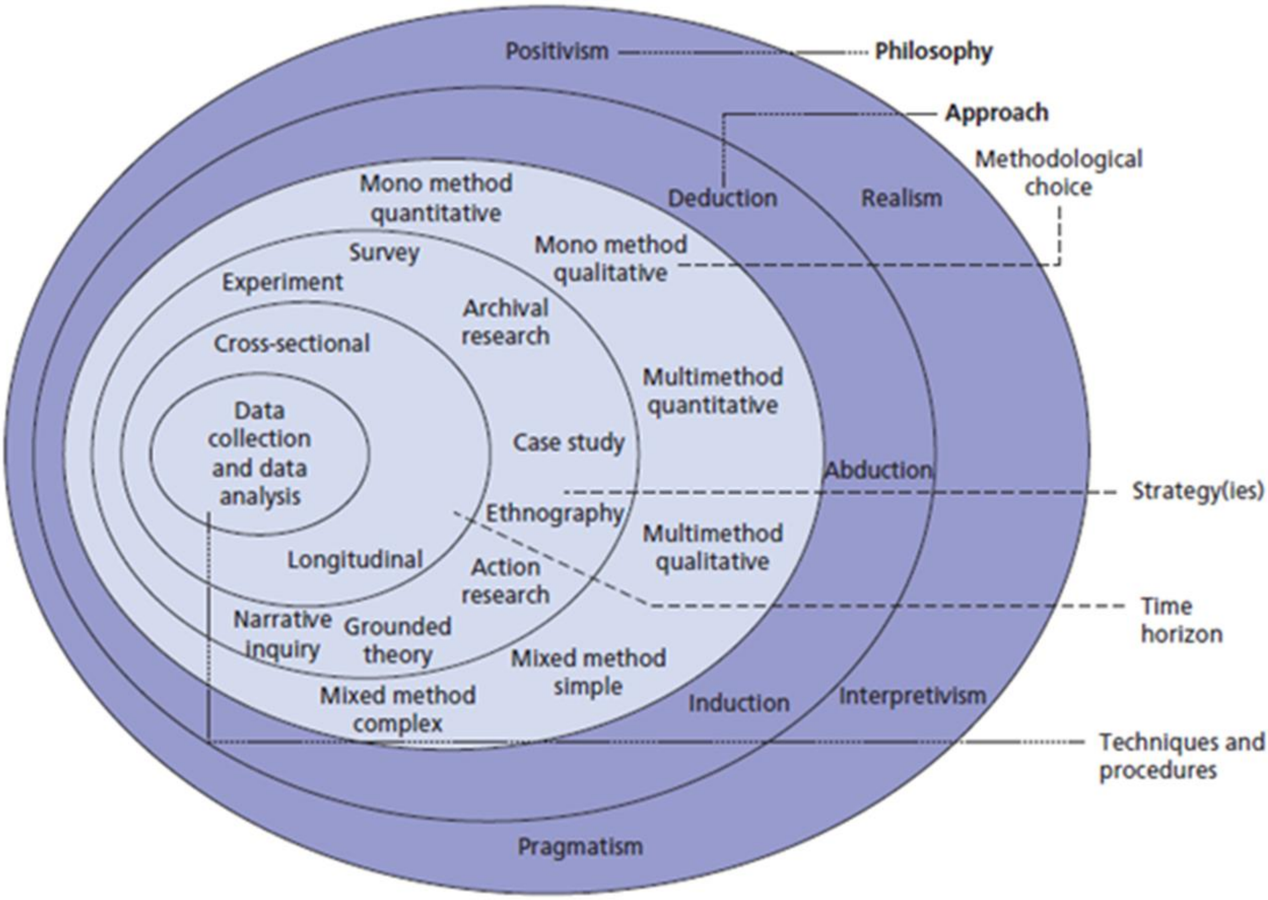


Figure 27:The Research Onion (Saunders, Lewis and Thornhill, 2009).

The research onion has three sections, the outer two rings represent the mind-frame of the researcher, the three middle rings represent the methodological frameworks that provide the focus for the research and the core represents the method used for data collection and analysis. The method used for research will depend on the approach to research and the subject under examination. The researcher will bring prior knowledge, skills, experience, a unique personality, and, ideally, an inquiring mind to the study. The rigor of the research and the validity of its findings is assured by framing the research in a framework that establishes a clear pathway (Saunders, Lewis and Thornhill, 2016). While the research onion provides a wide range of potential research pathways, the methodological approach will be heavily influenced by the nature of the problem under investigation as well as the researcher, with some of the pathways mutually exclusive.

4.2.1. Research Philosophy / Philosophical Paradigm

This research includes both social and technical aspects. Since DH are established technologies, the technical aspects are less open to interpretation, with a more fixed reality, while the social aspects are more open to individual interpretation and "mind set." Socio-technical transition is a multidimensional socially constructed phenomenon that can be explored in different ways and from various ontological perspectives (Geels, 2010). As a result, while certain research projects may have only one set of methodological pathways' that excludes other approaches, various approaches may be used in this research for different aspects due to its socio-technical nature. It is important to discuss the philosophy of research methodologies, before delving into the methodological framework in this study.

Research philosophy refers to how the real world is viewed and how the nature of reality and existence is explored (Corrine Glesne, 2011). It is a network of beliefs and assumptions regarding the formation of knowledge, which frames the ontological and epistemological choice that underpins the research design and methods of data collection and analysis (Saunders, Lewis and Thornhill, 2016). It is beneficial to have a good understanding of the philosophical approach in a research process for the following reasons: for clarity of the research design, for a good understanding of the right methods appropriate for the research design and to identify the research process that is well-suited to the research design and structure before conduction the research (Easterby-Smith, Thorpe and Jackson, 2012). In order to understand how knowledge is created, philosophers have posed two important questions: what is reality? and how do we know it? which are often referred to as ontology and epistemology respectively (DePoy and Gitlin, 2016). The ontology (the nature of reality), epistemology (the nature of knowledge), axiology (the values associated with research) and methodology (the approach used to collect, collect, and analyze data) all influence the research paradigm (Tracy 2012). The following sections discusses the philosophical approaches and paradigms in more details.

4.2.1.1. Ontology

The nature of the ‘truth’ ‘reality’ and ‘existence’ of the social world which reflects beliefs about the world’s reality and existence is referred to as ontology. It considers the knowledge of truth based on beliefs about what knowledge is. It relates to the perception of what reality is and whether there is a truth is to be discovered or not. The research's ontological perspective will determine the epistemology perspective because the researcher's view of the nature of reality will determine how the research is viewed and studied. The two extreme foundations of ontological assumptions are objectivism and subjectivism (Saunders, Lewis and Thornhill, 2016). Objectivism describes the situation where the data exists independently and thus the researcher has no influence on the findings (Bryman and Emma Bell, 2011). Subjectivism describes the situation where reality is socially constructed such that it provides an understanding of the reality and details of the situation to be analysed (Saunders, Lewis and Thornhill, 2009).

4.2.1.2. Epistemology

Epistemology is concerned with the nature of knowledge that informs research inquiry, such that it shapes and justifies the methods of inquiry into reality (Corrine Glesne, 2011; Easterby-Smith, Thorpe and Jackson, 2012). Epistemology not only concentrates on how knowledge is created and acquired but also on what is deemed acceptable knowledge. The three main approaches to theory development embedded in the ontological and epistemological foundations of a study are deductive, abductive and inductive (Saunders, Lewis and Thornhill, 2016). The nature of the reality of social and physical worlds within the social sciences had two main views on ontological and epistemological concerns were thought to be positivism and interpretivism until relatively recently (DePoy and Gitlin, 2016). A wide range of approaches exists between positivism and interpretivism (Saunders, Lewis and Thornhill, 2016).

4.2.1.3. Axiology

Axiology is concerned with what the researcher considers to be ethical and valuable. Fundamental ethical beliefs should direct a researcher's decision-making and be embedded in their study paradigms (Killam 2013). Our decisions and behaviours are influenced by our philosophical outlook as we move through life. Our perceptions of the universe and the world are ultimately shaped by our beliefs about reality, truth, and value (Bourne, Crossfield and Nicholas, 2017). Interpretivists believe that it is difficult to exclude a researcher's beliefs and experiences from the research process. In that sense, rather than dismissing them, the researcher should seek to identify, acknowledge, and 'bracket' their values (Ponterotto, 2005).

4.2.1.4. Methodology

Methodology is concerned with how knowledge is discovered and analysed in a systematic way (Ponterotto, 2005). It seeks to uncover the process and procedure of a study, explaining the philosophies that guide how knowledge should be gathered and questioning how knowledge about social reality is acquired (Moses and Knutsen, 2012). Methodology is also known as the study of methods, and a successful study is one in which the methods used are capable of generating reliable data (Moses and Knutsen, 2007). Four key philosophical approaches: realism, positivism, interpretivism, and pragmatism have been identified. Table 7 Outlines the four key research philosophies in business and management research (Saunders, Lewis and Thornhill, 2016).

Table 7: The four key research philosophies in business and management research adapted from (Saunders, Lewis and Thornhill, 2016).

	Pragmatism	Positivism	Realism		Interpretivism
			Direct	*Critical*	
Ontology *What is reality?*	Researcher views reality as external, multiple and chosen based on best techniques to answer the research question	Reality is external, objective and independent of social actors.	Reality is objective. Reality exists independently of human thought, beliefs or knowledge of their existence.	Reality is objective. Same as realist but adds that reality is interpreted through social conditioning.	Reality is a social construction and subjective. It may change and multiple realities can exist.
Epistemology *How do we come to create knowledge?*	Though the use of observable phenomena and/or subjective meanings. Focus is on practical, applied research. Data can be interpreted by integrating different perspectives.	Knowledge can only be created using credible data or facts which are observed. Phenomena is reduced to its simplest element and the focus is on causality and generalisations.	Facts and credible data are obtained through observing phenomena. Insufficient data means inaccuracies in sensations.	Facts and credible data are obtained through observing phenomena. Phenomena create sensations that are open to misinterpretation. The focus is on explaining within a context(s).	Knowledge is created by subjective meanings and social phenomena. The focus is upon the details of the situation and the reality behind these details. Subjective meanings act as a motivator for actions.

Axiology *What is the role of the researcher's values?*	Values play a large role in interpreting results. Both subjective and objective points of view are adopted.	Values do not play a role in the research. An objective stance is maintained and is independent from the researcher.	The research is value laden. Research bias by world views, cultural experience and upbringing impact on the research.	The research is value bound. The researcher and the research cannot be separated therefore the research is subjective.
Data collection techniques most often used	Mixed or multiple method designs – can be both quantitative and qualitative.	Large samples and highly structured. Mainly quantitative.	Methods can be quantitative or qualitative. However, the methods chosen must fit the subject matter.	Small samples sizes and in-depth qualitative investigations.

The most influential of the four theoretical approaches are positivism and interpretivism (Gray 2013). This philosophical debate focuses primarily on the disagreements between the positivist and interpretivist schools of thought. Positivism views reality as objective, independent, and external to social actors (Saunders et al. 2009), but accessible through study (Vildasen et al. 2017): reality exists outside of the researcher and must therefore be explored through systematic scientific inquiry (Gray 2013). In realism, reality is considered to be objective, although interpreted by humans, it exists independently of human, thought, beliefs or knowledge of their existence.

Interpretivism (social constructivism) opposes the latter two philosophies, maintaining that reality is socially constructed and is subjective emerging from the subject's interaction with the world and that reality does not exist in an external world (Gray 2013). Pragmatism considers reality to be external and multifaceted, but it is influenced by subjective meanings and observable phenomena. According to (Wilson 2014), pragmatists do not take a stance on either, they view both the social and physical worlds as important considerations.

According to positivist ontology, regardless of the researcher's belief, there is a single, external, and objective truth to any research question. The positivist researchers attempt to remain distant from the study participants by establishing space between themselves and the participants, which Saunders refers to as "a value-free way." Making explicit distinctions between reason and emotions, as well as science and personal experience, is an essential step in staying emotionally neutral. Positivists also argue that it is important to differentiate between 'resources' research, which is based on facts, and ‘feelings' research, which is based on value judgment (Wisker, 2007; Saunders, Lewis and Thornhill, 2009).

On the other hand, interpretivists believe that truth is relative and multifaceted. There can be more than one reality and more than one structured way of accessing those realities, according to this tradition; however, they are difficult to understand since their interpretations are dependent on other structures. Due to the complex, multiple, and uncertain nature of what is perceived as reality, an interpretivist researcher assumes that prior knowledge of the research topic is insufficient in creating a fixed research design. Throughout the study, the researcher is open to new ideas and allows it to evolve with the help of participants. The interpretivist theory requires the researcher to maintain an empathetic stance. The aim here is to be immersed in the social world of the participants by conducting in-depth interviews to gain a deep understanding of the world from their perspective and context, so as to gather as much specific information about the situation (Saunders, Lewis and Thornhill, 2009).

4.2.1.5. Research Paradigm

The interpretivist elements associated with ontology and epistemology, according to Guba and Lincoln (1989) and Neuman (2014), consider knowledge to be socially constructed around daily experiences and people's actions, rather than being objectively determined. Constructivism, on the other hand, recognizes that knowledge is content-dependent and relative, and that a researcher's or participant's views and values play an important role in knowledge creation through hermeneutic interpretation (Høiseth, Keitsch and Holm Hopperstad, 2014). Critical realism, however, focuses on providing an explanation for the observable changes in social and organisational structures through an in-depth historical analysis of the underlying factors and processes responsible for the marked changes and how these changes have evolved over time (Saunders, Lewis and Thornhill, 2016). The philosophical paradigms are summarized in Table 8.

Table 8:An overview of philosophical paradigms adapted from (Killam, 2013; Winit-Watjana, 2016).

Basic Beliefs	Positivism	Post-positivism	Constructivism	Critical Theory
Ontology (reality)	Realism: believes that one reality exists that can be discovered; independent of the human mind and behaviour	Critical realism: there is truth out there that cannot be accurately perceived	Relativism: realities are co-constructed by those experiencing the phenomena; multiple, dynamic, and many relative truths as opposed to one single truth	Historical realism: reality is shaped by experiences and values
Epistemology (knowledge)	Objective and dualist: results are true	Objective and dualist: results are likely to be true; insufficient data lead to inaccuracies	Interactions and findings are subjective; cannot separate the researcher from knowledge	Findings are subjective and influenced by values
Axiology (focus on ethical values)	Honesty, trust and integrity; independent of data	Respect and fairness	Viewpoint are balanced, raise awareness, and develop community rapport	Reciprocity, respect, beneficence, culture and social justice
Methodology (systematic inquiry)	Quantitative approach: verified hypotheses; highly structured	Interpretive studies are used to falsify hypothesis; selection of methods to fit the study	Qualitative approach: interpretative findings and well-described situations; Grounded theory, phenomenology, narratives, case studies, surveys	Logic and discourse based; both quantitative and qualitative methods

Individuals tend to create subjective meanings based on their experiences and worldviews, which are derived from a broad variety of experiences, necessitating the researcher to delve into the complexities of the various points of view rather than restricting interpretation to a few basic categories (Creswell and Creswell, 2017). From an interpretive standpoint, the present researcher considers that reality does not exist anywhere out there waiting to be discovered. Rather, reality and knowledge are uncovered through interaction, communication, and practice, which is translated through the researcher (Tracy, 2012).

4.2.2. Philosophical Stance

The philosophical position of the researcher, as well as the design and methodological approach, have been shaped by the nature of the topic and field under investigation (sustainability-focused innovation and technological studies), with the primary goal of creating a coherent and outcome-oriented research design. All paradigms considered, this study was socially constructed based on the assumptions individuals have, rather than being objectively determined. This study describes how the network of actors within organisations create structures and the processes that govern DH implementation through interactions with actors involved. Socio-technical transitions are socially constructed processes involving the perspectives of social actors, the researcher seeks to critically analyse the perspectives and experiences of social actors in the DH transition process. The researcher has a background in Geology and a master's degree in Energy and Environmental Management. Therefore, this researcher could be described as a critical analyst who is an interpretivist.

Due to the multidimensional interaction between actors and the DH network, actors may have different perspectives on the processes and structures that govern the operation of the entire socio-technical system. It involves the interaction with participants to gather a rich understanding of their perspectives on the DH implementation process and their influence on steering the transition to low carbon DH energy generation and supply. Constructivists believe that perceptions are channelled by the human mind, often in elusive ways, as such the world is not experienced objectively or directly.

After careful consideration, the **social-constructionist** view of knowledge as a socially constructed context-specific process determined by social structures has been observed to align with the views of the researcher and is the chosen philosophical position in this study (Saunders, Lewis and Thornhill, 2016). The axiological standpoint of the data in this research is **value-laden**, with a continuous critical reference to existing literature to allow for higher reliability of the results. This is largely due to the research questions and the aim of the study which requires a context-specific and detailed holistic process through a series of one-on-one discussion in the pursuit of a comprehensive understanding of the DH implementation process. Social Constructionism which asserts that reality is constructed by the interaction between social actors, is becoming popular in analysing environmental problems. These realities are dependent on the actors' interpretation and the established meanings and perceptions which are partly shared and socially constructed (Saunders, Lewis and Thornhill, 2016). The human nature introduced by Burrell and Morgan (1979), is particularly relevant to social theories research. The two extremes are determinism and volunteerism, mirroring objectivism and subjectivism, respectively. Determinism view man and his activities as being totally determined by the environment in which he lives, on the other hand, volunteerism views man as totally independent and free-willed (see figure 28). The time horizon in this research is a longitudinal study of successful city-based DH implementation in Copenhagen, Stockholm and Helsinki in order to build on existing literature to support widespread DH development and implementation (Saunders, Lewis and Thornhill, 2016).

Social actors view situations through their experiences to create various interpretations and perceptions of the situation through interactions with other members of the social group (Creswell, 2014). Actors engage with structures through negotiations, the exercise of power, alliances and economic transactions. These occur within the existing structures ' constraints and opportunities while changing the system structure simultaneously. Furthermore, structures do not only serve as constraints but they provide stability and coordination that enable human actions (Geels, 2005a). Rules also known as institutions are useful tools that coordinate and structure activities. Apart from laws and regulations other types of rules exist, based on (Scott, 1995) three dimensions or pillars have been identified: (i) regulative (ii) normative (iii) cognitive rules. Broadly speaking, social constructionism refuses to accept the notion that knowledge can be separated from social experiences and objectively accessed from external reality (Jones, 2002). This research focuses on the socio-technical transition processes with shared perspectives and understanding of transition processes experienced by social actors. Social and technical systems cannot achieve functionality in isolation as technology is designed, structured and developed by human actions and is dependent on its context which implies that socio-technical systems cannot fulfil societal functions without human actors and social structures (Raven and F W Geels, 2010).

Hence the researcher considers social constructionism to be the most appropriate and relevant to the study. This approach asserts that there is a dearth of knowledge and understanding regarding considerations made about the social capital available prior to the implementation of DH network projects, which has been ignored by previous researchers. As a result, this research adopts a theoretical viewpoint consistent with a subjective interpretivist (constructivist) approach (Carcary, 2009). According to Vildåsen, Keitsch and Fet, (2017), constructivists believe reality is mentally constructed, social, and based on local experiences shared by different people. People may look at the same thing but view it differently. Factors such as age, race, or gender, as well as social characteristics such as culture, era, and language, may influence or obscure one's perception of the world (Moses and Knutsen, 2012). Wentink *et al.* (2018), employed a social-constructivist approach to social capital in order to investigate a complex phenomenon in its natural context. The following research design diagrams (figure 28 & 29) shows the researcher’s philosophical position on the continua and the methodological approach in this study in details.

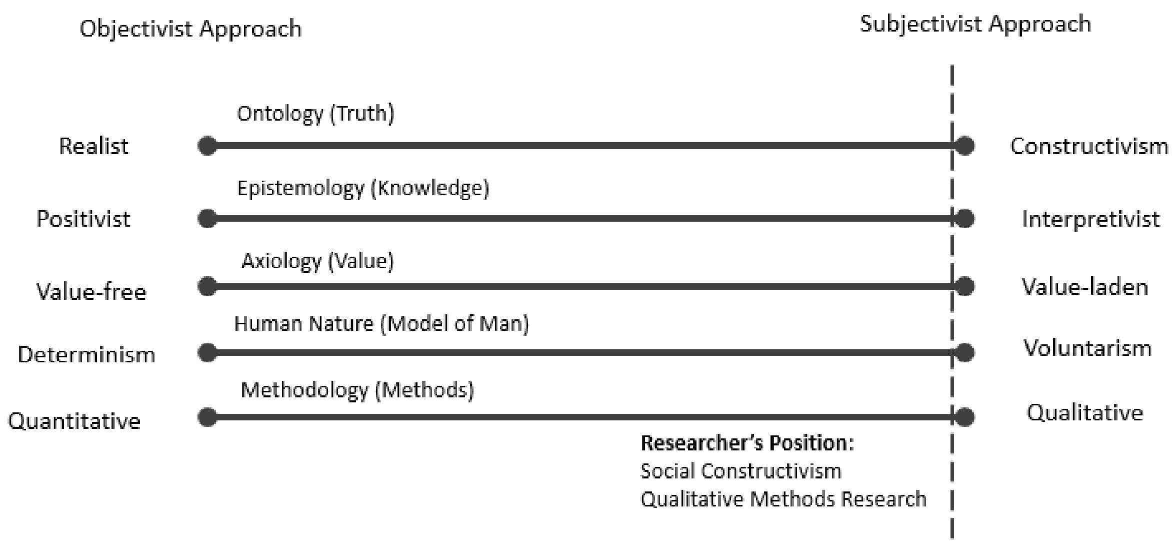


Figure 28: Philosophical Stance Continua + Researcher's Position (Burrell and Morgan, 1979; Saunders, Lewis and Thornhill, 2016).

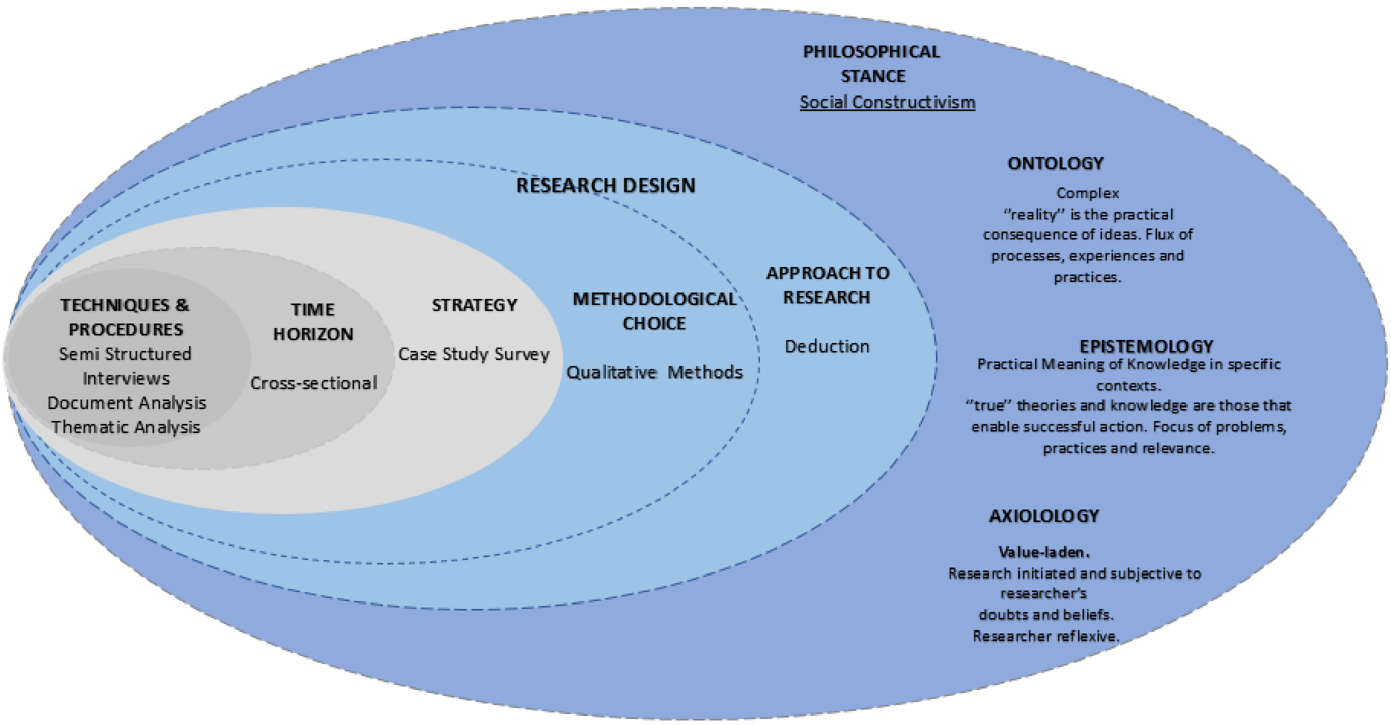


Figure 29:Philosophical Stance and Research Design. Recreated by Researcher from Saunders, Lewis and Thornhill, 2016).

This study employs a theoretical (top-down) approach to thematic analysis of data, using specific research questions based on the previously identified themes from the MLP on socio-technical transitions analytical framework to build a thorough understanding of the research problem. It used qualitative data to provide empirical evidence to explore the research questions; focusing on current gaps in the literature around micro level niche empowering processes, regime lock-in/instability, and actor agency in governing transition processes at local contexts, with the aim of providing empirical evidence to inform the development of this aspect of the literature. Thus, this research takes into account the subjective views of the experiences of actors in the implementation of large scale city based DH networks, and it has used qualitative, interpretivist, and constructivist approaches to understand the phenomena under investigation. The following sections describes how the theoretical approach to thematic analysis was conducted and how the theory was used.

4.3. Research Approach/Design

Research approaches are orderly plans and procedures of actions that cut across philosophical worldviews, detailed methods of data collection, analysis and interpretations. The choice of a research approach is dependent on the complexity of the research problem to be addressed, the researcher's personal perspectives and the research audience (Creswell and Creswell, 2018). There are three types of research approaches namely: qualitative, quantitative and mixed methods (Creswell and Creswell, 2018).

4.3.1. Qualitative Approach

This is approach investigates the underlying significance individuals or social groups ascribe to human or social problems to provide a comprehensive understanding of the problem. It involves the following processes and procedures; data collection in the participants' settings through a series of key questions, inductive data analysis for the discovery of emerging themes and the development of meaning as well as data interpretation. Qualitative researches endorse the inductive theory development approach with an emphasis on the individual significance and the description of the complex situation (Creswell and Creswell, 2018). A qualitative method approach is applied in this thesis. There are many reasons for the adoption of qualitative research methods. The application of qualitative methods has become a more common approach across the transitions literature as there has been a shift towards qualitative researches (Markard, Raven and Truffer, 2012; Geels *et al.*, 2018). Figure 30 illustrates the different types of qualitative research approaches.

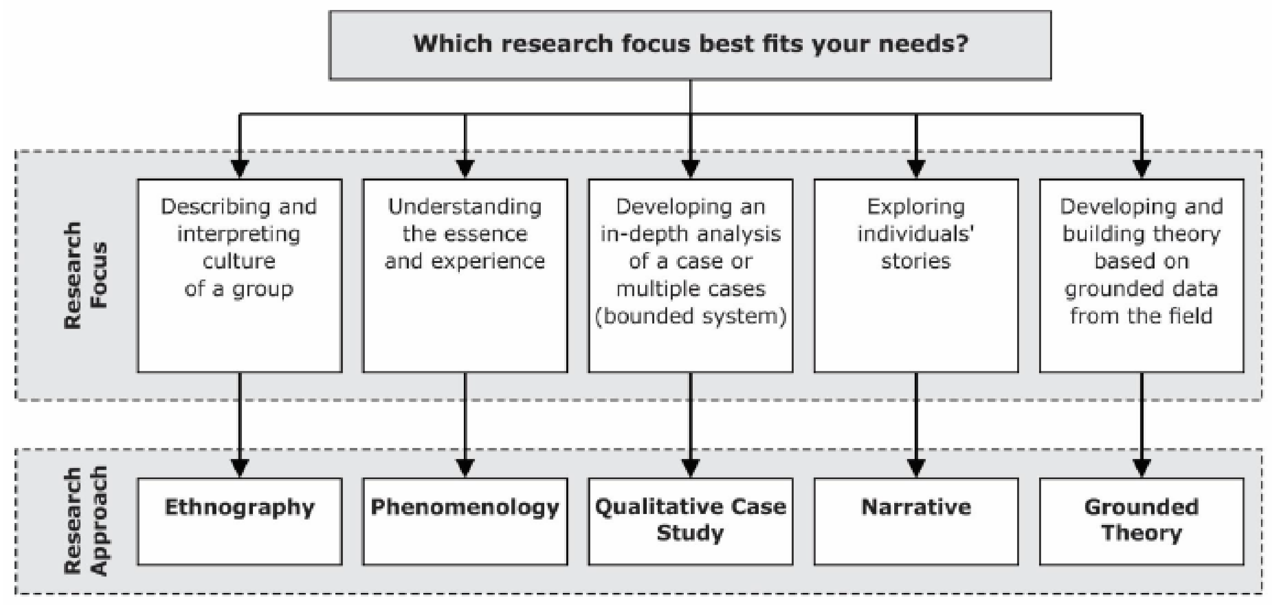


Figure 30:Qualitative research approaches adapted from (Merriam and Tisdell, 2016; Creswell and Poth, 2018).

Types of qualitative research designs

Narrative research: In this case, the researcher examines the lives of participants and requests that one or more of the participants give an account of their life experiences (Riessman, 2008). This is recounted by the researcher capturing both the participant and the researcher's views on life (Clandinin and Connelly, 2000).

Ethnography: This is an anthropological and sociological research design in which the researcher examines over a protracted period the collective behavioural patterns, language and activities of an intact cultural group in their natural environment (Creswell and Creswell, 2018).

Grounded theory: The researcher formulates a general theoretical concept of a process based on the participant's perspectives through a series of data collection phases, continuous improvement and interactions between information categories (Charmaz, 2006; Corbin and Strauss, 2008)

Action research: The researcher seeks to solve practical issues in the real world by providing practical knowledge that can be applied to improve efficiency and effectiveness in practice as part of the research process. It involves a cycle of findings and evaluation through a feedback loop in collaboration with practitioners (Denscombe, 2017).

Phenomenological research: The researcher gives a description of an individual's experiences in relation to a particular phenomenon as reported by the participant. This description gives insights which aid in the understanding of the lived experiences of individuals who have encountered this phenomenon (Moustakas, 1994; Giorgi, 2009).

Case study research: In this case, the researcher investigates a specific phenomenon within the contemporary real-world contexts and settings in order to provide a comprehensive analysis of events, activities, relationships, processes, or experiences of one or more individuals. It is particularly useful in instances where the boundaries between the phenomenon and the contexts are not quite clear. It involves the detailed collection of data within a timeframe, giving room for the use of a wide range of data collection methods in line with the nature of the research problem and objectives of the research (Creswell and Creswell, 2017; Denscombe, 2017).

4.3.2. Quantitative Approach

This approach is suitable for testing objective theories; it uses numbers as a unit of analysis to examine the relationship between variables. Numerical data is gathered through a statistical process which aids the analysis and interpretation of the variables. Qualitative research reflects on the deductive theory development approach which tests the theory or a hypothesis while guarding against bias and alternative or ineffective explanations such that results can be generalised and reproduced. Types of quantitative research designs include surveys and experiments (Creswell and Creswell, 2018).

Survey and Questionnaires

A survey design studies a sample of a population to provide a quantitative description of the trends, attitudes, and views of a population or tests for relationships among variables of a population. A survey employs a deductive approach and frequently seeks to answer "what," "who," "where," "how much," and "how many"-type questions Three types of questions can be answered using survey designs: (a) descriptive questions (b) questions regarding the interrelationships between variables (c) questions about how the relationships between the variables change over time. Using questionnaires to obtain information from a broad population is one of the most cost-effective approaches of conducting a survey (Creswell and Creswell, 2018; Saunders et al., 2009).

Experimental Design

Experimental design is the process of conducting research in a controlled and objective manner in order to obtain the most accurate results and reach definitive conclusions regarding a hypothesis statement. Experiments are useful because they enable one to determine the impact of a specific modification by holding other variables constant. By giving a treatment to one group but not the other (where "treatment" is the manipulated variable of interest), the experimenter can determine if the treatment, as opposed to other factors, influences the outcome (Creswell and Creswell, 2018).

4.3.3. Mixed methods

This approach integrates the quantitative and qualitative forms of data collection use of specific designs that may include theoretical constructs and philosophical assumptions. This method is considered to be ideal for some research questions, as it enables the generation of a range of different data types and perspectives. Types of mixed methods research designs include convergent mixed methods, explanatory sequential mixed methods and exploratory sequential mixed methods (Creswell and Creswell, 2018). Figure 31 illustrates the interrelationship between the three important components of research that needs to be considered by researchers namely, the philosophical worldviews, the research design associated with the worldviews, and the actual research methods that convert the theory into actions.

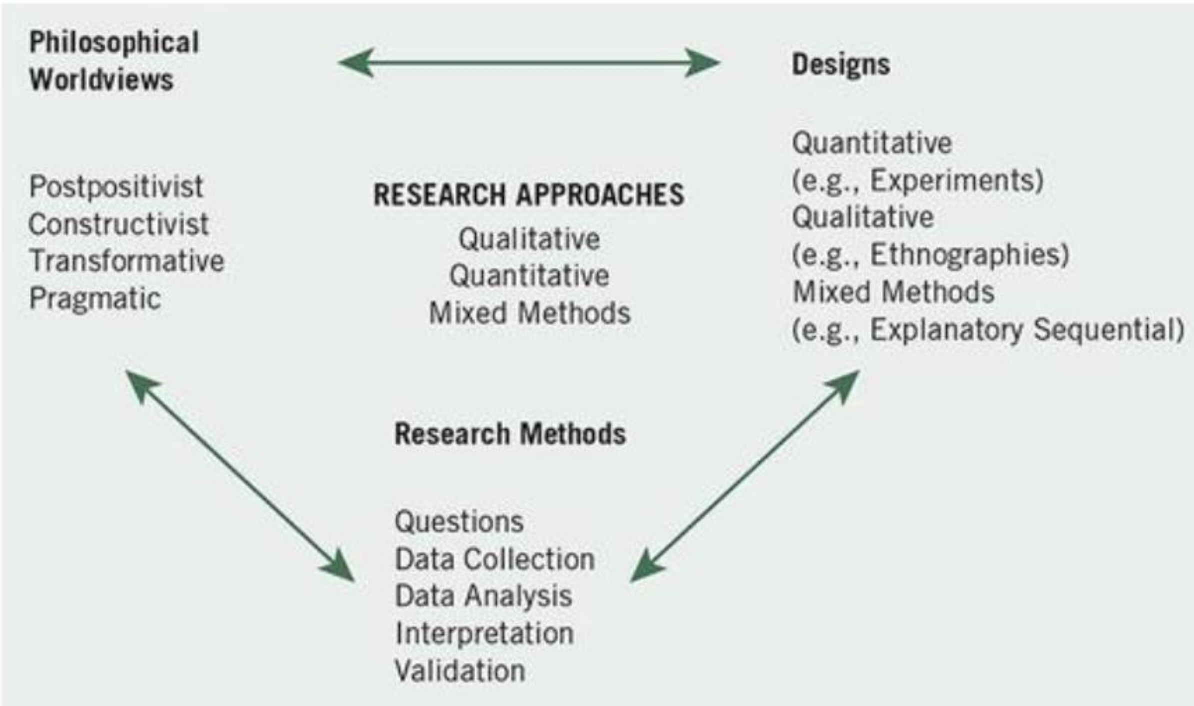


Figure 31:The Research Framework – The interrelationship between worldviews, design and research methods (Creswell and Creswell, 2018).

The research design is crucial in terms of establishing a framework for data collection and analysis (Bryman, 2012). A well-planned research design, as well as strong analytical skills, are required to conduct a good social science research (Abbott and McKinney, 2013). There are two main research methods that can be used for conducting a research namely:

- qualitative methods and
- quantitative methods

The method chosen would have an impact on how the study is conducted as well as the understanding of the phenomena being investigated. The decision to take on either or both of the methods is influenced by a number of factors, including how the researcher intends to examine the phenomenon and the researcher's perspective on the nature of the world (RITCHIE *et al.*, 2013). Also the research aim, objectives and view of the world are critical to the selection of an appropriate method (Mayer, 2015). Qualitative methods differ significantly from quantitative methods, some of the distinctions between qualitative and quantitative research methods are summarized in Table 9 below.

Table 9: Basic differences between quantitative analysis and qualitative research adapted from (Killam, 2013; Merriam and Tisdell, 2016; Harding, 2018; *Braun and Clarke, 2006).*

Basis for Comparison	Qualitative	Quantitative
Philosophical underpinning	Relativism, constructivism	Realism, positivism
Researcher perspective	Emic (insider's perspective)	Etic (outsider's view)
Aim	Subjectivity Build theories Describe phenomena Generate hypotheses Establish meaning in experiences	Objectivity Illustrate correlations among variables Hypothesis testing Measure concepts Concerned with cause and effect
Methods	Observations Interactions Documents	Surveys Experiments Questionnaires
Sample selection	Purposive Specific and limited	Random Large, representative
Data analysis	Study words and meaning Interpretive – Thematic: Inductive or Deductive	Uses statistics to define findings Deductive
Findings	Findings are richly descriptive, co-created, holistic	Numerical findings Precise 'Truth' is discovered

A quantitative research method relies on accurate and reliable metrics for statistical analysis, while qualitative research method is primarily a social research method that is applied to a specific problem in order to gain in-depth knowledge of the complex reality of a phenomenon (Almeida *et al.*, 2017). Harding (2018), distinguishes qualitative and quantitative research in terms of participant size, he posits that quantitative research tends to collect specific and limited data from a large number of participants, achieving a breadth-based examination; while qualitative research is centred around on a single question and the data is collected from a smaller number of participants (Patton, 2002; Harding, 2018).

Since socio-technical transitions are socially constructed processes, the preferred research approach in this research is the qualitative research approach, which aligns with the nature of the phenomena under investigation. It seeks to provide a holistic understanding of how cities implement large scale DH network from a socio-technical perspective, the role of individuals or social groups in the transition process and the underlying factors responsible for the barriers to DH implantation, how to govern DH transition and the drivers DH delivery in context specific situations. According to Yin (2018), qualitative methods are suitable for studies seeking to understand a complex reality and uncover knowledge, process and procedure in a specific context, field or setting, especially where there is limited knowledge about the phenomenon (Bryman, 2016). The aim is not to generalize, but to collect data that will provide an understanding of the phenomenon under investigation (Yin, 2018). According to Merriam and Grenier (2019), a key feature of qualitative research is that it considers meaning to be socially constructed by those who experience and interact with the world, as opposed to quantitative research, which considers the world or reality to be fixed or measurable. Qualitative methods are employed to gather data, to simplify the complexity of the research problem, and to provide a rich account of the situation that quantitative methods would not otherwise reveal (Hanson, Balmer and Giardino, 2011).

4.4. Research Strategy: Multiple Case Study

According to Yin (2018), a case study approach can be conducted in two ways: a single case study or multiple case studies. The researcher needs to decide whether a single or multiple case study approach is suitable before commencing data collection (Yin, 2018). Since this study seeks to explore a complex phenomenon in various local settings, this study lends itself to a multi-case study approach using qualitative methods. This research employs an exploratory multiple case study strategy, as it focuses on the development processes of DH implementation at city scale, involving the discourses, politics and interplay between different levels of governance (Flyvbjerg, 2006; Saunders, Lewis and Thornhill, 2016). It provides the opportunity for the researcher to define the study to explore a situation that has received little or no attention from other researchers (Saunders, Lewis and Thornhill, 2016). The decision to take on a multi-case study strategy is to explore this path and to fulfil the need for an approach that allows for the analytical and practical depth and details of the DH implementation process in Scandinavian cities of Copenhagen, Stockholm and Helsinki with extensive DH application as well as GM which is in the process of implementing DH at scale. This requires a systematic analysis of the interactions between key actors, institutions and social structures. The socio-technical analysis of energy system transitions requires a strategy that is robust and can track complex historical and emerging developments (Geels, 2005a).

According to Yin (2018), the only methodology that studies a phenomenon and seeks to understand casual links in complex situations involving the interaction of a number of variables in the real world are case studies. Case studies are suitable strategies for gathering a rich account of the dynamics of interacting processes. It focuses on the interconnections between multiple processes and activities rather than the linear cause-and-effect relationships. Furthermore, case studies provide the opportunity to explore the 'why' and 'how' of development over time (Yin, 2018). According to Kern (2011), case studies are particularly well suited to studying the politics of policy processes, and Flyvbjerg (2006), emphasizes the widespread use of case studies to investigate power in urban environments. Case studies have been used extensively in studies of local climate change governance (Pohlmann, 2011). Due to their ability to capture the "richness and multi-faceted nature of re-scaling an energy regime to a city-regional scale within a wider national context, (Bulkeley *et al.*, 2011). Hodson and Marvin (2012) recommend the use of documentary analysis and in-depth interviews to investigate the intersection of socio-technical transitions and urban political economy.

Local conditions, according to previous research (Hawkey, Webb and Winskel, 2013) play a significant role in the production of DH networks. As a consequence, making generalizations based on a small number of instances is difficult. While existing literature on governance systems and actors' relations in DH network implementation suggests a range of key themes, the use of a case study approach allows for a thorough analysis of these topics in context specific environments. Furthermore, one of the major advantages of the case study approach is the opportunity to draw on multiple data sources (Yin, 2018), and this study draws on a wider overview of the policy context in each of the case study cities. The aim is to gain a holistic understanding and a detailed account of the broad and complex (phenomena) social and political processes (Yin, 2018) involved in the interplay between actors, institutions, and technologies during socio-technical transitions. It is important to note that the aim of this study is not to compare cases but to gain an in-depth understanding of a phenomenon in multiple local contexts, hence a comparative case study was not considered (Creswell and Poth, 2018).

This research applies two main data analysis methods: qualitative document analysis of all secondary data (document) and thematic analysis of the primary data (interviews). This is discussed in more details in subsequent sections.

4.4.1. Justification for the adoption of a Case Study Strategy

While case studies have strengths, which aid in providing a detailed understanding of the particular contexts and settings of the phenomenon they also have disadvantages which are taken into consideration by the researcher. Case study research is often criticized for not providing generalisable findings that are representative which is largely due to their unique contexts and settings. While this is true case studies are useful in understanding processes, concepts and occurrences for the development of meaning and explanations as to how and why certain situations emerge and are useful for the development of theory and analytical generalizations which can be termed, representative. However, it is important to note that the theory and analytical generalizations is entirely provisional and would still require follow-up research in those areas (Denscombe, 2017; Yin, 2018). Although, the findings in this research will be representative of the contexts and settings in GM it will be useful for future analytical generalisations, evaluations and studies as such this research proposes to provide a resource for knowledge sharing on low carbon transitions that will be useful for other regions. Examples of similarities that aid the possibility of transfer of solutions include (Denscombe, 2017; Yin, 2018);

- **Institutional factors**: Policies, processes, size and type of organisations.
- **Physical factors**: structural settings, demography, geographical location, town, buildings, resources, town and city.
- **Social factors**: Demography, ethos, significance, user preferences, frameworks of political cultures, ideologies and government structures
- **Historical factors**: Heritage, developmental changes and transformations.

Furthermore, case studies often have unique characteristics representing a broad spectrum of factors and the practicality of having transferable findings is largely dependent on the similarities between other contexts of its nature (Denscombe, 2017; Yin, 2018). This research proposes to find potential solutions, key success factors and effective governing measures that can overcome the main barriers limiting the uptake and delivery of district heating at scale, in order to provide recommendations to actors involved in the DH implementation process or seeking to govern the transition to DH. Therefore, it is important to consider the transferability of the research findings.

4.5. Secondary Case Study Data Collection

The secondary case study analysis employed a systematic procedure to explore specific research questions to review, examine, and interpret the data to obtain meaning and analytical understanding of the phenomena being studied through the systematic review of secondary data. The qualitative data from the secondary case study cities of Copenhagen, Stockholm and Helsinki with widespread success in DH implementation were analysed using the previously identified themes from the MLP on socio-technical transitions analytical framework (see chapter 3 section 3.5) to build a thorough understanding of the research problem. The key reason for the selection of case studies with successful implementation of DH as opposed to the selection of unsuccessful case studies is due to the dearth of data in unsuccessful/failed case studies. The previously identified themes which include: (1) the implementation strategy; (2) technical solutions and heat sources; (3) policy instruments and regulatory framework; (4) pricing and consumer protection; (5) financial instruments and incentives were used to focus the secondary data analysis to examine the salience and influence of the five sociotechnical elements identified as key themes in the MLP framework. This helped the researcher gain more knowledge on the subject area for better understanding of how to conduct the primary case study research in GM. It was also useful in bridging the knowledge gap on the expertise and resources required to promote wider usage and integration of DH as part of a low-carbon energy system in the pursuit to deliver energy efficiency and climate mitigation objectives. The secondary data used in the 3 case studies were sourced from a mixture of the following:

- published reports,
- government publications
- Industry data and
- academic literature

According to Geels (2005a), sociotechnical transitions involve the conversion from one sociotechnical system to another through an active process of refinement and reconfigurations fulfilled by sociotechnical systems which include a combination of urban pathways, modes of governance, practices, networks, people, culture, technology, infrastructure, and goals that enable transformational change (Geels, 2005a). In addition, the activities of social groups such as academic institutions, organisations, public authorities, focus groups and users play an important role in transitions and are responsible for the change in elements and linkages in sociotechnical transitions (Geels, 2005a). Therefore, an understanding of the dynamics of socio-technical transitions will give insights on the technological and social changes that enable or inhibit socio-technical transitions in order to proffer solutions that foster successful transitions (Papachristos, 2014).

Consequently, a review of the existing literature on DH was conducted in chapters 2 and 3 in order to provide a detailed understanding of the DH development and delivery strategies, governance approaches, as well as theoretical frameworks that are used to analyse complex socio-technical systems. This research drew on relevant parts of the existing literature on socio-technical transitions with specific reference to DH to shape the research focus using the MLP analytical framework which posits that transitions require disruptions in the established order and a whole system reconfiguration with transformational changes not only in technologies, but also in consumer behaviours, policies, infrastructure, production networks, business models and market culture referred to as socio-technical transitions. Based on the MLP analytical framework the following key themes were used as the focus of the secondary and primary case study data analysis to provide a detailed understanding of DH implementation process in both contexts (Geels 2005a, 2011):

i. Implementation Strategy
ii. Technical Solutions and Heat Sources
iii. Policy Instruments and Regulatory Framework
iv. Pricing and Consumer Protection
v. Financial Instruments

This analytical framework helped to reveal how the case study cities have governed the transition to large scale DH networks considering the interplay between socio-technical elements and heuristic levels. It identified key success factors that can overcome policy and technical challenges with practical solutions to unlock the potential for driving the transition to district heating particularly in urban environments. Furthermore, it also provided insights into the skills required and some non-technical and organisational lessons which are critical in the implementation of DH networks while identifying key issues, underlying factors, drivers and barriers to DH implementation in their local contexts in the pursuit to deliver increased energy efficiency and climate mitigation objectives.

4.5.1. Search Strategy

This section highlights the study criteria, literature sources, and Boolean operators that were utilized to refine each search and merge the phases in the selected databases. It also describes the inclusion and exclusion criteria that were used in the selection and compilation of the findings as well as the adopted theoretical sampling technique.

4.5.1.1. Inclusion and Exclusion Criteria

The search included historical, technical, and management literature on DH technology, as well as DH network implementation in cities, which led to the identification of the Scandinavian cities of Copenhagen, Stockholm, and Helsinki, owing to the wealth of documented data and evidence of how DH has been successfully implemented in these regions. It also included energy transition studies, DH implementation policies and regulations, the multi-level perspective, socio-technical transitions literature and urban energy transitions with a specific focus on DH networks. Figure 32 highlights the databases used to retrieve literature sources and the ninety articles selected by the researcher to better understand the DH technology, implementation strategies, and policy landscape in the case study cities.

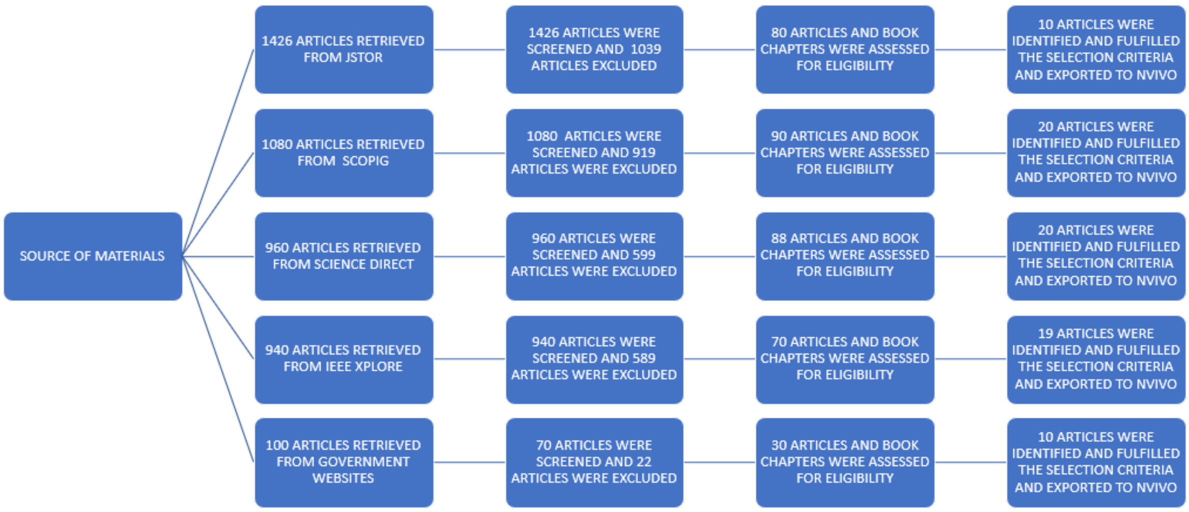


Figure 32: Source of material used in the literature review

Most studies included were selected based on publication dates of articles ranging from January 2000 to November 2021, enabling the study to identify the gap in the literature over the last twenty one years, which revealed a dearth of literature on case studies of what actually happens during the implementation of a DH technology from a socio-technical perspective. It also included articles on climate change research in relation to the need for the transition to clean energy technologies and energy efficient systems, as well as research on heat sources, renewable energy technologies, energy poverty/fuel poverty and energy security. Some of the government publications included in the review were originally written in Swedish, Danish and Finnish which were translated to English using the translation option available on the website.

4.5.1.2. Criteria for Studies

The following databases were used for the literature search through the University of Salford library: Scopus, JSTOR, IEEE Xplore and ScienceDirect to improve the reliability, validity and rigour of the selected literature for the research study through the use of peer reviewed journals and reliable documents (Long and Johnson, 2000; Cypress, 2017). This process included data source tracking and categorisation, notetaking, arrangement of key documents, and the creation of tabular materials. The creation of database accounts aided the storage and set up of alert notifications for recently published literature that match the study criteria, as well as the easy retrieval of data.

4.5.1.3. Search Terms

Some of the search terms used were Energy transition, urban energy system, socio-technical transition, climate change, district heating technology, heat sector, energy policy, district heating implementation, renewable energy technologies, heat sources, energy efficiency, fuel poverty, energy security, environmental sustainability, energy efficient cities, international climate regime. Keyword operators and Boolean operators were also used to combine search terms. For example:

- Energy system transition and DH technology.
- Urban energy transitions and / or socio-technical change
- District heating implementation and renewable energy sources

4.5.1.4. Case Study Selection

Several considerations can influence the selection of cases. Creswell and Poth (2018) acknowledge that there may be multiple case options to explore a given study, however the researcher must select the best cases to explore based on their knowledge value. A key consideration for the selection of Scandinavian cities was the availability of data and evidence on the previously identified themes from the MLP analytical framework. The researcher decided to select the three cities of Copenhagen, Stockholm, and Helsinki, which were found to have a good amount of robust and reliable evidence, including a wealth of documented data and evidence of how DH has been successfully implemented using the analytical framework structure. These cities have well established DH sector and are exemplar cities in the implementation of DH with extensive DH knowledge, experience and expertise.

4.5.2. Secondary Data Analysis - Document Analysis

Document analysis is a type of qualitative analysis in which documentary evidence is analysed using a systematic procedure to answer specific research questions. Document analysis, like other qualitative research methods, requires review, examination, and interpretation of written data in order to obtain meaning and analytical understanding of the phenomena being studied. Document analysis can be performed as an independent analysis or as part of a broader qualitative or mixed methods analysis, where it is sometimes used to triangulate findings from other data sources such as interview or focus group transcripts, observation and surveys (Frey, 2018). Document analysis is similar to content analysis, however the main difference is that content analysis examines all mediums in which words appear, whereas document analysis solely examines written documents. Documents analysis can be used in triangulation to corroborate or contradict, elucidate or draw on observations from other data sources, which helps in reducing bias (Frey, 2018). Also, the extensive document analysis of the secondary data was used to inform guidelines on how to conduct the research in the primary case study and what to ask during interviews and who is considered as key stakeholders to involve in the primary data collection process.

In the course of this study, document analysis was used independently in the case of the secondary case studies and in conjunction with interviews in the case of the primary case study. Several documents published by industry, government and sectoral organisations were analysed. These documents include policy and government related documents, reports and statistics relevant to DH implementation and the research objectives and questions. The analysis of documents aided in providing a detailed understanding of the DH implementation process in the case study cities. It provided an overview of the DH policy landscape. The data from the documents provided insights into the perspectives of the government and policy makers. The document analysis for the primary case study was analysed in the same way as the interview transcripts, using the inductive themes from the interview data to extract additional information. The documents used in this study were obtained from reliable government webpages, and their validity was also verified by participants, who referred to them during interview sessions. The analysis of the case study cities are presented in Chapter 5.

4.6. Primary Case Study Data Collection

The primary case study was undertaken within GM to explore how GM seeks to implement large-scale DH networks to capture DH development process. The early stage of DH development in GM makes it an ideal primary case study for this research, in order to capture the opportunities, challenges and barriers to DH implementation process at the start of the journey. This enabled the researcher to conduct a cross-case analysis of the two different contexts in the primary and secondary case studies, to provide a unique contribution to knowledge. In this study, two main data analysis methods applied were: thematic analysis of the primary (interviews) data which were informed by and complemented with a qualitative analysis involving a systematic literature and the document analysis of secondary data. The primary case study research involved the collection of data through semi-structured interviews with 20 key stakeholders involved in the implementation of DH networks in GM, to explore how GM seeks to implement large-scale DH networks to capture the DH development process from a socio-technical perspective using the theoretical (top-down) approach to thematic analysis.

Multiple data sources were used as a validation strategy to verify the accuracy of the collected interview data, according to Saunders, Lewis and Thornhill 2016 if the comparison of the data from multiple sources come back the same it will be perceived that the research has been thoroughly and accurately conducted with unbiased findings and results (Saunders, Lewis and Thornhill, 2016). In conjunction with the thematic analysis of primary data, document analysis was conducted on the secondary data sourced from academic literature, published reports, policy documents and meeting minutes to corroborate or contradict and to elucidate or draw on findings from the data, in order to in reduce bias using the same search strategy outlined in section 4.5.1. The findings from these analyses were triangulated to substantiate their validity. Figure 33 provides an illustration of the primary and secondary data methods used in the primary case study research.

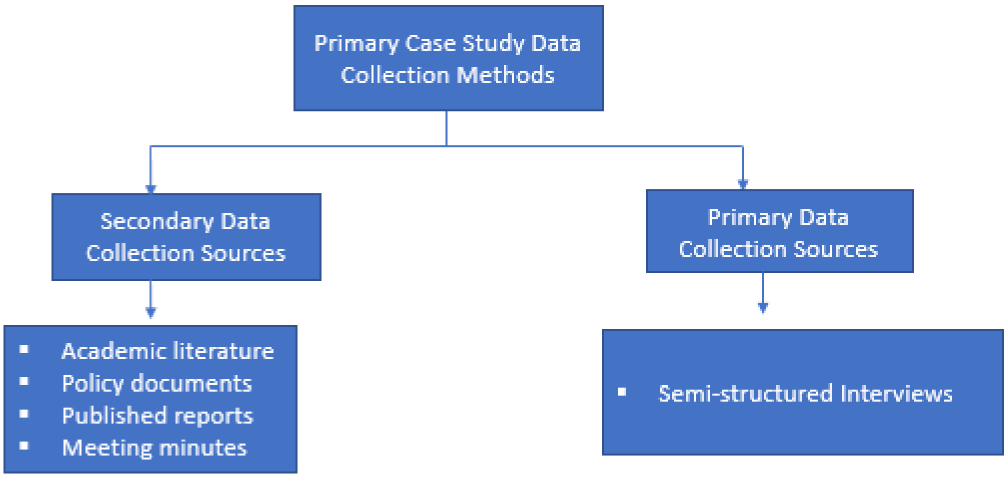


Figure 33:Adopted primary case study data collection methods

This study required participants to provide a detailed account of the complex transition process and the opportunities, challenges and barriers to the transition, development and implementation of DH in GM. Interview questions focused on the approaches and attitudes of actors towards the development of DH in Greater Manchester, exploring how they have changed over time and their perceptions of risks and threats to a successful transition to DH. This enabled the researcher gain insights into the process, find themes and develop meaning. According to Bryman and Bell, (2007) semi-structured interviews give room for flexibility and is one of the strategies to obtain a representative concept of an individual's perspective (Bryman and Bell, 2007).

4.6.1. Participant Selection and Inclusion criteria

Participants were selected strategically and purposefully based on their roles as key stakeholders involved in the DH implementation process within Greater Manchester Combined Authority (GMCA)

Energy Innovation Group and in the UK at large for a national scale perspective on DH network development. The researcher carried out a stakeholder analysis using a systematic four-step approach based on the identified relevant stakeholders from the secondary case study such as policy officers, local authority officers, DH operators, energy service companies (ESCOs) representatives, and asset owners. This ensured that participants are made up of a relevant range of key stakeholders, who are majorly involved in the implementation process as well as stakeholders who can influence DH implementation, across the private and public sectors, with the exception of end-users.

The aim of the stakeholder analysis was to identify and map key stakeholders across various policy sectors, to determine their interest and potential to influence the decision-making process in the implementation of large-scale DH networks as well as to illustrate the interdependence between them. A systematic four-step approach for stakeholder analysis (see figure 34) was developed based on the review of literature sources in the secondary case studies in line with the approach used by Acheilas, Hooimeijer and Ersoy (2020).

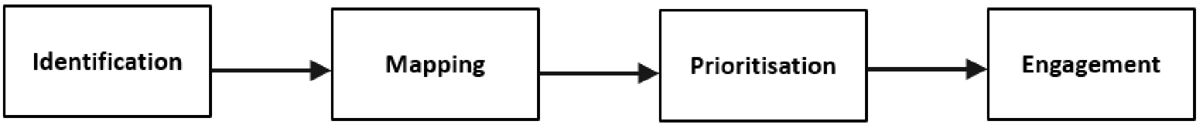


Figure 34:Systematic four-step approach for stakeholder analysis

First, a comprehensive list of the key internal and external stakeholder groups in the DH sector was drawn up. Second, a stakeholder map was created for the visualisation of the multi-level stakeholder landscape as shown in Figure 35. After the mapping process, a stakeholder prioritisation tool known as the power versus interest matrix tool was used to differentiate between the influence and interest of various urban district heating implementation groups (Pandi-Perumal *et al.*, 2015). This tool is useful for managing and analysing stakeholders. By positioning stakeholders within the matrix, it differentiates their roles, level and type of involvement in the implementation process.

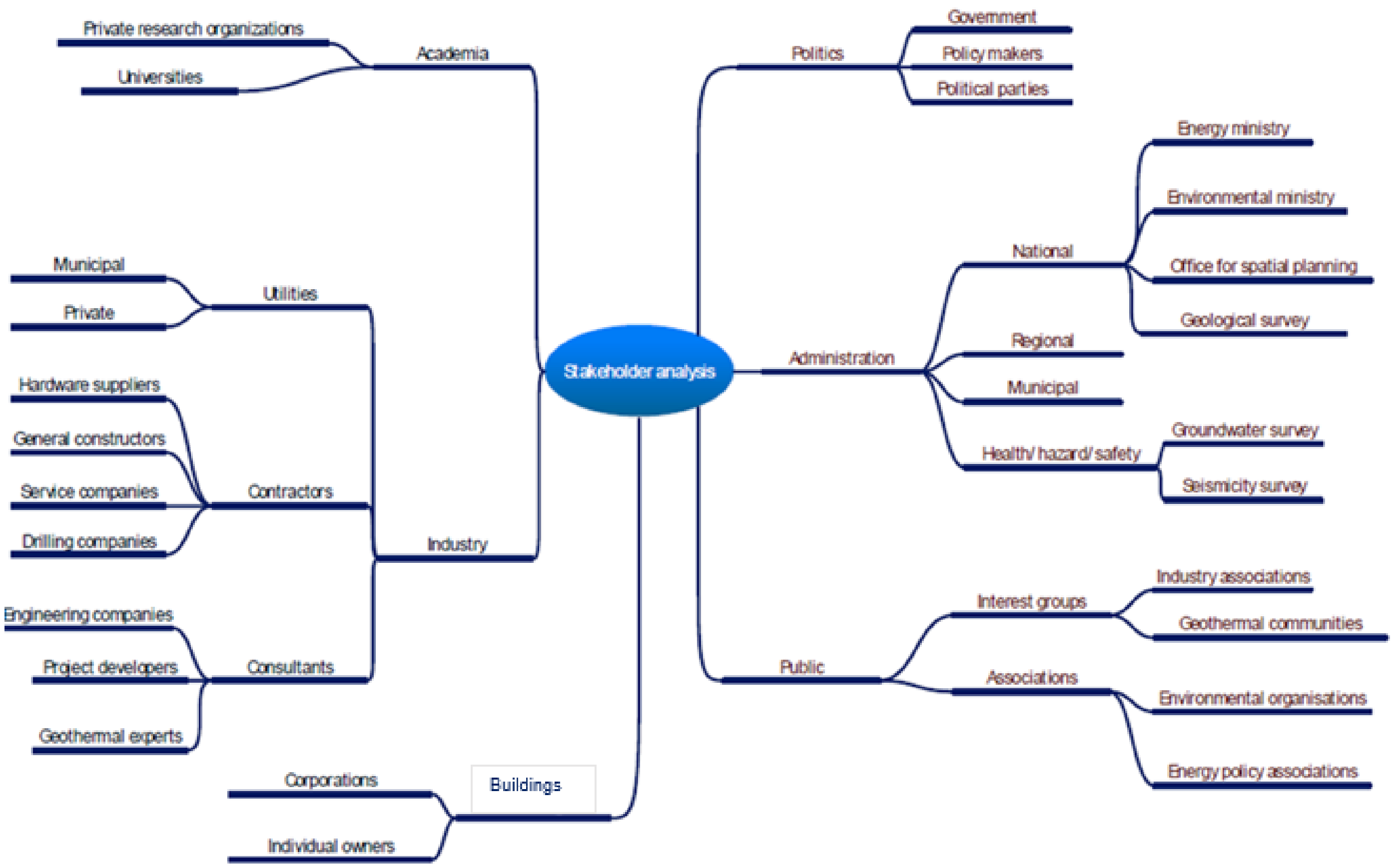


Figure 35: Multi-stakeholder landscape visualisation map based on Minder and Siddiqi (2013)

This ensured participants were made up of a relevant range of key stakeholders, majorly involved in the DH system implementation process in GM across the private and public sectors. It is important to mention that the key stakeholder analysis excluded end-users, as this is outside the scope of this research. The researcher employed the following sampling methods for participant selection:

- Purposive sampling
- Snowballing sampling

The Purposeful Sampling method involves the selection of individuals or groups that are knowledgeable and most beneficial to the objectives (purposes) of the research. It is often used in qualitative research, to acquire detailed knowledge about a specific phenomenon or subject of interest. An effective sample (purposeful) must be selected based on clear criteria and rationale (Creswell *et al.*, 2011; Palinkas *et al.*, 2015). Purposeful sampling was therefore, be useful in the selection of key actors across the public and private sectors, who are well-informed about the development of DH networks in GM, who are best suited to achieve the aims and objectives of this research.

Snowball sampling which involves the recommendation of potential participants to be involved in the research by the initial participants (Naderifar, Goli and Ghaljaie, 2017). In this case, initial participants were asked to suggest relevant stakeholders majorly involved in DH development in GM. The researcher then ascertained if the potential participants were considered to be stakeholders based on the identified stakeholder types from the secondary case study before engaging with them. Essentially, the intention is to keep interviewing selected participants until a representative sample is established and data saturation is achieved.

4.6.2. Profile of Interviewed Participants and Structure of Interviews

The study applies the MLP analytical framework structure to understand the early stage development of a DH implementation strategy in GM. The interviews were based on a set of questions designed to explore key socio-technical perspectives using the previously identified key themes also used for the secondary case studies to focus the analysis to explore the DH implementation process to better understand participants' perspectives on the development and implementation of large-scale DH networks in GM. These include: (1) the implementation strategy; (2) technical solutions and heat sources; (3) policy instruments and regulatory framework; (4) pricing and consumer protection; (5) financial instruments and incentives were used to focus the secondary data analysis to examine the salience and influence of the five sociotechnical elements identified as key themes in the MLP framework.

Questions were posed to capture actors' perceptions of the early-stage DH development and implementation in GM, as well as the DH transition drivers, the challenges and barriers to DH development. Additionally, strategies for overcoming these challenges in order to accelerate DH implementation in GM were explored. Appendix F has a full breakdown of the questions that were used to structure the interviews. The primary case study findings provided a blend of insights from a range of expert stakeholders which reaffirmed the findings from the literature review. Effort was made to seek inputs from stakeholders with a range of sectoral expertise, including academics, industry body representatives, policy makers and operators. Views expressed as part of this research may not represent those of the organisations involved. A total number of 20 participants participated in the current study, table 10 shows the breakdown of participants interviewed by type. The interview centred on the drivers and barriers to DH network implementation and the role the proposed Heat Network Regulation will play in addressing the barriers and in enabling decentralised energy generation. It also provided a national view of DH development in the UK. Table 10 shows the breakdown of participants by type.

Table 10: Breakdown of participants by type

Interviewees	Number
Local Authority Officials	4
National Policy Makers/Advisors	2
Energy Consultants	5
Academics	1
Regional Government Officials	2
National Government Representatives of Industry	1
Decentralised Energy Providers	6
Total	20

The participants were happy for me to disclose their organisational details, therefore before presenting the findings in this study, it is important to examine the profiles of all the participants in this study in order to provide context for the perceptions of participants and to put their experiences into perspective. The profile of participants is summarised in Table 11.

Table 11: Profile of Participants

S/N	Organisation	Background	Sector/ Category	Position	Experience
1.	Manchester Civic Quarter Heat Network	Degree in engineering and a PhD in combustion.	Public/ Local Authority	Technical Project Director	Over 20 years' experience in the energy industry in both public and private sectors
2.	Department of Business Energy and Industrial Strategy (BEIS)	Engineering	Public/ Government	Project Lead (North) Heat Network Delivery Unit (HNDU)	8 years' experience in the energy industry in both public and private sectors
3.	Department of Business Energy and Industrial Strategy (BEIS) Clean Heat Directorate	Economics and Policy of Energy and the Environment	Public/ Government	Head of Heat Network Policy	Almost 10 years' experience in energy policy in the public sector
4.	Aecom	Engineering	Private	Sustainable Development Group Lead	Experience in heat network development and delivery across various locations in the UK
5.	Aecom	Engineering	Private	Associate Director	Experience in heat network development and delivery across various locations in the UK
6.	Greater Manchester Combined Authority (GMCA)		Public/Government	Head of Low Carbon, Policy and Strategy Team	Over 10 years' experience in smart systems and heat program
7.	Ramboll Engineering company	Physics MSc in Renewable Energy	Private	Principal Engineer	Over 10 years' experience in the heat network delivery in the private sector
8.	Coal Authority	PhD in Metalliferous Mine Water Assessment and Treatment	Public/ Government	Commercial Manager – Mine Energy	Over 10 years' experience as an Assistant Professor in hydrogeology and heat recovery from abandoned coal mines
9.	Oldham Council		Public/Local Authority	Programme Manager – Community Wealth Building Transformation and Reform Team	Over 10 years' experience in the sustainable energy development strategy in the public sector
10.	The Heat Academy	International Business Administration and Economics	Private	Founder & Chief Executive Officer	Over 20 years' experience in the heat network delivery in the private sector
11.	Nordic Heat	Education Music and Sport. Post Graduate Certificate in Marketing	Private	Chief Operating Officer	Over 20 years' experience as an energy consultant for both public and private sectors organisations
12.	Arup Group Engineering company	Physics with Business Management MSc Nuclear Science and Technology	Private	Senior Consultant	Over 10 years' experience in the energy industry in the private sector

13.	ARUP Engineering company/ Chair, Decarbonisation of Existing Homes at Welsh Government	Civil engineering MSC Cloud physics, cloud systems and dynamic meteorology	Private/Public	Senior Consultant	Over 49 years' experience in the energy industry in the private sector
14.	Blue Yonder	Degree in psychology and a Master's in organisational design	Private	Professional in the District Heat Sector	A board director of four local heating network companies with well over 20 years' experience in DH network development and delivery in both public and private sectors organisations
15.	Association for Distributed Energy (ADE)	Philosophy and Politics MSc Environmental Change and Management	Private	Head of Policy	Over 5 years' experience in energy policy development and delivery
16.	Vital Energi		Private	Project Development Director	Wealth of experience in DH network delivery and energy performance
17.	Vital Energi	Physics	Private	Energy and Commercial Analyst	Worked in the energy across a range of technologies in the private sector since undergraduate days.
18.	Kew Consult Ltd	Civil Engineering MBA Business Studies	Private	Director, Delivery, commercial & funding expertise	Over 20 years' experience as an energy consultant for both public and private sectors organisations
19.	Bolton Council		Public/ Local Authority	Principal Officer (Sustainable Development)	Over 10 years' experience in the sustainable energy development strategy in the public sector
20.	Stoke-on-Trent Council	Mechanical Engineering	Public/Local Authority	DH Network Technical Lead Manager	Over 20 years' experience in the energy sector and over 10 years' experience in DH network development and delivery in both public and private sectors organisations

The interviewees were chosen for their expert knowledge and positions in industry, policy making and research as well as for their ability to understand a part or all of the process involved in the design, build, operation and maintenance (DBOM) of large-scale DH implementation projects. A representative sample was established, and data saturation is achieved. This was evidenced by the fact that the same set of potential participants who had already been interviewed were being recommended to take part in the study due to their extensive knowledge and ability to contribute significantly. Also, increased data consistency in the final set of interviews led to the conclusion that a meaningful data saturation point had been reached, which covered all the sociotechnical aspects. Therefore, 20 one-on-one interviews with participants were sufficient to enable the researcher to develop meaningful themes and robust interpretations. Increased data repetition over the course of the final few interviews, led to the conclusion that a meaningful data saturation point was reached. The theoretical (top-down) approach to thematic analysis, which aligns with the qualitative research was used during data collection, and analysis to establish consistencies, patterns, and meanings. The analytical framework of the multilevel perspective on socio-technical transitions was used to focus the analysis by searching for themes that have previously been identified in the literature to gain an understanding of the large-scale DH implementation process in GM (Braun and Clarke, 2006; Creswell and Poth, 2018). Thus, the primary case study analysis was structured using the MLP framework used for secondary case study analysis in order to better understand participants' perspectives on the development and implementation of large-scale DH networks in GM. The key themes and sub-themes which emerged from participant narratives contributed to answering the research questions.

4.6.3. Semi-Structured Interviews

Interviews can be conducted in a variety of ways: highly structured, unstructured, or semi-structured (Gray 2013; Merriam and Tisdell 2016). Semi-structured interviews have been chosen as primary data collection method in this research in order to achieve the objectives of this study. Interviews give room for a deep understanding of the premise that social and historical drivers which are important for inductive data analysis construction and interpretation (Braun and Clarke, 2006). This study required participants to provide a detailed account of how the implementation of district heating is governed in GM as well as the potential opportunities, risks and threats that currently exists within the DH sector in the pursuit to decarbonise the heat sector. This will help the researcher gain insights into the process, find themes, and develop meaning. Unstructured interviews can result in free-flowing discussions, which could lead to an unproductive deviation from the scope of the study while structured interviews do not give room for flexible capturing of details.

According to Bryman and Bell (2007), semi-structured interviews give room for flexibility and is one of the strategies to obtain a representative concept of an individual’s perspective. This will involve semi-structured interviews with a variety of transition actors ranging from local authority officers, business leaders, technology experts, innovators, policymakers in order to explore how GM seeks to implement large-scale DH networks to capture DH development process from a socio-technical perspective with the aim of finding potential strategies that can overcome the barriers to the uptake of low carbon DH network at scale. Consequently, semi-structured interviews which provide structure and direction while giving room to explore the depth and details of the scope of the study is an ideal method for this research (Braun, V & Clarke, 2013).

It is important to note that semi-structured interviews can be challenging and time-consuming as the process of preparing, setting up, conducting and analysing semi-structure interviews takes a considerable amount of time. It requires extensive resources, and it can be challenging to analyse open-ended questions as it often entails the arduous task of analysing huge volumes of data and several hours of transcripts. Also, the flexibility of semi-structured interviews may lessen reliability; therefore, in order to properly conduct semi-structured interviews, interviewers must have the right amount of training and substantive knowledge of the subject area (Braun, V & Clarke, 2013; Merriam and Tisdell 2016). Specific interview questions were generated to address topics relevant to the research questions based on the previously identified key themes from the MLP analytical framework. Despite the disadvantages and risks associated with semi-structured interviews, it was considered necessary for this study in order to obtain a first-hand understanding of the situation, a more detailed and in-depth investigation of participants' perceptions, and to allow for greater flexibility in narrating their accounts.

4.7. Primary Data Analysis

The semi-structured interviews involved interactions with a variety of key actors involved in the DH implementation process in GM ranging from local authority officers, business leaders, investors, technology experts, innovators, and policymakers. This is to provide an understanding of how DH implementation is governed in GM as part of the whole energy transition agenda. A total of 20 video interviews on Microsoft Teams were conducted in this study, which lasted between an hour to 2 hours 30 minutes and were recorded on Microsoft Teams. The interview recordings were transcribed, after which all the transcripts were double-checked for accuracy and then analysed using thematic analysis (MacLean, Meyer and Estable, 2004).

The primary data analysis was particularly time-consuming and one of the most challenging aspects of the study, owing to the large amount of data obtained. It was essential for the researcher to learn how to code correctly and quickly before commencing the analysis through a series of literature reviews and hands-on training for proficiency in the analysis (Braun and Clarke, 2006; Saldana, 2015; Merriam and Tisdell, 2016). The data analysis, which was carried out simultaneously with data collection, made it possible to assess and review the research questions to ensure they were clear and understood by participants. This necessitated the use of a transcribing tool to get it transcribed quickly, enabling the researcher to modify the research questions in line with the emerging categories, themes and concepts as the interviews progressed (Strachan *et al.*, 2015; Smith *et al.*, 2016; Merriam and Grenier, 2019).

The data analysis was guided by an interpretive paradigm which was deemed appropriate to understand participants' narratives and subjective views in their respective locations, in line with the aim of this research. Given the qualitative approach taken in this study, interpretation played a significant role in the data analysis (Eriksson and Kovalainen, 2016). NVivo 12, a qualitative data analysis software was used to ensure accuracy and in-depth analysis, as well as to organise the data (Brandão, 2015; Merriam and Tisdell, 2016; Woods, Macklin and Lewis, 2016). The theoretical (top-down) approach to thematic analysis, which aligns with the qualitative research was used during data collection, and analysis to establish consistencies, patterns, and meanings, using the previously identified themes from the MLP framework to focus the analysis (Braun and Clarke, 2006; Creswell and Poth, 2018).

4.7.1. Thematic analysis

Thematic analysis is one of the methods used to analyse qualitative interviews from participants' experiences and perspectives. It helps qualitative researchers to organise a wide range of information in a systematic manner in order to describe data sets in a logical fashion and to interpret several aspects of the topic studied (Boyatzis, 1998; Braun and Clarke, 2006). Thematic analysis is flexible and can identify patterns across a set of data, collected during interviews termed 'themes' which can be coded accordingly (Braun and Clarke, 2006). In thematic analysis, themes or patterns within data can be identified in one of two major ways: inductive (bottom up) or theoretical (top down). Data analyses is often carried out in order to extrapolate findings, mainly by means of manual or electronic material coding of interviews which can be completed with the aid of the NVivo technology to identify key themes that arise (Thomas and Harden, 2008; Braun and Clarke, 2006).

This research is context-specific with distinctive structural settings, demography, and significance, frameworks of political cultures, ideologies and government structures. Thematic analysis aligns with the researcher's goals as it utilizes an effective method to examine perspectives. It helps researchers to gather connections as well as the differences in responses which will aid in the discovery of emerging themes, it will, therefore, be useful in developing a clear analysis and detailed account of DH development in GM. The thematic analysis will follow a six-phase process, illustrated below in table 12 (Nowell *et al.*, 2017).

Table 12:Thematic Analysis Phases (Braun and Clarke, 2006)

Phases	Stages
Phase 1 →	Familiarising yourself with your data
Phase 2 →	Generating initial codes
Phase 3 →	Searching for themes
Phase 4 →	Reviewing themes
Phase 5 →	Defining and naming themes
Phase 6 →	Producing the report

Inductive (data-driven) and theoretical (deductive)thematic analysis are the two key types of thematic analysis identified by Braun and Clarke (2006). The inductive approach examines empirical data without first considering existing theoretical literature, allowing the researcher to discover which themes are important independently of any previous literature. This approach is useful for obtaining a broad picture of the overall data, especially in under-researched areas. An inductive approach signifies that the established themes are closely linked to the data themselves, while a theoretical thematic analysis is useful for answering focused research questions that seek to build on existing literature or to explore specific aspects of the data. The theoretical (top-down) approach to thematic analysis was used in this research using the previously identified themes from the multilevel perspective framework on socio-technical transitions to focus the analysis using specific research question to understand how the themes have played out across the data to gain a detailed understanding of DH development and implementation process in GM. The framework was used as the basis for the initial themes used to code the data, sub-themes were then identified within these. Each of the six phases in thematic analysis are discussed in subsequent sections.

4.7.1.1. Data familiarisation

The researcher ensured the interview transcripts were thoroughly cleaned by correcting any spelling errors and fixing missed words. The researcher listened to the interview recording while re-reading the transcript to acquaint herself with the data and to identify verbal emphasis in search for meanings, ideas and patterns. Following that, a coding system containing initial codes that emerged from each interview was created after which they were transferred into NVivo software to be analysed and interpreted. The researcher read the transcripts carefully and in detail to promote trustworthiness. The related paragraphs were highlighted during this preliminary reading to make the data analysis process easier (Creswell, 2014).

a thematic analysis method was used to identify interesting aspects of the data relevant to the research questions (Braun and

Clarke, 2006). The analysis was initially coded into categories of relevance to the

chapter's research questions (shown in table 4), using Nvivo software. Relevant

and interesting themes were then identified within the coding. These themes are

presented in the next section.

4.7.1.2. Generating initial codes

During the fieldwork, 20 interviews were conducted with a total duration of 1,443 minutes resulting in the review and analysis of 20 documents with a total length of 312 pages. Interview questions were generated to address topics relevant to the research questions based on the previously identified key themes from the MLP analytical framework. The initial coding is essential to provide a structure for data analysis. Coding, however, is an evolving process which develops and is refined within the analysis process (Braun and Clarke, 2006).

Each interview transcript was analysed separately at this stage to create initial codes and to reference quotes. It was necessary to summarise the data to keep it organized and easily accessible. According to Boschmann (2011), coding is "the process of reducing participant's words into smaller meaningful ideas by connecting them to specific concepts. The empirical data was analysed using an initial phase of coding structured based on the five key themes from the MLP analytical framework on sociotechnical transitions literature, which was also used for the secondary data analysis to explore the DH implementation process in order to better understand participants' perspectives on the development and implementation of large-scale DH networks in GM.

The researcher coded the datasets using specific research questions (see Appendix C, D and E) based on the previously identified themes from the MLP framework; sub-themes that emerged from participant narratives were then identified within these which contributed to answering the research questions. The researcher used open coding at the first stage, to assign initial codes, which enabled the researcher to consider any emerging codes (Merriam and Tisdell 2016).

The initial coding provided the researcher a chance to thoroughly reflect on what emerged from the data in order to take account of similarities or distinctions and identifies interesting aspects of the data that might form the basis of repeated patterns. It also provided an open-ended approach to data coding that would then follow a particular suggested guideline (Saldana, 2015). Codes were created based on the issues raised by the first set of interviewed participants about the topic under investigation. Additional codes and comparison were made as more transcripts were analysed. This approach aided in the organization of data into meaningful groups for easy access and retrieval (Braun and Clarke, 2006).

Descriptive coding was used to attribute and label data to construct a database of the emerging topics. NVivo coding was deemed appropriate because it values and prioritizes the expression and language of participants to create codes (Creswell and Creswell, 2018). Table 13 illustrates the process of generating initial codes. This shows several codes, themes, and quotes as an example of the relationship between the themes, data collected, and sub-themes.

Table 13:Phase 2 generating initial codes

Interview Quo(Original transcript full extracts as per question and answer)	**Initial codes**

Implementation Strategy	Strategic planning
Researcher: What is the strategy for the large-scale implementation of DH in GM?	Economic/Commercial benefit
Participants: *''So from a greater Manchester's decarbonisation of heat plan. We're working with BEIS and AECOM on something called a City Deep Decarbonisation Plan (CDDP). That we will look at, where we need to strategically place DH networks of both high temperature and low temperatures, that includes ground source, shared loops, etc. And it also leads to look at how we're going to transition our building stock more generally, from gas, and fossil fuel powered heating through to decarbonize heat.''*	Capital funding
''Anchor loads are so important to making your networks. commercial anchor loads are really the thing that drives it. So we believe that public sector, commercial buildings should be mandated to connect to heat network zones, where zones are the best way to go. And we also support I think, mandatory connections on larger non-domestic buildings as well. So if there's big office blocks, big new developments, kind of commercial real estate going on, they should be eventually mandated or very strongly incentivized to connect to the heat network in the area''	Government funding
''That strategy has been helping local authorities start to build up their capacity and expertise in developing DH networks through the heat network delivery unit, injection into the market of capital funding with Heat Network Investment Project and more recently announced Green Heat Network Funds (GHNF) to try to build expertise, get key projects off the ground, and to get the market going in the UK, in England or Wales more specifically.''	
'Public sector can borrow capital at 3%, the private sector has to pay 10%. So, in terms of having that focus management and ring fence budget with low cost capital, it sort of naturally leads towards a public sector approach.''	

Initially, 40 codes were created, afterwards some codes were eliminated/merged, considering the research questions and objectives, selected themes were refined and labelled resulting in a final number of 21 main codes which were identified.

4.7.1.3. Searching for themes

This phase involves the generation of key themes that are relevant to the topic under investigation with the coding process evolving and refined all through this phase (Braun and Clarke, 2006, P.87). The identified codes were organised into coherent groups of codes and themes in relation to the study. Some themes were subdivided into sub-themes during the analysis to illustrate the research questions. Since this study's data analysis was primarily deductive, using the initial codes generated in phase 2, the researcher identified patterns connecting codes to form themes. At this stage, some codes were discarded, and some identified themes were grouped as subthemes (Thomas and Harden, 2008; Braun and Clarke, 2006).

4.7.1.4. Reviewing themes

This is the phase in which all preliminary themes are modified and developed (Maguire and Delahunt, 2017). The researcher should also check whether any of the themes and data are related to one another. Additional themes can be created by the researcher if required to further support the data. According to (Buetow, 2010) when identical data continues to appear under the same possible theme, it can be considered as a significant theme. The themes that emerged from the interviews, described as collective pieces of perceptions, ideas and experiences were gathered and categorised in a consistent, meaningful way to map the views of participants (Aronson, 1995). Sub-themes continued to emerge from the data, indicating that broad themes were broken down into more organized themes. As a result, more data was associated with sub-themes in relation to each theme. In this phase, the researcher examined the themes identified in phase 3 to (a) ensure that the data coded into each theme is consistent, (b) ensure that the themes accurately represent the whole data set, and (c) determine whether any themes are missing. The data analysis in this study is predicated on previously identified themes from the analytical context, however the researcher identified an emergent key theme which was included as the sixth theme. The same process was used to categorise all the data set into the identified theme, which were combined and categorized into a coherent map of reality interpreted by participants.

4.7.1.5. Defining and naming themes

The researcher determined the category of themes that captured data. The themes were identified based on the data and in relation to the research questions to obtain a detailed map of the data from the emergent and theoretically defined themes (Braun and Clarke, 2006). In this phase, the researcher attempts to describe each of the themes, ensures that they do not overlap, and begins to build a comprehensive narrative to answer the research question. Five key themes emerged from the analysis of the primary data, were a match with the analytical framework structure derived from the review of existing literature. Table 14 outlines the five themes from the MLP framework used to structure and focus the thematic analyses and the sixth theme which emerged from the data analysis with key themes and the codes in each theme.

Table 14: The thematic analysis of the qualitative interview data with key themes and the codes in each theme.

S/N	Research Questions	Code
1	**Implementation Strategy** *What is the strategy for the large-scale implementation of DH in GM?*	Strategic approach Commercial approach Public fund approach
2	**Technical Solutions and Heat Sources** *What technical solutions and heat sources are currently being considered or have been applied to implement DH in GM ?*	Gas CHP Biomass Geothermal heat
3	**Policy Instruments and Regulatory Framework** *What policy instruments and regulatory framework underpin DH implementation of DH in GM and are these the right ones?*	Policy land scape Future policy
4	**Pricing and Consumer Protection** *How does DH work in terms of consumer protection and how is it priced?*	Pricing and Consumer Protection
5	**Financial Instruments and Incentives**	HNIP

	How are DH development projects financed in GM?	HNDU Funding
6	**Challenges/barriers to DH network implementation in GM**	Lack of DH skills, knowledge and resources High monetary cost and funding issues Policy and regulatory issues Technical challenge: poor technical and performance standards Lack of commitment, trust and buy-in Lengthy development and implementation periods

4.7.1.6. Building arguments and producing the report

At this stage, the data set had been constructed and was ready for writing a report of the findings which is an integral part of the analysis process. The aim of this process was to create and present a coherent argument based on logic in relation to the research questions and objectives (Braun and Clarke, 2006). This was accomplished by choosing emergent themes from the data that were relevant to the research. The analysis revealed a systemic interaction between technical system development, institutions, and social actors presented in chapter 7.

4.8. Validity and reliability of the study

Validation involves the authentication of research data, analysis and interpretation in order to confirm their validity, authenticity and credibility (Saunders, Lewis and Thornhill, 2016). Types of validation strategies include triangulation, participant or member validation and reflexivity

Qualitative research is often challenged because they are considered to be biased. Validation is a means of demonstrating that the research has been thoroughly and accurately analysed with unbiased findings and results. Several processes can be used to ensure that research is validated. Some researchers carry out multiple data collection methods as a validation strategy and if the data comes back the same it is perceived to be validated this is referred to as triangulation. Participant or member validation involves the provision of the research data to the participant in order to have them confirm the veracity of the data (Saunders, Lewis and Thornhill, 2016).

Reflexivity acknowledges and reflects on how the researchers perspective arising from the researcher's background and experiences may influence the interpretation of results, the assumptions and conclusions in the research in order to reduce bias (Creswell and Creswell, 2018).

According to Saunders, Lewis and Thornhill 2016 multiple data sources are often used as a validation strategy to verify the accuracy of the collected interview data, if the comparison of the data from multiple sources come back the same it will be perceived that the research has been thoroughly and accurately conducted with unbiased findings and results. This research study adopted a number of strategies to validate the research: the reflexivity approach, participant or member validation; a summary of the interview results was shared with the participants to validate the data and triangulation. Triangulation is often used to cross reference collected data to validate findings (Yin, 2018; Bryman and Bell, 2015). In addition to thematic analysis of primary data from interviews, extensive document analysis was performed on secondary data sourced from academic literature, published reports, policy documents, and meeting minutes to corroborate or contradict and elucidate or draw on findings from the primary data, in order to reduce bias and establish reliability by cross-referencing the secondary data with the primary data to verify the accuracy, and to validate the research. The findings from these analyses were triangulated to substantiate their validity (Yin, 2018; Bryman and Bell, 2015).

4.9. Ethical considerations

Ethical and data protection considerations have been carefully thought-out in the design of this research in line with the research ethics and data protection policies in the UK in order to protect the rights, safety and well-being of the participants while pursuing the objectives of this study. This research required an ethical application submission to the University of Salford Ethics Approval Committee (see appendix A). It complies with the University of Salford's data protection guidelines and the regulatory principles set out in the Data Protection Act 2018 (GOV.UK, 2018) which brings up the discussion on what the data will be used for as well as where and how the data will be stored which will be addressed in the consent form (see appendix B). The collected data will be stored securely and anonymously, and it will be used to provide an in-depth understanding of the DH implementation process in GM in order to proffer potential solutions to improve the process and to overcome the identified barriers.

4.9.1. Obtaining Access

I attended a meeting with the GM Energy Innovation Group, which includes a range of key stakeholders from academic institutions, private organizations and public authorities to get an understanding of their energy transition concept and how the system works. I did a presentation on the aim and objectives of my research and the value proposition to GM which is to contribute to the development and delivery of effective policies that would drive the successful implementation of a low carbon DH network in GM. I outlined some of the key policies and regulations that have been pivotal to the successful implementation of efficient DH networks in other regions.

The group identified that they had not explored effective policies from other regions. I then offered to write a detailed report for the Group on Urban policy in District Heating Delivery Lessons from three cities with extensive use of DH. The report provided a detailed analysis of strategies, technical solutions, expertise, policies, regulations, pricing, consumer protection and financial instruments vital to the successful implementation of efficient DH networks in Copenhagen, Stockholm and Helsinki which has aided the decarbonisation of their heating sectors.

This demonstrated the value of the work I could potentially deliver, as a result of that I was able to engage with members of the Group for my field work research interviews which is a significant aspect of my thesis.

4.9.2. Participant Consent, Engagement and Trust

All participants were provided with an information sheet about the research, stating that participants are under no obligation to participate in the study. Participants have the right to withdraw their contribution without giving reasons and without any consequences if they wish to do so. The identity of the participants involved in the research will be concealed in all publications. Unless prior consent has been granted by the participant(s) involved, any data that can identify participants will not be published. This assured the participants that the purpose of the interview was to understand their perspectives and upon agreeing to take part in the research the researcher provided an electronic copy of the consent form, to be signed prior to the interview.

Prior to the interview, the interview questions were ‘shared' with the participants. This was an effective strategy that served two purposes. It helped to increase participants' interest in the subject, it also allowed participants to prepare their contributions, resulting in more fruitful conversations and a natural flow during interviews (Marshall and Rossman, 2011). Also, it was essential in establishing ‘trust' (Easterby-Smith, Thorpe and Jackson, 2012). It also ensured the participants provided thoughtful knowledge and insights rather than impromptu brainstorming. Overall, it strengthened the confidence and trust between the researcher and participants. Building effective communication and trust was a fruitful exercise in this study because participants exchanged information with the researcher about future events and conferences, recently published reports and documents, and introductions to additional contacts and relevant training sessions, associations and organisations.

4.9.3. Location, Recording and Ethics

Although this research was meant to be one-on-one face to face interviews, however, due to the government guidelines around remote working and social distancing in order to keep people safe this was changed to remote interviews. A series of remote one-on-one video interviews were conducted with all the participants via the University of Salford's secure Microsoft Teams application over a 4-month period. The interviews lasted between 1 hour to 2 hours 30 minutes for each session with some participants willingly having, more than one session, in order to provide a detailed understanding of the phenomena under investigation. According to King, Horrocks and Brooks (2018), remote interviews can be used in qualitative research if the participant is unable to attend a physical interview or if the nature of the interview topic requires it. Also, all participants were informed that the interviews will be recorded to capture the data for analysis and inference, to add clarity and value to the data being collected. This was recorded using the Microsoft Teams Consent was obtained from each of the participant and all participants were assured about confidentiality and data protection. The data is stored in the password protected university F-drive. At the end of the study, collected data will be stored electronically and anonymously in accordance with the data protection laws. The data will be archived for up to three years from the submission of the thesis and held on a password protected drive that only the researcher and her supervisor will have access to the data in line with the University's data protection policy.

4.10. Chapter summary

This chapter explained the research methodology and justified the methods used in this study, in the pursuit to understand how cities implement large-scale DH networks from a socio-technical perspective in order to overcome the barriers limiting the uptake of DH networks at scale. The study employed an interpretivist approach based on the philosophical stance of the researcher, which considers reality to be socially constructed by those who experience the phenomenon rather than objectively defined. A social constructivism approach was deemed appropriate to elicit various perspectives of participants. The chapter described the qualitative approach used in this study, as well as the methods used to collect and analyse data.

The analysis of the study is based on document analysis of secondary data from Copenhagen, Stockholm and Helsinki as well as the thematic analysis of primary data from the interview with 20 key stakeholders involved in the DH development and implementation process in GM. This was guided by a literature review to better understand the perspectives of key actors in the development and implementation of large-scale DH networks in urban environments, using the inductive to approach to thematic analysis of data. The following chapter, chapter 5, analyses how large-scale DH networks have been successfully implemented in the secondary case study cities of Copenhagen, Denmark; Stockholm, Sweden and Helsinki, Finland using the analytical framework derived from the literature review of relevant parts of the existing literature on DH and the socio-technical transitions studies to frame the research structure.

5. CHAPTER FIVE SECONDARY CASE STUDY ANALYSIS

5.1. Introduction

This chapter analyses qualitative data from the secondary case study cities of **Copenhagen, Denmark; Stockholm, Sweden and Helsinki, Finland** with widespread success in DH implementation from a socio-technical perspective to draw lessons on how these cities have successfully implemented large scale DH networks, to deliver increased energy efficiency and climate mitigation objectives. The aim of this chapter is to provide a set of basic concepts and an in-depth understanding of how DH has been successfully implemented.

The MLP analytical framework on socio-technical transitions was used to structure and focus the analysis using the previously identified themes in order to understand how DH has been implemented in the case study cities. These cities have well established DH sector and are exemplar cities in the implementation of DH with extensive DH knowledge, experience and expertise. DH development and implementation strategies in Copenhagen, Stockholm, and Helsinki are discussed in detail in order to build the evidence base on how DH has been implemented in these cities, and to enable the identification of critical success factors that can help overcome the main barriers limiting the take up and implementation of DH at scale. This will be useful for actors seeking to implement DH at scale in GM or other regions to understand how the key barriers limiting the large-scale implementation of DH networks can be overcome.

The document analysis of **published reports, policy documents, industry data and academic literature** helped to narrow the scope of the investigation through the analysis of secondary data to identify previously established themes in the literature (see section 4.5). The identified key themes vital to the successful implementation of DH networks derived from the literature review of relevant parts of the existing literature include **implementation strategies, technical solutions, expertise, policies, regulations, pricing, consumer protection and financial instruments.** This was used as an analytical framework to structure the secondary case study data analysis.

This approach was effective for analysing specific aspects of the data by answering the research questions in this study in a systematic manner in order to extract meaning and analytical comprehension of the phenomena being studied and to expand on existing literature. The key reason for selecting the case studies with successful implementation of DH as opposed to the selection of unsuccessful case studies is due to the dearth of data based on the MLP framework structure in unsuccessful/failed case studies . The findings provided an in-depth understanding of how DH has been developed and implemented in these cities, it also aided in identifying the drivers, key stakeholders, key success factors, effective governing measures and prospective research directions on how to conduct the primary case study research, who should be involved and what data should be collected in the primary case study research in GM.

5.2. Case Study Analysis: District Heating in Copenhagen, Stockholm and Helsinki

Currently, space heating and domestic hot water in Helsinki, Stockholm and Copenhagen are mostly based on district heating systems accounting for 92%, 80% and 98% of total heat demand, respectively (Galindo Fernández *et al.*, 2016; City of Helsinki, 2019b). The first **DH network in Copenhagen** began in 1903 with a small local system. Since the 1980s, the city of Copenhagen has developed a world-class DH network comprised 21 municipal and community-owned local networks that currently provides 98% of all heat demand in the city, making it one of the world's largest and most successfully integrated heat networks. The heat supply is mainly from waste to energy plants, renewable energy and CHP combined heat and power) plants (BEIS, 2018b; World Economic Forum, 2019). Copenhagen has an ambition to be the world's first carbon neutral city by 2025, being the world's first capital city to make such commitments. It has developed climate targets and initiatives that are specific and unique to the demand of their climate goals. It aims to focus on innovative and sustainable solutions to completely eliminate the carbon footprint of the city in its commitment to address environmental challenges through cost-effective low carbon heat supply to one million residents in 22 municipalities (European Union, 2013; BEIS, 2018b). Several natural gas networks in the city have recently been replaced by district heating, and the heat networks are expanding to supply the city's new urban areas in order to achieve its net-zero carbon targets (European Union, 2013; BEIS, 2018b).

Despite the city's continued growth of 100,000 new residents and 20,000 new jobs, Copenhagen has committed to eliminating the city's 2 million tons of carbon footprint over a 10-year period. Traditional district heating, has made the greatest contribution to CO_2 reduction in the municipality, saving 665,000 tonnes of CO_2 per year (BEIS, 2018b; World Economic Forum, 2019). At the core of Copenhagen's eco-innovation strategy are partnerships with academic institutions, companies and the civil society to collaboratively create interactive forums committed to green growth development and increased job creation in the district heating industry (European Union, 2013).

The **DH network in Stockholm** has been in existence for more than 50 years and the location of the city in Northern Europe is a major contributor to the high demand for heating in the city (Luhr, 2015). Stockholm's initial 2012 goal was to become fossil fuel free by 2050, was brought forward by a decade from 2050 to 2040 in 2015. The revised long-term goal is for the city to become fossil fuel free by 2040 (City of Stockholm, 2010, 2017; C40 Cities, 2015). Stockholm's active energy policies have aided the establishment of an efficient energy infrastructure that has succeeded in surpassing its climate targets in recent years with an achievement of 55% reduction in carbon emission in comparison to 1990 levels (C40 Cities, 2015; City of Stockholm, 2017). As part of the city's commitment to becoming a climate smart city operating solely on renewables, in November 2016, the **Strategy for a Fossil-Fuel-Free Stockholm by 2040** was created by the City Council to tackle sector-based emissions and consumption-based emissions. The strategy focuses on the analysis, trends and projection of fossil fuel consumption in each sector and the potential for achieving the 2020 target of 2.3 tonnes of CO_2 per inhabitant as well as the goal to become fossil fuel free by 2040 (City Executive Office of Stockholm, 2016). It provides guidelines and outlines the measures, strategic partnerships and responsibilities of the local authority, various sectors and city residents in reducing the impact of human induced climate change for the successful transition to a renewably fuelled city (C40 Cities, 2015; City Executive Office of Stockholm, 2016).

The construction of the **DH network in Helsinki** began in the 1950s, large buildings, such as housing firms and apartment buildings, are connected to the DH network (City of Helsinki, 2019b). Helsinki aims to become a carbon neutral city by 2035. This requires that greenhouse gas emissions are decreased by at least 80% from 1990 levels and the remaining 20% will be offset by implementing emission reductions outside the city or an increase in the number of carbon sinks. The reduction of carbon emissions in Helsinki has been mainly achieved through lower CO_2 emission factors of the Helsinki district heating network (City of Helsinki, 2019a; Rossknecht and Airaksinen, 2020). The demand for district heat in Helsinki is approximately 7TWh, which represents approximately 20% of the total demand for district heat in Finland (City of Helsinki, 2019b). The share of district heating in Helsinki during past decades has remained stable representing approximately 92% of the total heat demand, while oil and electricity heating account for the remaining 8% of the heat demand (City of Helsinki, 2019b). Currently, approximately 95% of the city of Helsinki is heated by district heat and around 600,000 inhabitants live in apartment buildings heated by district heat (Helen, 2020).

5.3. Implementation Strategy

5.3.1. Copenhagen, Denmark- Mandatory connections

Local authorities in Denmark carried out infrastructure and environmental planning to establish the geography of DH and natural gas networks which paved way for the installation of DH networks (Christensen and Jensen-Butler, 1982). **Planning regulation amendments** in 1979 introduced the Heat Supply Act which required municipalities to allocate certain areas to DH, mandating buildings to be connected to the DH network, which paved the way for the installation and increase in the coverage of DH considerably. In the 1980s, the Danish Government led a **rigorous national heat planning**

program in all its municipalities, the goal was to reduce oil demand in a cost-effective manner through the expansion of DH networks powered by coal-fired CHP plants and waste-to-energy plants or the natural gas infrastructure. City councils had the responsibility to carry out the heat planning for their cities to establish that the most affordable heating solution is retained. Heating and zoning decisions are premised on a 20-year **cost benefit analysis (CBA)** focused on **environmental externalities** (i.e. environmental cost or benefit imposed on a third party that is not included in the final cost) and residual value. The plan must **demonstrate that the project is viable** for both DH companies and new customers alike. Upon approval the **city council has the right to compel** new and existing buildings to be connected to the chosen heat supply (DH or natural gas) within the zone. Several local councils (1980-1995) utilized the power provided by the Act at the beginning, however, it is rarely used, as DH has become increasingly **competitive and cost-effective** for consumers and it will play an important role in achieving Copenhagen's goal to become the world's first carbon-neutral city by 2025 (Dietrichson, 2015; Galindo Fernández *et al.*, 2016). All **distribution companies are either owned by municipalities or by customers** in order to maximise technical, institutional and financial efficiency to lower heat costs (profit to customers who own distribution companies are in compliance with the Heat Supply Act) (Ramboll, 2020). The Heat Supply Act, which was amended in 1994 to include a ban on conversion to electric heating in existing buildings, also allows for the ban of electric heating in new buildings located within DH network zones. Cooperatives owned by consumers, municipalities, utility companies, or a combination of these are the main ownership structure. The Danish Energy Regulatory Authority (DERA) oversees all commercial contracts and has the authority to intervene if necessary, while the Danish Competition and Consumer Authority oversees general supervision (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018; Ramboll, 2020).

5.3.2. Stockholm, Sweden- Market Forces

DH was initially developed to improve energy efficiency and air quality, and then as a response to the oil crisis of the 1970s. **Municipalities owned and operated the first DH systems** in Sweden, introduced in the 1940s, and were also responsible for providing gas and electricity to their residents through municipal utilities. Several DH networks were established in the 1980's and in the 1990's virtually every city and municipality had its own DH network. Initially, DH was regulated on a public-private partnership basis and was governed by the Local Authorities Act (1991) (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018). Three principles guided the regulation: equal treatment, cost-based pricing and locality. A new law was introduced in 1996 that deregulated the electricity market, which also included the district heating market, enabling the operation of the market-based DH sector. This led to an increase in private ownership of DH networks from 2% in 1990 to 25% in 1998 and 35% in

2011. Prior to deregulation, all DH plants and distribution networks in Sweden were owned and operated by municipalities on a not-for-profit principle. Ownership is now a mix of municipal limited companies, state-owned, private companies, and publicly owned. Deregulation created issues in the DH market, including high prices and a lack of pricing transparency (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018). The Government underestimated the impact of deregulating the electricity market on the DH industry because it was never considered a separate market. In 2008, a government commission implemented light-touch voluntary regulation focused on consumer protection under the District Heating Act. Fortum Värme is Stockholm's main DH operator which is co-owned by the city of Stockholm and Fortum Corporation both having an equal share of 50% and equal voting rights. It produces an average of 8 TWh/y, 10,000 clients and direct supply to 6 municipalities (City of Stockholm, 2017).

5.3.3. Helsinki, Finland- Business Based DH

Helsinki has well developed district heating systems, throughout its history, Helsinki DH has always been business based (Helen, 2011). The DH business is **not directly regulated** and there is no obligation to connect to a district heating network in Finland, in most cases connection has been required locally as municipalities have imposed DH connection in their city plans. Customers connected voluntarily as a result of the competitive price level. Customers are free to select their own heating method and also switch away from DH to other heat methods without any additional charges. Due to the investment required, DH users usually consider disconnecting from the DH network when district heat exchangers need to be replaced. However, switching from the established DH systems in buildings to other heating systems typically involves a financial implication on the customer as a result of the system change (Helen, 2019a; Vadén *et al.*, 2019). Ground source heat pumps (GSHP)require a larger initial investment than DH but have lower operating costs. The levelised cost of heat produced by GSHP is typically in the same range as DH prices. It is also possible to provide hybrid heating solutions where heating is produced by combining district heating and a customer-owned heating system, such as GSHP. However, in the densely populated city area, GSHP are restricted (City of Helsinki, 2019b; Vadén *et al.*, 2019). The city of Helsinki is the sole owner of Helen Ltd which is the municipal DH energy company in Helsinki. The company was formed in 1977, when the municipal electricity company and the municipal gas company merged (Helen, 2019a; Vadén *et al.*, 2019).

5.4. Technical Solutions and Heat Sources

5.4.1. Copenhagen, Denmark Technical Solutions

The Danish government has locked-in certain technological solutions through policy, in particular CHP. The Heat Supply Act mandates that plants larger than 1 MW must be operated as combined heating plants, which has resulted in about 80% of district heating being co-produced with electricity. The heat supply is mainly from waste to energy plants, renewable energy and CHP combined heat and power) plants, as well as industrial waste heat from thermal processes (BEIS, 2018b; World Economic Forum, 2019). While connection by a manufacturer is voluntary, the supply of excess heat is in both operators' and manufacturers' financial interests, which is a successful driver. Several natural gas networks in the city have recently been replaced by district heating, and the heat networks are expanding to supply the city's new urban areas in order to achieve its net-zero carbon targets (European Union, 2013; BEIS, 2018b). Furthermore, CHP plants are being replaced by biomass-based heat-only boilers, and the incentive to reinvest in CHP capacity is limited (Donnellan *et al.*, 2018).

The Copenhagen district heating network, recognised to be the largest in the world, integrates 160 km of primary pipes and 1500 km of distribution pipes with 10 major combined heat and power (CHP) stations, three heat storage plants, peak load plants and pumping stations (C40 Cities, 2011). Heating is mainly supplied by an integrated DH network, involving 24 distribution companies and 3 transmission companies, which work together to maximise the operation of the overall system. The public heat transfer companies were set up in the 1980s to improve the network. They are operated by the municipalities they supply and are also responsible for peak capacity and part of the output of heat on behalf of the related distribution companies. They own their networks and production facilities and market their heat to distribution firms on fair terms (at pool prices) (Galindo Fernández *et al.*, 2016). The energy mix of the DH system in Copenhagen is listed in figure 36.

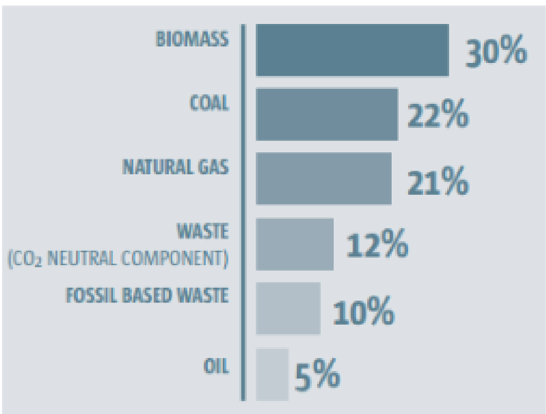


Figure 36: Sources of fuel used for DH in Copenhagen (Galindo Fernández et al., 2016).

A range of initiatives to reduce CO_2 emissions from energy supplies to levels of 75% in 2005 is part of the strategic plan to achieve this target (Copenhagen Climate Plan). The strategic plan includes the following (Galindo Fernández et al., 2016):

- Move from coal to bio-mass in CHP plants.
- Upgrade DH networks and waste incineration plants.
- Increase the share of renewable energy in the supply mix.
- Improve efficiency and enhance cooperation between the various DH companies.

5.4.2. Stockholm, Sweden – Technical Solutions

Following the oil crisis, Swedish energy policy prioritised the replacement of oil, primarily with biomass. DH in the city of Stockholm is largely powered by renewables from biofuels, waste heat and energy from waste and electricity (Galindo Fernández *et al.*, 2016; City of Stockholm, 2017; Donnellan *et al.*, 2018). The use of surplus heat is voluntary and not mandated by law. Industrial waste heat has played a significant role in the development of DH systems in a number of Swedish cities and towns. Although no incentives or subsidies exist to encourage industrial plants to recover heat, the additional revenue generated by DH operators is sufficient to drive the sale of excess heat (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018). The increased take up of district heating through the expansion of the district heating network is one of the initiatives that has had the greatest impact on reducing GHG emission in Stockholm, thus contributing to the overall emission reduction from 5.6 tonnes to 2.5 tonnes per inhabitant. With more buildings replacing their oil and gas boilers with district heating, the share of **biofuel use in district heating** production has increased. District heating accounts for approximately 80% of heating needs in the city largely powered by renewables from biofuels as well as waste heat and energy from waste while electricity accounts for about 15% (City of Stockholm, 2017). Fortum Värme produces an average of 8 TWh/y, 10,000 clients and direct supply to 6 municipalities (City of Stockholm, 2017). The energy mix of the DH network in Stockholm is shown in Figure 37.

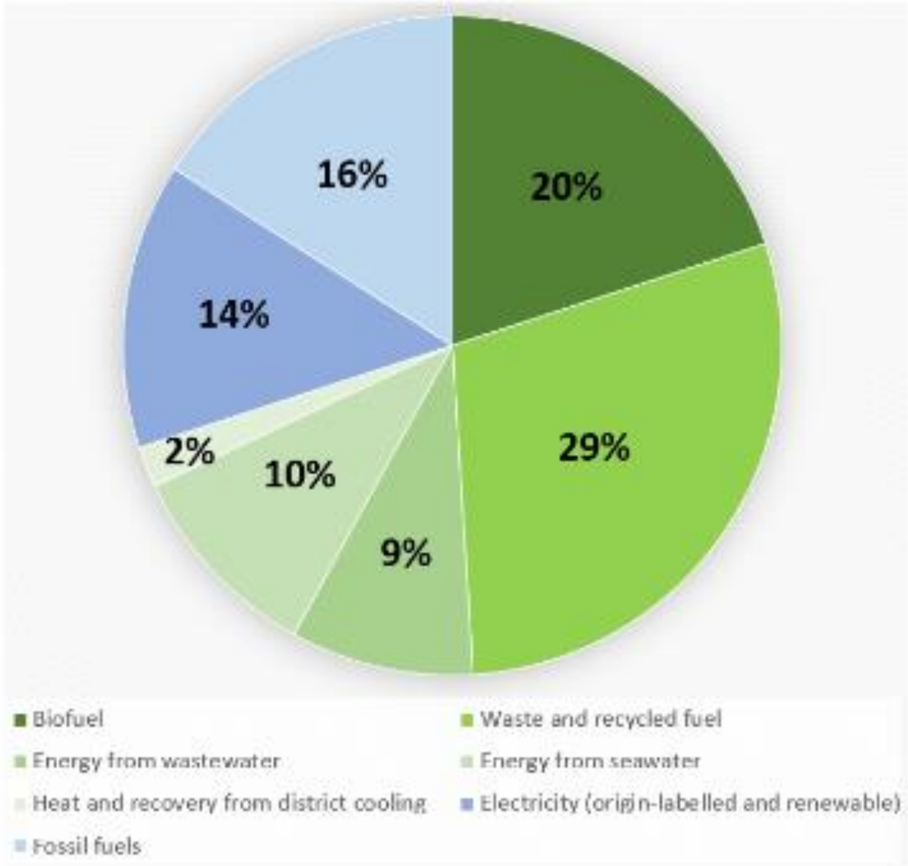


Figure 37: Energy mix of Fortum Värme DH system (Fortum Corporation, 2018).

5.4.3. Helsinki, Finland – Technical Solutions

Helsinki is one of the major cities using district heating in Europe. The building volume of district heated buildings is over 170 Mm^3 and floor area over 60 Mm^2. The Helsinki district heating network operates a combined heat and power DH system with a pipeline of about 1,400 km, which supplies the entire city of Helsinki (City of Helsinki, 2019b; Vadén *et al.*, 2019). The production of DH in the Helsinki network is mainly based on coal and gas-fired cogeneration of heat and electricity (CHP) and is supported by a fleet of smaller heat-only production units. The network has a total district heating capacity of 1,330 MW from two coal-fired CHP plants located in Salmisaari and Hanasaari and two gas-fired CHP plants located in Vuosaari. In order to achieve the goal of being carbon-neutral by 2035, Helsinki plans to transition away from fossil fuels, towards carbon-neutral DH by incorporating sustainable renewable energy sources into its DH system (City of Helsinki, 2019b; Vadén *et al.*, 2019).

Figure 38 shows the recent district heating generation by fuel use in Helsinki (City of Helsinki, 2019b).

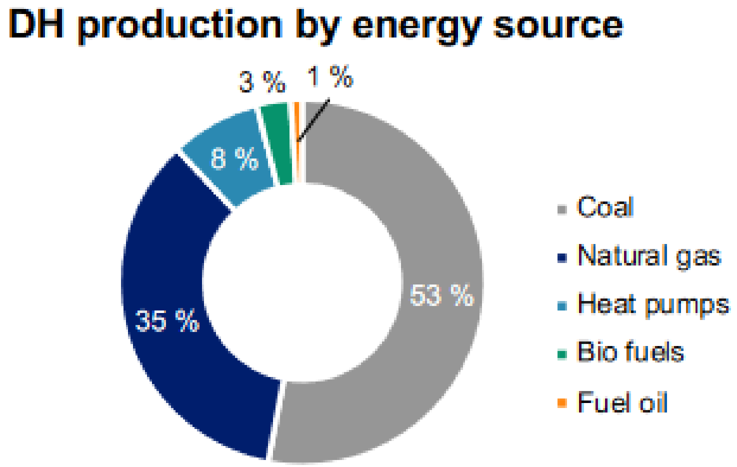


Figure 38:District heat production by energy in Helsinki, 2018 (Helen, 2019b).

Approximately 56% of carbon dioxide emissions in Helsinki currently originate from the production of energy used for heating purposes. In addition to other actions, Helsinki needs to reduce its emissions from heat production in order to achieve its carbon neutrality goal. Helen, the city-owned energy company in charge of the district heating system responsible for the production, distribution, and sale of district heat in Helsinki, will have to replace its coal-fired power plants on or before 2029 due to the coal phase-out regulation. Coal accounted for 53% of the district heat produced by Helen in 2018 with a total of about 6.5 TWh of coal to generate both heat and electricity. Due to the volume, variation and location of the heat demand, it has been difficult to find low-carbon alternatives to fossil fuels in Helsinki (City of Helsinki, 2019b; Vadén *et al.*, 2019). Helen aims to phase out coal in two phases, the first being the shutdown of the CHP coal plant in Hanasaari by 2024, and the second is the shutdown or conversion of the new CHP coal plant in Salmisaari by 2029. The coal phase-out will result in a net loss of 920 MW of heat production capacity which would need to be replaced in order to ensure adequate and reliable capacity during the cold winter seasons. This is approximately 3.5 TWh of heat in heat production terms. Helen's current plan for the first stage of replacements includes the following (City of Helsinki, 2019b; Vadén *et al.*, 2019):

- An increase in waste heat recovery and heat pump capacity.
- Geothermal heat.
- Local heating solutions
- An increase in heat supply from the adjacent DH networks in Espoo and Vantaa.
- A new biomass heat-only boiler investment.

5.5. Policy Instruments and Regulatory framework

5.5.1. Copenhagen, Denmark – Policy Instruments and Regulatory Framework

The energy crisis in 1973-74 gave rise to strong support for DH and CHP through new energy policies and instruments aimed at prioritising increased energy efficiency and output, security of supply and cost-effectiveness, thus reducing the reliance on fuel imports. The new policies, in conjunction with the discovery of natural gas resources and the creation of the gas infrastructure, played a crucial role in making it possible for Denmark to achieve energy self-sufficiency in 1997. While the DH and natural gas infrastructure were in operation in the 1990's, environmental problems became a concern owing to the discovery of the impacts of human induced climate change, the developments of global climate regimes and its resulting international emission reduction commitments (Galindo Fernández *et al.*, 2016; IPCC, 2018). As a result, policies and carbon emission reduction targets were developed in compliance with international emission reduction targets to reduce emissions above pre-industrial levels and increase renewable energy generation. Also, subsidies and taxes promoted these improvements towards increased renewable energy generation, thereby enhancing the overall environmental performance of the Danish heating and electricity systems (Galindo Fernández *et al.*, 2016).

Strong planning regulation, as outlined in the Heat Supply Act (1979), combined with national and municipal buy-in, aided in the establishment of a solid foundation for regulating and expanding the network. Direct policy intervention has also aided in the promotion of DH. Municipalities have the authority to impose mandatory connections on new and existing structures, which was one of the main reasons for the success of the system. A carbon tax (higher than their European counterparts) was implemented in 1992 to discourage the use of fossil fuels, and oil burners were banned in new construction in 2013 and existing structures in 2016. Financial incentives were implemented to ensure the continued economic viability of DH and CHP (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018). Subsidies and taxes promoted improvements towards increased renewable energy generation, thereby enhancing the overall environmental performance of the Danish heating and electricity systems (Galindo Fernández *et al.*, 2016).

Danish heat regulation is based on a clear division of responsibility. National and regional regulation have been relaxed to give local decision-makers complete control over the design of their heating systems. This is achieved through the national government's technical framework and centralized policy. Municipalities are responsible for developing and updating municipal heating plans, as well as approving heating projects within their locality (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018). District heating networks have been largely regulated by the Heat Supply Act and the obligation to connect buildings to the DH network was one of the main reasons for the success of the system. The Heat Supply Act has two primary objectives(Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018):

- To promote socio-economic and environmental efficiency in the supply of heat and hot water to buildings.
- To promote the highest possible standard of CHP systems.

A summary of the taxes, subsidies and incentives are outlined below:

Subsidies have been used to promote energy transition to low carbon, in the 1990s the Danish Government introduced investment subsidies to boost energy efficiency, CHP development and energy generation from renewables. While these grants can no longer be obtained for the development of new DH systems, decentralised CHP plants operating in the electricity market are entitled to receive a premium tariff (capacity credit) in addition to the market price and subsidies to produce electricity (for gas and waste powered plants) or a surcharge for biomass or biogas-fuelled plants. It is important to mention that since 2018 premium tariff is only available for CHP plants using renewable energy (Galindo Fernández *et al.*, 2016).

Tax and tax exemptions: Tax incentives on fuel for power plants was introduced in the mid-1980s. In some cases, less than 50% of fuel taxes are reduced by using CHP, which allows DH companies to sell heat at a lower price to consumers. This one of the most effective incentives for energy efficiency and increased share of renewables as a heat supply source. They have significantly promoted the development of CHP systems and DH systems since the late '80s through surplus heat and renewable energy while bearing in mind that the State requires consistent tax revenue from the energy sector.

Regulated-profit principle: The return on invested capital is limited to 7-8% and only the actual cost of production and delivery to the consumer can be included in the price of heat. The key justification for this is to optimise efficiency in the interests of customers. Consequently, co-operatives or local public corporations’ consumers have ownership or control over 99% of DH companies.

Heat planning and cost-effective zoning: New heat planning systems were introduced for existing and new urban areas in which municipalities were required to upgrade their old heat plans using the ‘’project proposal’’ method to establish that the heating solution with the most cost-effective option retained to facilitate the transition of natural gas zones from gas to district heating. This led to the introduction of gas in some of the new CHP plants, and most small DH companies developed decentralised gas-fuelled CHP plants with integrated heat storage systems. This led to a rise in take-up rates of almost 100%. While consumer choice was eliminated, it also reduced heating cost to consumers. The planning program was designed primarily to identify an effective zoning system for district heating (mostly large buildings) and natural gas (mostly single family areas) (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018).

5.5.2. Stockholm, Sweden – Policy Instruments and Regulatory Framework

Swedish Government has implemented a **comprehensive collection of policy instruments** and incentives to promote a sustainable and market-based heat supply (Galindo Fernández *et al.*, 2016).. There is no specific national government policy on DH, rather they provide an overarching policy agenda to transition away from fossil fuels. These policies are often technology agnostic and will not promote DH over other technologies that provide comparable results (e.g., heat pumps). In 2008, the DH Act was introduced by the Swedish Government to protect consumers and improve transparency in the DH sector. Key elements of the Act are summarised as follows (City Executive Office of Stockholm, 2016; Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018)**:**

- It outlines the **general framework for DH contracts**, such as the content, compensation, termination, etc.
- It mandates DH companies to **provide pricing information** to their customers and the general public.
- It requires DH companies to **negotiate changes in prices and terms** of heat supply with their consumers. In the event of any discrepancy, customers may notify the National District Heating Board for **mediation.**

- **Investment subsidy programs** for biomass CHP were implemented from 1991 to 2002, and tradable certificates for renewable energies were introduced in 2003.
- **A high carbon tax,** a tax on natural gas used for heating, a tax on heating oil, and an exemption for renewable energy and combined heat and power production.
- The **introduction of landfill bans** on combustible/biodegradable waste in 2002 and 2005, resulted in an increase in heat generated by waste incineration.
- **Subsidies for households** to switch from oil to alternative heating systems between 2006 and 2010.

- It **regulates arbitrary modifications to the DH contract** as well as the discontinuation of district heat supply.
- It requires DH companies to **notify the supervisory authority** which is the Swedish Energy Markets Inspectorate (SEMI) of its activities and operations on an annual basis in order to ensure compliance with the DH Act.

The DH Act was amended in 2011 to incorporate **additional metering and billing requirements**. The amendment required DH companies to monitor the energy use of their customers using measuring meters and to report the results on a monthly basis. It also established that, unless otherwise agreed between the parties, the billing must be made at least four times a year. In August 2014, the DH Act was amended to introduce a set of rules aimed at facilitating the supply of surplus heat to the DH network under certain conditions. The development of renewable energy, DH and CHP generation and consumption in Sweden has strongly been supported by incentives, taxes and subsidies. A summary of the most significant taxes, subsidies and incentives that support renewable energy-fired DH systems is provided below (City Executive Office of Stockholm, 2016; Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018)**:**

- **Sulphur tax:** Sulphur tax applies to the presence of heavy fuel oils, coal and peat in the exhaust gas. However, if the sulphur is removed from the exhaust gas, the tax charge for each kg of sulphur extracted will be refunded at the same rate.
- **Household tax reductions:** Act No. 2009:194 sets out the guidelines for the deduction of taxes on installation works to improve energy performance in single-family houses. This is applicable to all forms of installation and retrofitting works, including the installation of renewable energy equipment and the replacement of conventional heating sources or systems with renewable energy or DH. The installation costs excluding the material costs may be deducted from the income tax.
- **Subsidies for conversion from oil and direct electricity**: Between 2006 and 2010, subsidies were available for conversion from oil and direct electricity for heating, which contributed to an increase in DH connections.
- **CO_2 and energy taxes:** A tax imposed on the carbon content of energy fuels, known as carbon taxes, was introduced in 1991 and became Sweden's key policy instrument for the reduction of fossil fuel consumption. Renewable energy sources are exempt from all taxes imposed on energy generation.

- **Incentives to CHP:** Since the 1990s, Sweden has promoted CHP and increasingly adapted schemes to support the use of renewable energy sources (majorly biomass) in CHP plants connected to DH systems. The **Electricity Certificate Scheme,** came into force in 2003 to increase renewable electricity production, have particularly benefited biomass-fuelled CHP plants. An electricity certificate issued by the government is given to an approved facility owner for every MWh of renewable electricity produced. This certificate, which is valid for 15 years after commissioning, can be sold on the market. This mechanism also introduced a quota obligation for electricity suppliers and certain electricity consumers to purchase a proportion (quota) of electricity certificates in relation to their electricity sales or consumption. Quotas are calculated annually according to the expected rise in renewable electricity generation, the expected sales of electricity and the electricity used by organisations with quota obligations. The quota was 14.3 per cent in 2015. The overall Swedish target of the Green Energy Certificate Scheme for 2002 was recently increased to 30TWh of new renewable electricity by 2020. Furthermore, the new target of 18TWh of additional renewable energy by 2030 was recently decided by 5 of the key political parties in Sweden. The electricity certificate scheme has proven to be an effective policy instrument to for promoting renewable energy in Sweden. The rise in the number of issued certificates has had an impact on the price of renewable energy, which has generally decreased since 2003. In 2015, the price was on average EUR16 per certificate. A joint electricity certificate market between Sweden and Norway was established in 2012. This enables trading in both Swedish and Norwegian certificates with certificates issued for renewable electricity production in any of the two countries.

Based on resource availability, market conditions, and demand, the initiative to develop DH networks is at the local level. This arrangement is successful because it allows for greater flexibility than a central government policy. While municipalities continue to play a critical role in DH development, their responsibilities and powers have decreased following energy market liberalisation, and heat planning has become less prevalent (City Executive Office of Stockholm, 2016; Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018).

5.5.3. Helsinki, Finland – Policy Instruments and Regulatory Framework

There is no equivalent of a District Heating Act in Finland. The Competition Authority asserts that district heating operators have a monopoly over their current customers. The prohibition on market dominance imposes certain pricing and cost elements on district heating operators, such as new capacity investments. Third-party access to the district heating network is unregulated and there is no obligation to connect a district heating network (Dahal, Juhola and Niemelä, 2018; Donnellan *et al.*, 2018; City of Helsinki, 2019b, 2019a; Värri and Syri, 2019). A summary of the taxes, subsidies and processes are outlined below:

- **Policy impacting heat demand**: The Energy Authority is responsible for promoting energy efficiency improvements through energy audits, energy information for consumers, voluntary energy efficiency agreements and the eco-labelling and eco-design of products. The government and participating sectors chose the voluntary approach to avoid introducing new regulations to meet national energy efficiency goals (City of Helsinki, 2019b).
- **Energy taxation:** Fossil fuels (coal, natural gas, oil) used in the production of heat are regulated in Finland on the basis of their energy content and CO_2 emissions. Energy taxes is a means of promoting renewable energy as renewable fuels are generally tax-free (City of Helsinki, 2019b; OECD, 2019).
- **Land use and permitting procedures:** Land use procedures are also taken into account when assessing the potential for heat production in the Helsinki region (City of Helsinki, 2019b; OECD, 2019). Many of the permitting processes are participatory processes, particularly in operations with environmental and social impacts. Any installation can only be constructed in areas where land use is intended for the purpose of the facility (e.g. industrial usage, energy generation or other particular purpose) (City of Helsinki, 2019b).

5.6. Pricing and Consumer Protection

5.6.1. Copenhagen, Denmark – Pricing and Consumer Protection

The Danish legislation states that the consumer's heat price should cover all necessary costs. This includes production, transportation, financing, and asset depreciation to ensure long-term financial viability for operators. To protect consumers from monopoly abuse, both production and network companies must be non-profit. For greater transparency, each DH company sets annual heat tariffs based on actual expenditures, which are then made public (population, industry, public sector etc.). Since all apartments have sub-meters, users' bills include both usage and fixed costs. In some cases, fixed costs and mandatory connection help vulnerable consumers (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018; Ramboll, 2020).

Contrary to popular belief, the not-for-profit rule does not protect consumers from inefficient management or practices. The Danish Energy Regulatory Authority (DERA) is responsible for governing the DH market and ensuring consumer protection. DERA introduced voluntary benchmarking analysis for DH companies to promote transparency, efficiency and action to reduce heat prices. DH companies have an obligation to provide this Authority with information about pricing and services so that complaints and disputes can be resolved. It provides the opportunity for DH companies to compare their performance with other similar firms. Most operators use the benchmarking model to compare their prices and improve cost-effectiveness. In the event of inconsistent tariffs extorted by DH companies, consumers can appeal to the Energy Appeal Board (Galindo Fernández *et al.*, 2016).

The regulation requires that all aspects be financially better than usual, which still leads to better network and market efficiencies with waste reduction wherever possible to save money. Complaints from private consumers are handled by their DH provider. Unsatisfactory outcomes are escalated to The Energy Supplies Complaint Board (non-sectoral issues) or DERA (regulated issues) while the Energy Board of Appeal is the next level (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018; Ramboll, 2020).

5.6.2. Stockholm, Sweden – Pricing and Consumer Protection

The 1996 deregulation removed DH's non-profit pricing principle. As a result, some consumer prices increased by more than 15%, which sparked protests and national debate. Protesters claimed that energy companies were abusing their natural monopoly. This was a major impetus for the District Heating Act of 2008, which focuses on price transparency. The Swedish Competition Authority has advocated for price regulation since market deregulation; however, this was not included in the DH Act. A key argument against price regulation is that DH is part of a larger heating market in which other technologies such as heat pumps compete. Also, DH companies can concentrate on efficiency and meeting customer needs, rather than meeting the terms of the regulations.

In 2013, DH companies and customers began a voluntary price agreement initiative known as Prisdialogen ('PriceDialogue'). Approximately 70% of DH companies have enrolled in the scheme, which requires price forecasts for the next two years to promote transparency and predictability of DH pricing. It aims to strengthen the position of customers in relation to the DH business in order to increase security and confidence in the pricing of DH suppliers through a fair, consistent and sustainable price change model (Luhr, 2015; Donnellan *et al.*, 2018; Prisdialogen, 2020)..

On a voluntary basis, DH suppliers may apply to join the initiative following the four steps outlined in Figure 39.

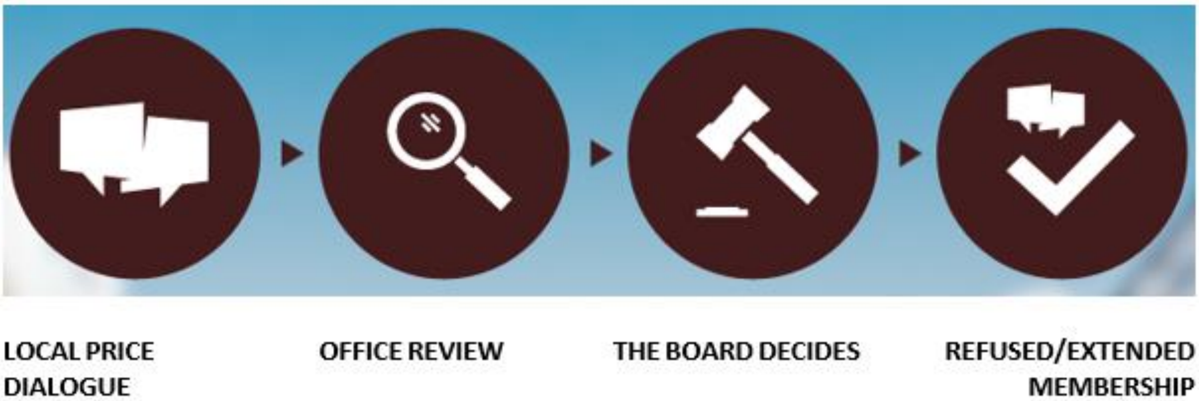


Figure 39:Phases of a price dialogue (Prisdialogen, 2020).

Following an initial conversation with its clients on the price evolution model, it is sent to the Prisdialogen Office for review and to determine whether or not to become/ remain a member of the initiative. This membership proves that the DH supplier has successfully concluded a price dialogue with its customers and that the price change model meets the requirements set out by the initiative. The liberalised DH market promotes competition between various heat suppliers, while offering a legal framework for customer protection and increased transparency in the industry, particularly through the DH Act (Galindo Fernández *et al.*, 2016).

Sweden's light-touch price regulation and Prisdialogen initiative have been largely successful, with DH prices generally lower than those of other countries with regulated prices. Consumers have the right to negotiate prices and price changes. If a district heating company and a customer are unable to reach an agreement, either party may seek mediation from the DH Board. Customer engagement is critical for DH companies in Sweden, as there are no mandatory connections, and companies rely on good customer relations to grow their market share in the heating market (Luhr, 2015; Donnellan *et al.*, 2018; Prisdialogen, 2020)

5.6.3. Helsinki, Finland – Pricing and Consumer Protection

The exploitation of the dominant market position is prohibited, and this sets out certain conditions for district heating operators, as regards their pricing and cost elements including new capacity investments. Several district heating companies have published terms and pricing structures for the purchase of heat from third party producers. The Finnish Competition and Consumer Authority (FCCA) may initiate investigations if it suspects that prices are being abused by unreasonably high prices, as a result of the dominant market position of district heating (City of Helsinki, 2019b; FCCA, 2020).

5.7. Financial Instruments and Incentives

5.7.1. Copenhagen, Denmark – Financial Instruments and Incentives

The massive investment in and prioritization of DH over the last four decades has had significant consequences in Denmark, and not just for fuel security and efficiency, as intended. Since 1979, all investments have been 100% financed by competitive loan rates. Funding through affordable loans for DH investments is readily accessible, at estimated interest rates of around 2%. The revolving fund is supplied by the Danish "Kommune Bank" which provides competitive debt financing of long term loans for Danish municipalities, which also finance 100 % of its DH investments through these loans in compliance with municipal guarantees (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018). Copenhagen has developed and benefited from a strong supply chain as a result of its DH success in terms of market share, network length, and competitive market. Access to capital is a critical factor in the development of the Danish DH sector. Low interest rates on capital (ca. 2%) enable a financial case to be built even if the rate of return on a network is only 4%.

Additionally, there is a public works fund from which municipalities can borrow money to fund DH development (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018).

5.7.2. Stockholm, Sweden – Financial Instruments and Incentives

The first major developments in CHP were introduced in 1991 and mainly supported by subsidies from investment grants programmes that promote the development of efficient electricity and energy technologies, providing around EUR 116 million in the period 1991-1998. Investment grants covering 25% of the investment costs were made available to only CHP biofuels powered plants with a maximum of SEK 4000 / kW (EUR 415 / kW) between 1998 and 2004. Grants for converting heat plants to CHP plants were also available. Currently, DH network development and investment are currently driven by DH companies, rather than municipalities or the central government. DH companies are investing heavily in interconnecting existing DH networks between cities and towns financed from profits/third party investments. This enables systems to accept large amounts of excess heat, thereby increasing system security and efficiency. The corporative investment, innovation and collaboration among DH companies is perceived as a good outcome of the lack of regulation (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018).

5.7.3. Helsinki, Finland – Financial Instruments and Incentives

DH in Helsinki has always been for profit-driven with a competitive price level. The investments made to improve operations are financed through profits earned in the free DH market in accordance with free competition. In certain instances, investment in renewable heat sources can be financed through investment funding which may be provided by businesses, municipalities and other organisations to new small heating plants powered by renewable energy (Helen, 2016; MEAE, 2018a, 2018b; City of Helsinki, 2019b).

5.8. Chapter Conclusion

Countries like Finland, Sweden and Denmark provide documented evidence of DH uptake which was mainly driven by the oil crises of the 1970s and the need to minimise reliance on imported fossil fuels, but it is now emerging as a key player in overcoming the challenges of reducing carbon emissions and improving energy efficiency. This chapter provided a detailed analysis of the implementation of large-scale DH systems in the three case study cities of Copenhagen, Stockholm and Helsinki. It also provided insights on the most important lessons to consider in the implementation of large-scale district heating systems in order to build capacity in this rapidly emerging industry sector to achieve 50% reduction in carbon emissions by 2030 and net-zero emissions by 2050. The implementation strategy differs between the cities studied, and the regulatory model can only be evaluated reliably within the context of each city.

Given the emerging nature of their DH sectors and comparable economies, it offers some lessons on the role of DH in decarbonising heat and the transition away from a historical reliance on fossil fuels. Lessons were drawn from the case studies with regards to how intermediary activities can support the development of DH and considerations of various DH policies and how DH regulation can be introduced. The findings revealed that the implementation of efficient DH networks can be achieved through certain key success factors which include various organisational, technical, social, policy design considerations.

The analysis of the secondary case study cities provided a detailed understanding of successful large-scale city based DH implementation, which would be valuable for analysing how to effectively drive DH implementation in GM, identifying gaps, and assessing whether and how regulation should be introduced. As well as to identify / develop effective policies, strategies and DH network optimisation solutions that can increase the share of renewable energy sources for low-carbon heat generation and supply through DH while contributing to the understanding of how to reduce fossil fuels in the energy balance of modern societies.

It also identified key stakeholders, key success factors, effective governing measures and prospective research directions on how to conduct the primary case study research, who should be involved and what data should be collected in the primary case study research in GM. This was used to frame and shape the primary case study research in GM, which is in the early development stage of DH implementation, allowing for a cross-case analysis of the DH implementation strategy in the primary and secondary case study contexts in order identify the gaps, to aid the recommendation of relevant policy design considerations in order to outline strategic directions toward the implementation of large-scale DH networks within the target of a carbon neutral city region. and to examine whether the identified success factors are replicable in GM. The next chapter explains the empirical context of the primary case study by providing a brief history of DH in the UK and GM In order to better understand the dynamics and peculiarities of the DH development process in GM.

6. CHAPTER 6 SETTING THE EMPIRICAL CONTEXT – A SHORT HISTORY OF DH IN THE UK

6.1. Introduction

This chapter describes the context of the primary case study by providing a brief history of DH in the UK and industry context in order to better understand the multilevel governance, dynamics and peculiarities of the DH development and implementation process in GM. The chapter begins by setting the scene with an overview of the vision for decarbonising all sectors in the UK, it introduces the DH network market in the UK and the primary case study, followed by a summary of the DH network market drawing on government policy documents, previous research, public sector reports and industry case studies, supported by data gathered by the researcher in the course of her fieldwork. This included excerpts from national-level interviews with BEIS and the Association of Decentralised Energy (ADE) policymakers about the Heat Network Market Framework and the proposed Heat Network Regulation. A parallel aim of this research is to acknowledge the critical role of national and local government in energy transitions through the multilevel perspective on socio-technical transitions by undertaking an evaluation of the current state and future prospects for the development and implementation of DH technology in the UK. The purpose of this chapter is to acquaint the reader with the context for the structures, functions and dynamics analysed in later chapters by providing a synthesised account of DH development in the UK.

6.2. The Vision for Decarbonising all Sectors in the UK

The energy system in the UK has a complex history that includes a reliance on fossil fuels and imported energy, that spans eras of industrialisation, nationalisation, sector privatisation, and, more recently, the low-carbon transition to combat climate change (Geels *et al.*, 2016). The 2008 Climate Change Act committed the UK to reducing greenhouse gas emissions by at least 80% by 2050, compared to 1990 levels, through the establishment of 5-year emission caps known as "Carbon Budgets." The act was amended in 2019 by Parliament to commit the UK to net zero emissions by 2050, making the UK the first major economy to enshrine a net zero emissions target into law (HM Government, 2020a; HM Treasury, 2021). In addition to the net zero target, the Carbon Budgets now require a target of 78% reduction in carbon emissions across the UK economy by 2035 compared to 1990 levels. To date, greenhouse gas emissions have been reduced by over 40% between 1990 and 2019 while growing the economy by almost 80% (HM Government, 2017, 2020a; BEIS, 2018a; HM Treasury, 2021).

There are about 30 million buildings in the UK, which account for 30% of national emissions. The majority of buildings are still largely dependent on burning fossil fuels for heating, hot water and cooking (BEIS, 2018a; HM Treasury, 2021). Currently, 1.7 million fossil fuel (gas, oil and coal) heating systems are installed per year. Heat emissions are the most significant source of carbon emissions in the UK, accounting for 37% of total emissions and 40% of total energy consumption making the heat sector the largest energy consuming sector in the UK with 85% of UK households (78% in Scotland) being heated using fossil fuels (BEIS, 2018a; HM Treasury, 2021). In total, homes and non-domestic buildings account for approximately 30% of UK emissions, with heating accounting for 79% of all building emissions and about 23% (see figure 40) of all UK emissions, mostly through the use of gas in existing homes (BEIS, 2020a, 2021g, 2021h; HM Treasury, 2021). Overall, net UK GHG emissions from heat and buildings decreased by 17 percent between 1990 and 2019 (BEIS, 2020a, 2021g, 2021h; HM Treasury, 2021). Meeting the net zero target will require all heat in buildings and in industry to be reduced to zero carbon emissions. In 2017, the UK Government set out in the Clean Growth Strategy (CGS) proposals for decarbonising all sectors of the economy through the 2020s. It explains how the UK can benefit from low carbon opportunities while meeting national and international emission reduction targets and climate commitments (HM Government, 2017, 2021b, 2021d). Figure 40 illustrates the proportion of emissions from buildings in 2019 to the nearest whole number; of the 454.8 mega tonnes of CO_2 equivalent ($MtCO_2e$) total emissions, heating buildings accounted for 23%, with homes accounting for the majority.

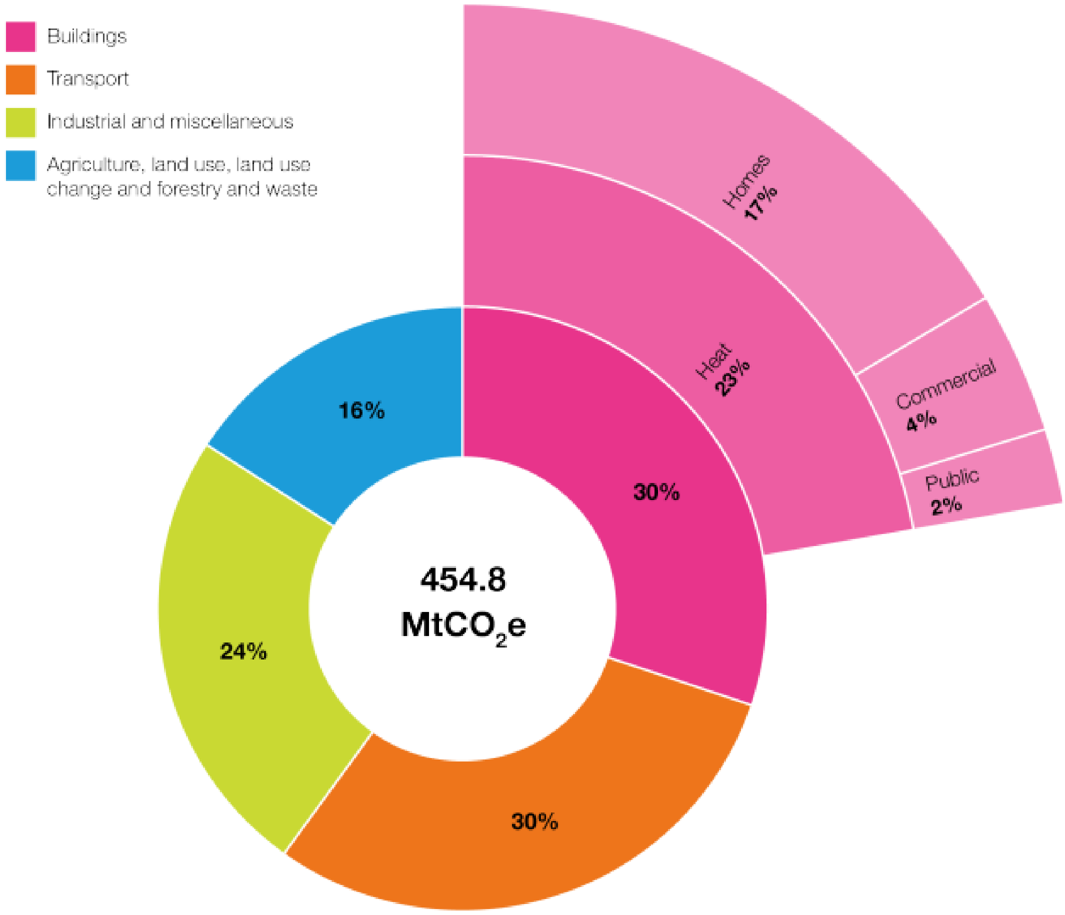


Figure 40:UK Emissions in 2019(HM Government, 2021b).

Figure 41 illustrates the proportion of direct emissions from heat in buildings from 1990 to 2019, broken down by building type: residential, public, and commercial.

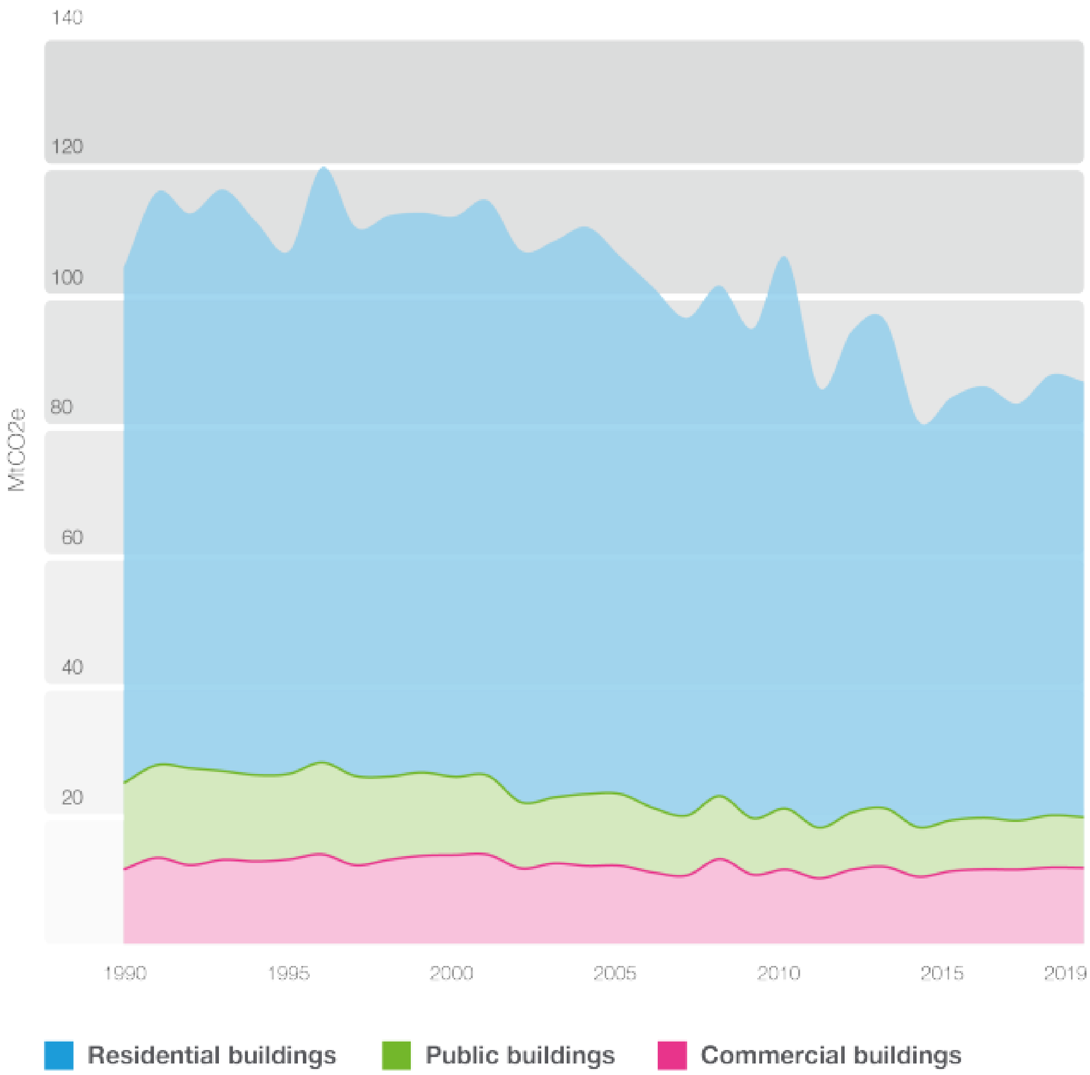


Figure 41: Direct Emissions from Heat in Buildings (1990-2019) (HM Government, 2021b)

The government plans to support growth through significant investment in infrastructure, skills and innovation and to pursue growth that levels up every part of the UK, enables the transition to net zero and supports the vision for sustainable low carbon economy. Decarbonising heating is a key aspect of the UK Government's Clean Growth Strategy to deliver net zero emissions by 2050 which is underpinned by the Prime Minister's Ten Point Plan for a Green Industrial Revolution. This will require fabric efficiency improvements, changes to heating and cooling methods, large-scale transformation and wide ranging change to energy systems and markets and the development of local green industrial capacity and capability (HM Government, 2017, 2020c).

The 2020 Energy White Paper and the Ten Point Plan signal the steps needed to achieve the net zero target. Also, the Industrial Decarbonisation Strategy and the Heat and Buildings Strategy sets out more details on how decarbonisation will be achieved in key sectors as well as the immediate actions and long-term signals required to reduce emissions from buildings by 2050. These actions include the deployment of energy efficiency measures and low carbon heating as part of an ambitious programme of work required to enable key strategic decisions on how to achieve the transition to low carbon heat and the path to decarbonise all homes and buildings. Likewise, the recent Net Zero Strategy sets out steps to achieve a credible path to net zero by 2050 with the lowest costs and greatest benefits. This will require rapid decarbonisation across all sectors with changes to the ways in which both electricity and heat is generated and used (HM Government, 2017, 2021b, 2021d).

6.3. Policy Context for DH in the UK

Heat is a devolved matter in Scotland and Northern Ireland in the United Kingdom, as these nations are responsible for developing their own heat policies. Wales has non-devolved powers over the production, distribution, and supply of heat and cooling, as well as the regulation of heat networks and energy efficiency. Heat networks, renewable energy incentive schemes, and promotion of energy efficiency, on the other hand, are devolved. In relation to these subject areas, Wales is responsible for developing its own heat policies (BEIS, 2021d).

6.4. The UK DH Network Market

DH currently accounts for 2% of the domestic, public sector, and commercial buildings heat demand in the UK (DECC, 2015a; Colmenar-Santos *et al.*, 2016; ADE, 2018a; CMA, 2018). It is estimated that over 14,000 DH networks and communal heating schemes of various sizes exist, serving 200,000 dwellings as well as 2,000 commercial and public buildings. The most extensive DH network schemes are typically found in cities and on university campuses. In the domestic sector, there are numerous smaller schemes that often connect blocks of flats. Natural gas has long been the largest fuel type in the UK energy generation, but the associated emissions need to be addressed and virtually all areas of heat and power demand need to take significant action in order to effectively decarbonise to meet future carbon budgets. The UK government recognises that DH will play a vital role in making net zero a reality and to reduce heating bills for customers. To meet the net zero target, carbon emissions produced in heating residential, commercial and public buildings need to be addressed. The Committee on Climate Change have estimated that around 18% of UK heat will need to come from DH by 2050 if the UK is to meet its carbon targets cost effectively which could create between 20,000 and 35,000 direct additional jobs by 2050. Councils across the UK have declared climate emergencies and DH networks will play a vital role in helping them achieve their decarbonisation objectives (HM Government, 2017, 2021b, 2021d). It is estimated that £16 billion in capital investment may be required for heat networks to contribute fully to net zero (BEIS, 2021e). Recognising that DH networks are a crucial part of the UK heat decarbonisation, the UK Government aims to create the conditions to accelerate growth towards a self-sustaining DH market that does not require on going market subsidy through a market driven approach by (HM Government, 2017, 2021b, 2021d):

- Attracting new entrants to the market and enabling market expansion
- Enabling market competition and effective choices
- Helping the DH industry to develop the right skill set across the supply chain and build capacity
- Linking up market players to form an independent ecosystem by building connections

Although the use of DH networks in the United Kingdom is currently very limited, the government recognizes the environmental and economic benefits that DH networks can provide and has established a Heat Network Delivery Unit to assist local governments in developing networks. In 2013, the Heat Network Delivery Unit (HNDU) in the Department of Business Energy and Industrial Strategy was set up specifically to support local authorities in England and Wales through the early stages of DH project development. The HNDU has led progress in sharing of best practice and knowledge across the market by promoting new guidance on technical standards, creation of standardised documentation and facilitating project development. Its remit has since expanded in response to stakeholder needs to include facilitating the delivery of a wider range of projects, both public and private including major housing developments and hospitals, and utilising energy from waste heat sources (Raine, Sharifi and Swithenbank, 2014; HM Government, 2017; CMA, 2018; CIBSE and ADE, 2020). The Heat Network Transformation Programme (HNTP) was introduced in Autumn 2020 see figure 42 (HM Government, 2017, 2021b, 2021d).

HEAT NETWORKS TRANSFORMATION PROGRAMME

tackling climate change, driving the green economy, achieving net zero

Initiative	Purpose	Timeframe	Budget
Heat Networks Investment Project (HNIP)	Network Growth & Promote Self-Sustaining Market	2019/20 to 21/22 In delivery	£281m
Green Heat Networks Fund (GHNF)	Network Decarbonisation & Market Preparedness for Regulation	2022/23 to 24/25 In design	£270m
Heat Networks Efficiency Scheme (HNES)	Improve Efficiency of 'Legacy' Networks	2022/23 to 24/25	TBA
Heat Networks Skills Programme (HNSP)	Enhance Supply Chain Capability	2022/23 to 23/24	TBA
Heat Networks Market Framework & Regulation (Incl. Zoning)	Introduce Statutory Regulator, regulations on CO_2 emissions, and zoning requirements (funding requirement TBC)	2021 onwards	Regulatory

Figure 42:Aim of the Heat Network Transformation Programme (HM Government, 2021b, 2021d).

The programme represents a major step-change in the DH sector by facilitating series of inter-dependent projects which will deliver increased low carbon heat through the creation of new and more efficient DH networks through the Heat Network Investment Project (HNIP) and the proposed Green Heat Network Fund (GHNF) as well as new funding to increase the efficiency of existing networks and increasing delivery capacity, skills, supply chain and jobs to develop the DH sector (HM Government, 2017, 2021b, 2021d). Other wider supporting activities and studies include:

- **Waste Heat and National Comprehensive Assessment (WHNCA)**: The study on opportunity areas for DH networks on the UK: The report includes information on the policy initiatives underway to accelerate the deployment of heat networks and, more broadly, the decarbonisation of heat. Where applicable, the study includes descriptions of policy measures for each of the four nations as well as for the United Kingdom as a whole (BEIS, 2021d).
- **Energy from Waste (EfW) study**: This is an annual report on the UK energy from waste sector. The report focuses on conventional moving grate (which is the typical incineration plant for municipal solid waste) EfWs and Advanced Conversion Technology (ACT) facilities in the UK that generate energy from the combustion of Residual Waste as well as the use of residual waste as a solid recovered fuel (Tolvik, 2021).
- **Waste heat from Water Sector:** The UK is exploring waste heat recovery from wastewater. Wastewater in domestic, industrial, or commercial buildings maintains considerable thermal energy quantities, which is discharged to the sewer system with temperature ranging from 10 to 25^{o}C. Waste heat from buildings and industrial processes in the UK, could be used to supply 14% of the hot water and heating demand in UK (CIBSE, 2020; Nagpal *et al.*, 2021).
- **Heat Network Optimisation Opportunities (HNOO) Scheme**: The HNOO programme was a set of projects funded by BEIS in 2020. Many of the existing heat networks in the UK have poor performance, resulting in high operating costs for Housing Associations and high tariffs for their residents. The primary objective of the HNOO programme was to analyse existing heat networks with suboptimal performance in order to develop business cases for performance improvements to the heat network operator for cost-effective interventions to reduce carbon emissions. The investigations and analyses carried out by the HNOO programme provide a good overview of the most frequently occurring performance issues across heat networks operated by housing associations. Following the analysis, a series of interventions were proposed to address the performance issues in each of the heat networks (BEIS, 2018c; Fair Heat, 2020).

- **City Deep Decarbonisation Projects (CDDP)**: As part of Greater Manchester's heat decarbonisation plan, GMCA is working closely with BEIS and AECOM on a project dubbed the City Deep Decarbonisation Project (CDDP). The CDDP outlines business cases to deploy decarbonised DH networks in Greater Manchester. The aim of the programme is to focus on areas that require the strategic placement of high and low temperature heat networks. It also considers how GM intends to transition its housing stock and the built environment in general away from gas and fossil fuel-powered heating and toward decarbonised heating systems (GMCA, 2019).
- **Industrial Heat Recovery Support Programme (IHRS):** The Industrial Heat Recovery Support (IHRS) program was created to promote and support investment in heat recovery technologies. This includes assisting businesses in identifying and investing in opportunities to recover and reuse heat that would otherwise be wasted. Recovered waste heat can be used in a variety of ways, assisting businesses in lowering fuel costs, reducing waste heat, and lowering emissions. Usage examples include by another end-user (for example, a heat network), within the same industrial facility or by converting waste heat to power. The objectives of the programme where to boost industry confidence in investing in heat recovery technologies from industrial processes and to increase the use of such technologies in England and Wales. As of July 31, 2020, the IHRS Programme closed to applications. However, it runs until March 20, 2022 (BEIS, 2019a; HM Government, 2020b).

6.4.1. Regulatory Framework

Until 2014, DH network locations were unrecorded, and their operations were unregulated. Currently DH customers do not have the same regulated customer protections like other comparable services such as domestic gas and electricity customers (BEIS, 2018d; CMA, 2018).

The Heat Network (Metering and Billing) Regulations 2014 established requirements for heat metering, as well as fair and transparent billing based on actual consumption, in addition to general consumer protection laws applies. The Regulations require network suppliers to notify the regulator, the Office for Product Safety and Standards (OPSS), when the network becomes operational and to report on the network's status and performance every four years as well as how their bill is calculated. Amendments to the Regulation, the **Heat Network (Metering and Billing) Regulations 2020** entered into force on 27 November 2020, to transpose requirements of the Energy Efficiency Directive (EED) 2012 pertaining to DH network metering and billing. OPSS is responsible for enforcing the Regulations.

6.4.2. Developing a Heat Network Market Framework

The UK Government is seeking to increase the share of DH networks in the energy system, recognizing their importance to the future energy mix and the critical role they can play in decarbonizing the UK's heating sector in order to achieve net zero carbon emissions. The illustrative scenarios in the Clean Growth Strategy suggests that DH could provide 17-24% of UK heat demand by 2050. Similarly, the Committee on Climate Change estimates that by 2050, around 18% of UK heat will need to be supplied by heat networks if the UK is to meet its carbon targets at a reasonable cost. The UK Government has set a target for DH networks to supply around a fifth of heat by 2050 (HM Government, 2017; CMA, 2018; Committee on Climate Change, 2018). The Competition and Markets Authority (CMA) 2018 report on the market for heat networks recommended the establishment of a regulatory body to ensure consumer protection standards for heat network customers comparable to those for electricity, gas, and water network customers; to increase transparency in contracts between customers and heat network operators; to educate consumers about their bills; and to protect customers from poorly designed, built, and operated heat networks (ADE, 2018c; CMA, 2018; CIBSE and ADE, 2020). To achieve this a heat network market regulatory framework is being developed to increase investment, support market growth, develop low carbon networks and put consumer protections in place for heat network customers that are currently lacking. The consultation on the development of the policy to implement the regulation of new and existing heat networks closed June 2021 (BEIS, 2020b; CIBSE and ADE, 2020). The consultation is a step towards delivering an efficient DH sector. As at the time of writing the consultation response had not been published. Figure 43 illustrates the evolution of the Heat Network Market Framework.

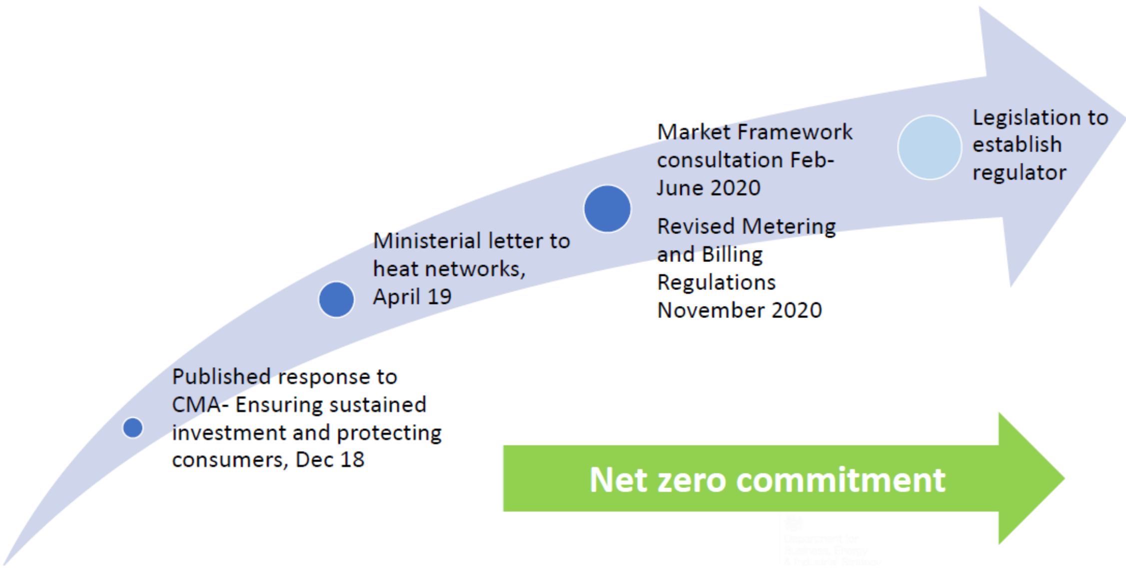


Figure 43:Evolution of the Heat Network Market Framework (BEIS, 2021).

The framework seeks to help support the development of a self-sustaining heat network market by the mid-2020s. The Government's long-term market framework priorities include driving investment in DH networks, ensuring consumer protection, and promoting decarbonisation. The aims of the Market Framework are illustrated in figure 44.

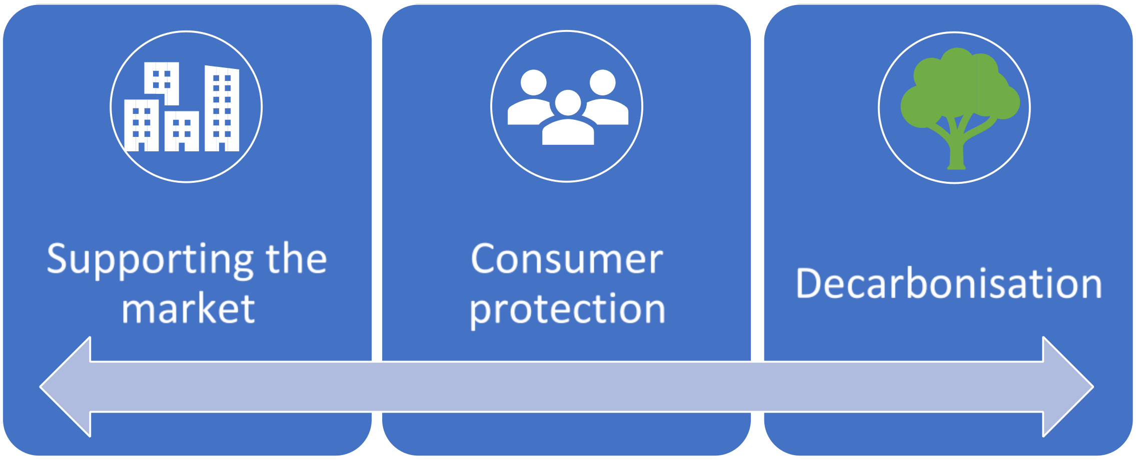


Figure 44: Aims of the Market Framework (BEIS, 2021).

In order to achieve the scale of ambition set out by the UK Government, it is important that that DH sector grows very quickly. To this end, the UK Government is committed to supporting this growth through policies in a variety of areas, including providing heat networks with the same statutory rights as electricity, gas, and water companies, such as the right to dig up streets and cross linear obstacles like railway lines and canals, as well as purchase lands with the same negotiating rights. In addition, as stated in the 2020 Energy White Paper, the market framework will support the implementation of a new heat network zoning policy by 2025 (CMA, 2018; HM Government, 2020a). This would be a system whereby areas within cities and towns are designated as heat network zones where heat networks are that the most cost-effective solution for the consumer and the most cost-effective way of transitioning to net zero. The consultation on heat network zoning was rolled out in October 2021 to run till November 2021 which will aid in developing the policy design as government plans to implement local authority zoning by 2025 (CMA, 2018; ADE, 2020; BEIS, 2021c). This will be useful in gathering views on the proposed approach to deliver heat network zoning in the UK, to aid effective policy decisions and to strengthen appropriate policy design to further support the growth of the sector. Furthermore, the market framework aims to decarbonise by leveraging capital investment through the Green Heat Network Funds (GHNF), but also by implementing regulations that encourage the sector to transition away from gas and toward lower carbon heat sources in the 2030s (CMA, 2018; ADE, 2020; BEIS, 2021c).

6.4.3. Industry Representatives

Industry representatives, which include non-trade associations, community group networks, or government programmes play an important role in supporting the framework for DH development trajectories to overcome the barriers to the successful development and implementation of DH networks in the UK (BEIS, 2018d; CIBSE and ADE, 2020). Additionally, several industry representatives are initiating improvements and advocating for quality developments in the UK DH sector. The UK government continues to work collaboratively with industry representatives to determine how to best support the implementation of technical standards such as the Code of Practice CP1, as well as how to create the conditions to accelerate growth, integrate high technical standards, fair pricing and consumer protection into a longer-term coherent framework for consistency across the sector and integration into the proposed DH regulation, to achieve the vision of a cleaner and sustainable sector (BEIS, 2018d; CIBSE and ADE, 2020).

Heat Trust

Heat Trust is a self-regulatory, industry-led customer protection scheme for the district heating industry that also offers an independent dispute resolution service through the Energy Ombudsman. Heat Trust provides customer protection for the DH sector. It puts in place a common standard in the quality of service that is provided to domestic and non-domestic micro business customers by their heat energy supplier with customer free access to the Energy Ombudsman (BEIS, 2018d; CIBSE and ADE, 2020). Protecting customers adequately is critical for any new heat network, as they are effectively unregulated monopolies in the UK (BEIS, 2018d; CIBSE and ADE, 2020). The development of appropriate customer protection schemes, such as the Heat Trust, will be critical to the success of networks in general. Heat Trust is a customer protection scheme that establishes service standards comparable to those found in the gas and electricity markets and provides customers with access to an independent ombudsman (BEIS, 2018d). To ensure customer satisfaction, it will be critical to provide clear information about heat prices, projected heating costs, and comparisons to alternative heating systems. Clients, designers, and operators must ensure that operating costs for heat networks are kept to a minimum, ensuring that heat charges to customers are reasonable and not higher than the counterfactual (BEIS, 2018d; CIBSE and ADE, 2020).

Association for Decentralised Energy (ADE)

The ADE is another umbrella body for the heat network sector driving the decarbonisation of heat, promoting industry's role in the green transition, and advocating for energy-efficient smart homes, workplaces, and public services in the UK. It establishes a vision for a decentralized, efficient, low-carbon energy system that empowers energy users to make their own choices. With over 140 members representing a diverse range of technologies and markets, the Association is widely recognized as one of the leading industry associations in the sustainable energy sector. ADE believes that decentralized energy is energy generated at or near the energy user and that it plays an important role in delivering a flexible, smart energy future (CIBSE and ADE, 2020; ADE, 2021). ADE works to foster a strong, dynamic, and long-term environment for a variety of technologies such as combined heat and power, demand side energy services, energy efficiency, and DH networks. However, does not advocate for one decentralized energy technology over another, believing that the solution should be driven by customer needs (ADE, 2018c, 2019). The Chartered Institution of Building Services Engineer (CIBSE) and ADE have worked very closely in the development of the Heat Network Code of Practice for the UK CP1

UK District Energy Association (UKDEA)

In 2010, the partners, owners and operators of the most significant district energy schemes in the UK joined forces to form the UKDEA, a not for profit, non-trade association of companies and public sector organisations involved or interested in DH schemes of all sizes. The UKDEA is one of two umbrella bodies for the heat network sector, and its mission is to represent current and prospective owners, developers, consumers, partners, operators, product suppliers, and other interested parties in the UK's District Energy sector. The UKDEA offers guidance, tools and support to members and organisations across the sector particularly local authorities to build and grow their schemes and develop their businesses , they also raise awareness of district energy as a low carbon solution as well as the benefits it can deliver. It aims to promote district energy as a means to deliver significant carbon reduction and to establish a direct link between the Government and the industry market base. With well over 1330 members all major district energy schemes in the UK are represented by the UKDEA (UKDEA, 2021).

Heat Network Industry Council (HeatNIC)

The Heat Network Industry Council launched in 2020 is a group of companies that came together in the same way that the offshore wind sector developed a very successful model through their Offshore Wind Industry Council. The Council represents key stakeholders in the DH network sector effectively working together to put forward a coherent ask and to support the Government, in achieving its vision of a cleaner, fairer future and sustainable industry. The Heat Networks Industry Council is currently administered by The Association for Decentralised Energy, with support from Council Members which include Siemens, ENGIE, EON, Pinnacle Power, Ramboll, SSE, BU-UK, EDF Energy, Vattenfall, Switch 2, Vital Energi and Veola. It is worth noting that BEIS and the Industry Council have formed a partnership called the Heat Network Exchange to facilitate the sharing of people and parts across the industry to offer their services and unlock opportunities (Heat Network Exchange, 2020; HeatNIC, 2020).

6.4.4. Financial Instruments/Funding Mechanisms

DH networks have high development and capital costs which has been identified as a key challenge limiting the development of the sector as well as low third-party investment due to lack/insufficient regulation which creates uncertainty in the sector. While the UK Government aims to create the conditions to accelerate growth towards a self-sustaining DH market that does not require on going market subsidy, a combination of historic underinvestment, lack of regulation, poor service levels leading to disconnection of consumers and rigid price caps have created a unique obstacle to investment. The UK government intends to increase the contribution of district heating to building heat demand from 2% in 2018 to 18% by 2050. This will require several billions of pounds in investment, with a significant portion of the capital invested in district heating going toward enabling heat generation. The UK government has set up a number of funding options to support the development of the DH sector. (CMA, 2018; CIBSE, 2020; CIBSE and ADE, 2020). Some of the main funding options are discussed below:

Heat Networks Delivery Unit (HNDU) Funding: The Heat Network Delivery Unit administered by the Department for Business Energy and Industrial Strategy (BEIS) provides grant funding and guidance to local authorities in England and Wales for DH network project development. Since its inception, HNDU has so far supported over 250 projects across 150 local authorities –awarding in excess of £23 million in total (Raine, Sharifi and Swithenbank, 2014; HM Government, 2017; CMA, 2018; CIBSE and ADE, 2020).

Heat Network Investment Project (HNIP) Funding: The Heat Networks Investment Project is a capital funding programme administered by Triple Point Heat Networks Investment Management (Triple Point). HNIP provides £320 million of capital funding to gap fund heat network projects open to the public, private and third sectors in England and Wales (HM Government, 2017; CMA, 2018; CIBSE and ADE, 2020).

Green Heat Network Fund (GHNF): The proposed Green Heat Network Fund Transition Scheme is a new £270 million Government capital grant fund open to public, private, and third sector applicants in England and Wales. The aim of the scheme is to incentivise the transition of new and existing heat networks to be low and zero carbon technologies and to connect to low carbon heat sources. The scheme will replace the HNIP from 2022 and aims to fund 10.3 megatons of carbon emission savings by 2050 (BEIS, 2021a).

Scottish Government's District Heating Loan Fund: The Scottish Government supports district heating through its District Heating Loan Fund managed by Energy Savings Trust. It is designed to support the development of district heating networks in Scotland to help address the financial and technical barriers to district heating. It provides capital loan funding for renewable and low carbon energy in the DH sector, to assist organisations to implement district heating projects that benefit local communities, with a focus on local authority projects in Scotland (Energy Saving Trust, 2021; Scottish Government, 2021b).

Renewable Heat Incentive (RHI): The RHI is a government funded scheme administered by Ofgem which was launched in 2014 to provide financial incentives to households that use renewable energy to heat their homes, both on and off the gas grid. Switching to low carbon, energy-efficient heating systems can help the UK reduce its carbon footprint and meet its renewable energy targets. The aim of the scheme is to assist businesses, public sector and non-profit organisations cover the costs of installing renewable heat technologies in order to help the UK meet its legally binding target of reaching net zero emissions by 2050. It runs in England, Scotland and Wales. There are two versions available: one for residential properties and one for non-residential properties (industrial, commercial, public sector and community organisations). The scheme will close to new applicants on March 31, 2022 (HM Government, 2018; ofgem, 2021). Types of heating that can be claimed include(HM Government, 2018; ofgem, 2021):

- biomass
- heat pumps (ground source, water source and air source)
- deep geothermal
- solar thermal collectors
- solar water heating
- biomethane and biogas
- combined heat and power (CHP) systems

Industrial Energy Transformation Fund (IETF): The £315 million Industrial Energy Transformation Fund administered by BEIS is designed to assist businesses with high energy use, such as energy intensive industries, in reducing their energy bills and carbon emissions through investments in energy efficiency and low-carbon technologies. The fund is available until 2025 (HM Government, 2021c).

Public Sector Decarbonisation Scheme (PSDS): The BEIS-funded Public Sector Decarbonisation Scheme provides grants to public sector organizations to finance energy efficiency and heat decarbonisation measures. The phase 3 of the scheme is now open for applications. Applications for phases 1 and 2 of the scheme are now closed. Phase 1invested £1 billion to aid the UK's economic recovery following fromCOVID-19, resulting in the creation of up to 30,000 jobs in the low-carbon and energy-efficient sectors. Phase 2 provided grant funding of £75 million for the financial year 2021/2022. It places a greater emphasis on heat decarbonisation than Phase 1, in order to achieve a greater reduction in carbon emissions. It supports the public sector in decarbonizing their estates using a 'whole building' approach (BEIS, 2021e).

Public Sector Low Carbon Skills Fund (LCSF): The Public Sector Low Carbon Skills Fund, funded by the BEIS, provides grants to develop decarbonisation skills and unlock decarbonisation in the public sector. The first phase provided up to £32 million in grant funding, while the second phase provided up to £11.5 million in grant funding to eligible public sector bodies to develop bids and deliver projects under the Public Sector Decarbonisation Scheme (BEIS, 2021f).

Public Works Loan Board: The government supports local investment in part by providing low-interest loans to local governments through the Public Works Loan Board (PWLB). The PWLB is the primary lender to local governments, accounting for roughly two-thirds of all LA debt. PWLB loans are now legally issued by the Treasury as a result of legislation passed in February 2020. The name 'PWLB' has been retained because it is well-known and well-established in the industry (HM Treasury, 2020b).

Local Energy Accelerator Programme (LEA): Local Energy Accelerator is a new £6 million program co-funded by the Mayor of London and the European Regional Development Fund (ERDF). It provides public and private organisations with expertise and support to develop clean and locally generated energy projects in London in order to make London's homes warm, healthy, and affordable, its workplaces more energy efficient, and to supply the capital with more local, clean, and flexible energy. These projects include district energy networks that use renewable heat sources (such as river water and waste heat from London Underground) as well as energy technologies such as heat pumps, solar panels, batteries, and smart electric vehicle charging to transform how London generates, supplies, and uses clean local energy in buildings and transportation. LEA will concentrate on assisting projects that are nearing completion and would benefit from support to deliver carbon savings (London City Hall, 2021).

Greater Manchester Low Carbon Fund: The Greater Manchester Combined Authority Low Carbon Fund is a £15 million loan fund designed to promote the production and distribution of energy derived from renewable resources/low carbon technology installations and district energy networks, with the focus on greenhouse gas reduction. It is funded by the 2014-2020 European Regional Development Fund and has a life span of 15-years. This is to promote energy efficiency and renewable energy use in businesses, and to support energy efficiency, smart energy management, and renewable energy use in public infrastructure, including public buildings and the housing sector in Greater Manchester. Projects must be located within the Greater Manchester Local Enterprise Partnership area (GMCA, 2021).

Heat Network Efficiency Scheme (HNES) Demonstrator: The BEIS Heat Network Efficiency Scheme (HNES) Demonstrator is a £4.175m grant scheme for financial year 21/22 that will soon be open for applications, with a funding drawdown deadline of March 31, 2022. It will provide funding to applicants from the public, private, and third-sector in England and Wales to support improvements to existing DH networks or communal heating projects that are underperforming and resulting in poor outcomes for operators and customers (BEIS, 2021b).

6.4.5. DH Procurement Routes

DH procurements routes are designed to help local authorities which may recognise the potential benefits of DH understand the process and how to successfully deliver a DH network. The available procurement routes for DH in the UK are discussed below.

Heat Network and Electricity Generation Assets (HELGA): HELGA provides energy demand management and generation services through a flexible, user-friendly dynamic purchasing system that is compliant with the Official Journal of the European Union (OJEU). It uses an automated, electronic process to help customers find relevant suppliers through a filtering mechanism with existing supplier selection tools and systems (CCS, 2021).

BEIS Heat Network Investment Vehicle (BHIVE): The BEIS Heat Investment Vehicle (BHIVE) is a dynamic purchasing system (DPS) for heat networks established by BEIS. It will enable public sector heat network owners and developers to obtain funding and funding-related services from a variety of prospective funding partners for their heat network projects. Heat networks in the UK have one of the highest investment potentials in Europe, with a potential investment of £13-£22 billion by 2050. The DPS will help create a market that attracts investors, creates and sustains jobs, exports, and economic benefits, and continue to position the UK at the forefront of investment destinations. BHIVE is administered by TriplePoint and all public sector entities in England and Wales can access BHIVE via TriplePoint (HM Government, 2021a).

Yorkshire Purchasing Organisation (YPO): YPO is a publicly owned procurement organisation owned by 13 local authorities, with over 100 frameworks available for providing a wide range of goods and services from UK suppliers ranging from office supplies and furniture to energy and HR solutions to help drive efficiency savings through bulk purchasing power for product supplies and centralised contract services (YPO, 2021).

Clear Futures: Clear Futures is a framework for solving long-term sustainability challenges through procurement and delivery. It was created in collaboration with Eastbourne Borough Council, Lewes District Council, AECOM, and Robertson Capital Projects. The framework provides an efficient method for combining and coordinating resources between the public and private sectors (Clear Futures, 2021).

Local Energy Accelerator Programme (LEA): In June 2021, LEA replaced the Decentralised Energy Enabling Project (DEEP) which was established in June 2017 to promote large-scale decentralised energy projects in London that the market had failed to deliver. The LEA is one of a number of 'accelerators' designed to accelerate carbon reduction and decarbonize energy supply by supporting smaller, more decentralised energy sources in order to achieve net zero carbon emissions in Greater London Authority (GLA)by 2030. The aim is to build integrated clean and smart energy systems that rely on local and renewable energy sources through grant funding to support public and private organisations design and implement clean local energy schemes. Through the provision of technical, commercial, legal, and strategic expertise from service providers, the grant funds will help to de-risk and increase the viability of projects. The LEA framework can also be used to procure the expertise needed to deliver projects across the UK (Authority, 2020). As outlined in subsequent sections, a number of these industry representatives, financial instruments DH procurement routes were identified/mentioned by participants in the primary case study as being beneficial in providing the needed support for the development of DH projects in GM.

6.5. Chapter Conclusion

This Chapter provided an overview of the national policy and industry context in order to better understand the multilevel governance, dynamics and peculiarities of the DH development and implementation process in GM, as well as the identification of some of the key issues, such as a lack of regulation, statutory regulator, technical standards, pricing structure, and consumer rights protection in the DH sector. DH networks have been identified as critical to the UK's target of decarbonising heat and achieving net zero emissions by 2050. The DH network market growth in the

UK is already being supported by strong government commitments of up to £320 million through the Heat Network Investment Project (HNIP) and the work of the Heat Network Delivery Unit (HNDU), which assists local governments and project developers in the early stages of scheme development. In addition, the Green Heat Network Fund (GHNF), aims to stimulate the growth and transition to low-carbon heat networks by promoting low-carbon thermal generation. This chapter highlighted the government's goal to significantly increase the number and scope of DH networks in the UK and in GM in order to achieve their full contribution to net zero, as well as the role of industry representatives and funding mechanisms in providing the framework for DH development trajectories at the local level.

It also aided in understanding the DH multi-level governance by providing a brief history of DH in the UK and GM in order to better understand the dynamics and uniqueness of the DH development and implementation process in GM. While the government proposes to establish a regulatory framework for heat networks that protects consumers, promotes technical standards, and accelerates market growth and decarbonization, the following chapter presents research findings on the current process of DH development and implementation in GM, based on semi-structured interviews with 20 key stakeholders involved in the DH development and implementation process in GM.

7. CHAPTER 7 DISTRICT HEATING DEVELOPMENT AND IMPLEMENTATION IN GREATER MANCHESTER

7.1. Introduction

This chapter introduced the primary case study and presents findings from the early stages of DH development and implementation in GM, based on the semi-structured one-on-one interviews with twenty key stakeholders involved in the GM DH implementation process. It involved the analysis of secondary literature, to provide a full picture of GM's strategy for the implementation of large-scale DH networks from a socio-technical perspective, using document analysis of secondary data and a deductive approach to thematic analysis of primary data.

The early stage of large-scale DH development and implementation across GM makes it an ideal case study for this research to provide an understanding of what actually happens during the DH implementation phase. The data analysis highlighted the influence of the technical and social aspects of socio-technical elements characterised by social actors, as well as the interactions between these elements within the DH sector. It provided insights into the unique drivers, challenges and barriers to DH development in GM. It also provided a stakeholder view of DH implementation in GM, the policy landscape in the heat network sector, as well as the role of the public and private sector in the DH network development and implementation process. The findings provided a better understanding of the DH implementation (GM) in terms of the main barriers limiting the uptake and implementation of district heating at scale to develop proposals to address them. It also provided an avenue to understand how actors seek to implement DH, the impact of context on the implementation of DH and the systematic interactions between the factors that influence the development and implementation of DH networks in GM.

7.2. Introducing the Primary Case Study: Greater Manchester

Greater Manchester city region is located in the Northwest of England. It is the third-largest region in the UK with a population of **2,867,800** million inhabitants and about **1.2** million households (Energy Systems Catapult, 2016; GMCA, 2021)). It is a highly urbanized area with significant ecological footprint stemming from its active involvement in industrialization during the industrial revolution era. Climate change in Greater Manchester is dealt with as a devolved issue governed by the Greater Manchester Combined Authority (GMCA). GM comprises of ten metropolitan boroughs (councils) see figure 45: Bolton, Bury, Oldham, Rochdale, Stockport, Tameside, Trafford, Wigan, the City of Salford, and the City of Manchester is the world's first industrial city, and might be considered the cradle of human-induced climate change characterized by the use of fossil fuels and the release of large amounts of carbon emissions (Energy Systems Catapult, 2016; Science and Industry Museum, 2019).

Figure 45:Greater Manchester (BEIS, 2019).

Greater Manchester's ambition is to be a national trail blazer for the transition to net zero, it is one of the first city-regions in the UK to set self-imposed climate change mitigation targets to become carbon neutral by 2038. The city region's commitment to becoming a global leader in smart energy innovation, through its goal to deliver a decarbonised heating sector through the implementation of DH systems makes it an ideal case study for the ongoing research on the exploration of urban DH delivery (BEIS, 2019c). The Whole System Smart Energy Plan (WSSEP) for Greater Manchester was developed to aid the decarbonisation of the energy system and the interconnected sectors (energy sector, transport sector, and the heat and cooling sector) and the first phase of the plan would run for a 5-year period between 2019 to 2024 The plan also aims to accelerate its long-term goal to become a carbon-neutral green city region by 2038 (BEIS, 2019c).

7.2.1. The Whole System Smart Energy Plan for Greater Manchester

The Whole System Smart Energy Plan for Greater Manchester was developed to aid the transition to a local decentralized smart energy system in Greater Manchester. It provides evidence-based data on energy system modelling for future investment in the technologies and innovation in the smart energy system. It outlines a roadmap of projects and activities focused on four priority areas to support the decarbonizing of heat in Greater Manchester within the wider energy system. It puts forward 5-year goals to be achieved by 2024 (BEIS, 2019). This plan is supported by Local Area Energy Planning, a GM

Buildings Retrofit Plan, the GM Environment Plan, GM Local Industrial Strategy and the 2040 Transport Strategy (BEIS, 2019c).

The main strategy of this plan is to significantly support low carbon transitions by enabling local, regional, and national actors, as well as outlining strategic directions towards the creation of a local decentralized smart energy system which is in line with the long-term goal to become carbon neutral by 2038. Greater Manchester seeks to leverage innovation, system integration, and regulatory policies to drive low carbon transitions and sustainable low carbon development as contributions to strengthen climate actions in line with international commitments and global efforts to combat climate change (BEIS, 2019c).

GM envisions to be an Energy Transition Region (ETR) where facilities, assets, academia, public estates, research and facilities are fully maximized for the development of innovation through the introduction of smart energy technologies and services for the optimal improvement of existing technology and integration. Consequently, GM has set clear and focused objectives to achieve the decarbonisation levels needed to address climate change challenges and has set out focused goals for 2024 under four priority areas presented in table 14.

Table 15: Year focused goals for Greater Manchester (BEIS, 2019).

WSSEP for GM 5-Year Goals (2019 - 2024) – Energy Innovation Challenge	
Energy Generation and Storage	45 MW of additional energy generation from renewables
Decarbonisation of Heat	10.2 TWh of low carbon heat
Low Carbon Transport	Up to 200,000 low carbon vehicles
Diversity and Flexibility	45 MW of diverse/flexible energy load

One of the objectives of this study is to explore the drivers and barriers to district heating implementation with a view to finding effective strategies that can overcome the barriers to the implementation of DH to aid the decarbonisation of the heat sector. In order to achieve Greater Manchester's decarbonisation of heat targets for 2019-2024 (10.2TWh of low carbon heat), it is imperative to explore potential low carbon heating alternatives. While several low carbon technologies such as the introduction of electrified heating, heat provision through DH networks and hydrogen injection into the gas grid may replace the conventional gas-fired system to minimise carbon emissions (BEIS, 2019c), this study focuses on exploring low carbon heat provision through the district heating technology.

7.2.2. Heat Demand in Greater Manchester

Heat demand constitutes a significant proportion of the total energy demand in Greater Manchester. The total heat demand for GM is estimated to be **21.7 TWh / year**, which is divided into the following in table 16 (Energy Systems Catapult, 2016):

Table 16: Heat demand breakdown in GM

Heat Demand in GM	**Annual demand in each division**
Domestic	**14.5 TWh / year**
Non-Domestic	**5.8 TWh / year**
Transport	**1.4 TWh / year**

The projected construction of new homes and non-domestic buildings in GM could lead to an increase in energy demand by approximately 3% by 2037. Individual heating systems such as gas or electricity boilers are used in most domestic and non-domestic buildings to provide heating (DECC, 2016a).

The demand for electricity and gas in GM represents 23% and 42%, respectively, of total energy consumption (DECC, 2016a). Figure 46 shows the percentage breakdown of the total of 51.6TWh of fuel consumed in GM across domestic, non-domestic and transport sectors (with the exception of transport, the total is 37TWh), with a number of fuels contributing to the final total.

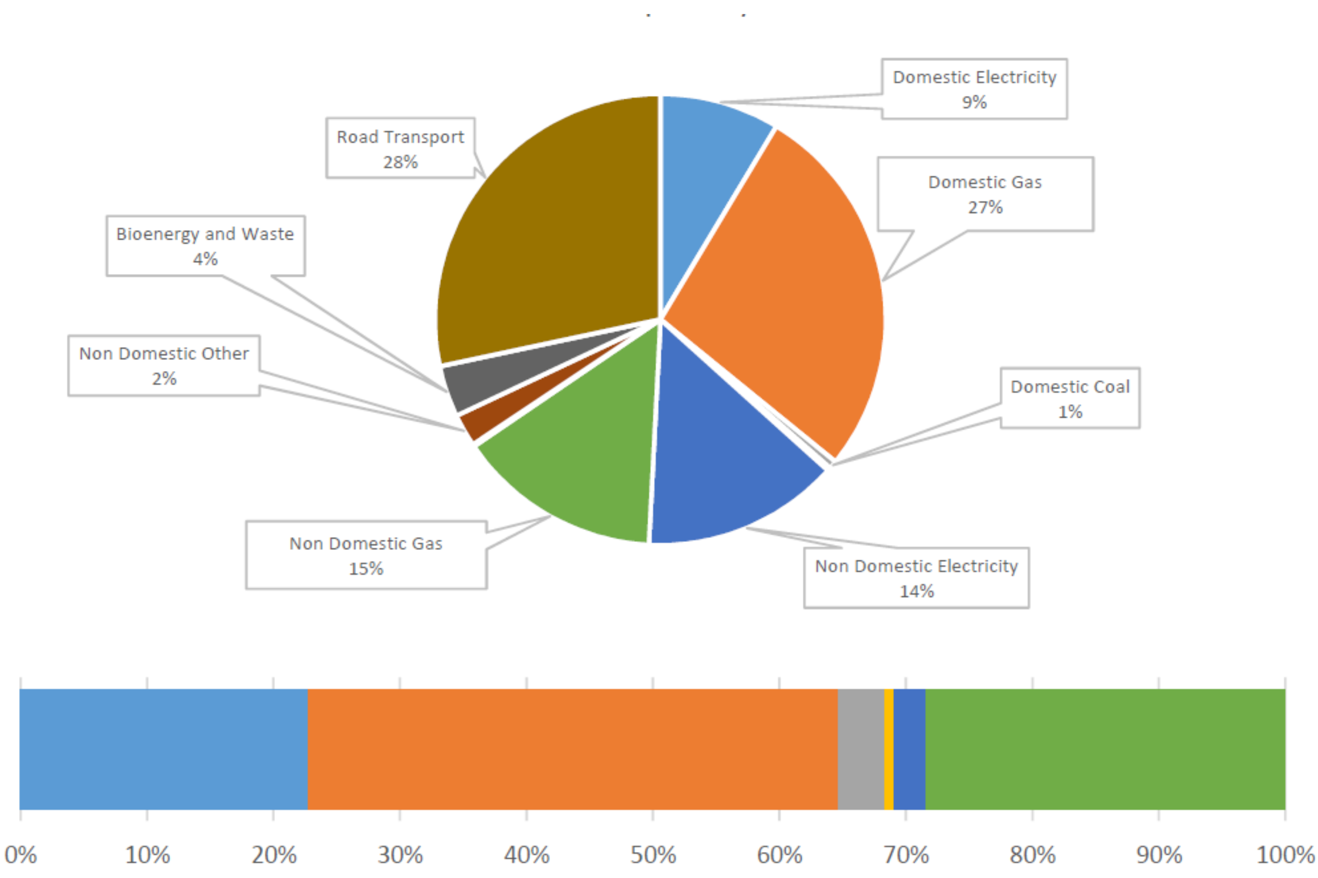


Figure 46: Fuel consumption by sector in GM (DECC, 2016a).

Gas is the predominant means of providing hot water and heating in GM. 95% of post codes in GM are connected to the gas grid. Although electricity can be used to provide heating, lighting as well as to power appliances and processes, its use for heating is not predominant in GM. However, coal and oil are used for heating in some buildings in parts of GM, such buildings have low thermal efficiency and are often in areas identified to have high levels of fuel poverty (Energy Systems Catapult, 2016). While there are a number of heating networks exist in GM: at the Birley Fields campus of Manchester Metropolitan University, MediaCityUK and Oldham's St Mary's district, as well as the Civic Quarter network in Manchester city centre which is in procurement by a distribution partner, GM seeks to expand support for district heating development and local heat delivery to address the low carbon heat gap before hydrogen is potentially mainstreamed in both the short and medium term (BEIS, 2019c).

Heat decarbonisation and the significant reduction in the use of energy for heating and hot water in buildings are key to achieving GM's heat decarbonisation targets. Over the next remaining years of the first initial 5-year phase of the WSSEP, GM intends to significantly accelerate the rate and scale of deployment of new energy generation. While a number of technologies can be used to decarbonise the heat sector in GM (as previously mentioned) this research considers the dynamics of governing the transition to low carbon heating with a specific focus on the role of DH and the pathways that enable the successful implementation of DH systems. The early stage of the heat decarbonisation plan to implement DH systems at scale in GM, makes it a valuable primary case study to explore policy considerations, implementation processes and the influence of key stakeholders in the pursuit to drive large scale DH implementation in GM.

7.2.3. District Heating Networks in GM

Figure 47 shows the locations of DH networks in GM (DECC, 2016a; Energy Systems Catapult, 2016). The newly completed Civic Quarter network in Manchester city centre is projected to reduce the Council's direct carbon emissions by approximately 2,200 tonnes of CO_2 when fully operational (Manchester City Council, 2021).

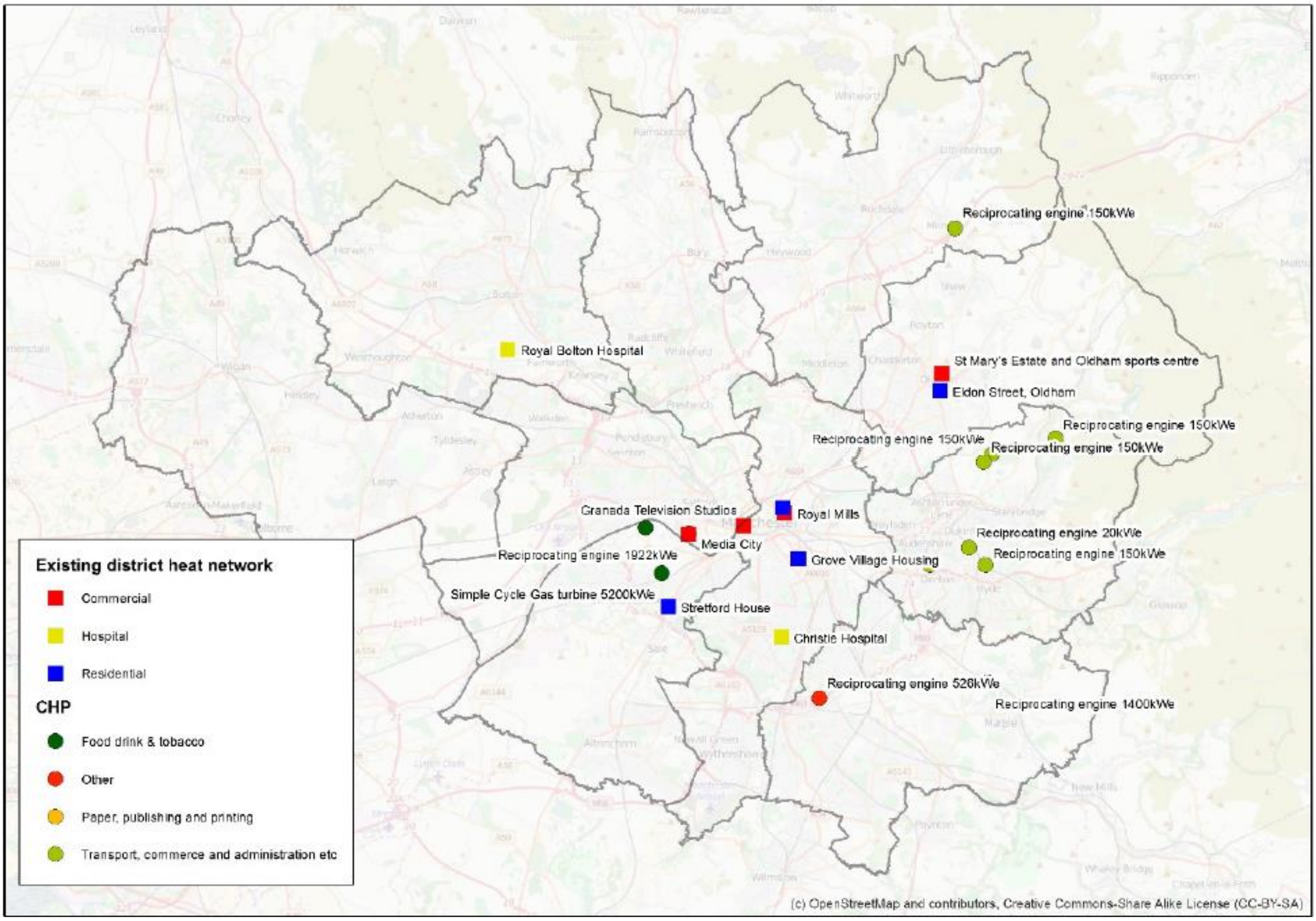


Figure 47:Locations of known DH networks and CHPs in GM (Energy Systems Catapult, 2016).

Several local authorities in GM have conducted feasibility studies that have shown long-term financial and carbon savings. Currently, there are six new heat network proposals and one improved existing heat network proposal (Greater Manchester Environment Commission, 2016; Farrell, 2018):

- Bury Town Centre
- Manchester City Centre/Corridor
- Stockport Town Centre
- Trafford (Manchester Ship Canal Corridor from Carrington CHP)
- Oldham District Heating Centre (re-investment/expansion)
- Bolton Town Centre heat network

Heat decarbonisation and the significant reduction in the use of energy for heating and hot water in buildings are key to achieving GM's heat decarbonisation targets. Over the next remaining years run up to the first initial 5-year phase of the WSSEP, GM will need to significantly accelerate the rate and scale of deployment of new energy generation. While a number of technologies can be used to decarbonise the heat sector in GM (as previously mentioned) this study considers the dynamics of governing the transition to low carbon heating with a specific focus on the role of DH and the pathways that enable the implementation of DH networks in cities. The following sections provides a detailed account of GM's strategy for the implementation of large-scale DH networks from a socio-technical perspective, using an inductive approach to thematic analysis of data to understand participant narratives from their own perspectives. The following sections presents the research findings drawn from the semi-structured interviews and discussions that were conducted with a diverse set of 20 key actors across GM. Section 7.3 provides a summary of the key themes.

7.3. Analysis and Findings: Key Themes

The results generated by the data analysis provided a deeper understanding of the perceptions of actors which captured the early-stage development and implementation DH networks in GM which aims to deliver increased energy efficiency and climate mitigation objectives. It also identified some of the key barriers and challenges associated with implementing DH networks in cities. In addition to the five key themes that emerged from the literature review of existing literature, some additional codes identified during the interviews where explored as subtopics under relevant key themes. The six key themes and the codes that emerged from the analysis of the semi-structured interviews are outlined in table 17 and presented in subsequent subsections.

Table 17: Analysis and findings table with key themes and the codes in each theme.

S/N	Main Theme	Code
1	**Implementation Strategy**	Strategic approach
		Commercial approach
		Public fund approach
2	**Technical Solutions and Heat Sources**	Gas CHP
		Biomass
		Geothermal heat
3	**Policy Instruments and Regulatory Framework**	Policy land scape
		Future policy
4	**Pricing and Consumer Protection**	Pricing and Consumer Protection
5	**Financial Instruments and Incentives**	HNIP HNDU Funding
6	**Challenges/Barriers to DH network implementation in GM**	Lack of DH skills, knowledge and resources High monetary cost and funding issues Policy and regulatory issues Technical challenge: poor technical and performance standards Lack of commitment, trust and buy-in Lengthy development and implementation periods

7.4. DH Development and Implementation Strategy

The study enquired about participants' knowledge of the DH development and implementation strategy in GM. This aims to address the first research question: What is the strategy for DH development and implementation in GM? What are the decision criteria and approaches used to develop DH in GM? This section analyses the history and context of DH development in GM. It explores the strategies that actors used to realize their aspirations for a DH implementation and the decision criteria that actors used to develop DH projects. It is important to provide this background because DH systems are characterised by their contexts. The three DH implementation strategies which were highlighted by participants during the interviews include the strategic approach, commercial approach and public fund approach.

7.4.1. Strategic Approach

Most participants highlighted that the strategic approach which identifies opportunities for DH use and the potential for the successful DH implementation to determine the optimal level of DH provision for a given area was the key strategy for DH development in GM. These include the use of socio environmental parameters such as the availability of low carbon heat sources and areas of high heat demand and fuel poverty alleviation. Participants believe that the strategic approach is a locally coordinated development approach which relies on strategic energy planning to coordinate a phased deployment of DH, with network expansion and increased connection occurring over time. DH projects that connected mixed demand portfolios with multiple low carbon heat sources, such as linking dense housing, commercial sites such as shopping and leisure centres with potential heat sources from industrial and waste heat sources, as well as thermal storage for balancing intermittent heat sources were mentioned by interviewees.

A view expressed was that heat maps could potentially provide an evidence base for long-term strategic DH plans across a district, as well as the potential to support niche empowering processes. Although heat maps were not being used to their full potential in the GM case study, some participants indicated that they had begun to use heat maps to inform planning policy for new developments. By incorporating the maps into planning policy, it was possible to connect DH planning to new-build developments, highlighting potential for expansion and interconnection with existing schemes. This strategy aimed to use new-build developments as a catalyst for network expansion in retrofit areas at a later date. Participants also stated that heat map data was used to inform energy master planning exercises for specific areas of potential.

> *''So from a greater Manchester's decarbonisation of heat plan. We're working with BEIS and AECOM on something called a City Deep Decarbonisation Plan (CDDP). That we will look at, where we need to strategically place DH networks of both high temperature and low temperatures, that includes ground source, shared loops, etc. And it also leads to look at how we're going to transition our building stock more generally, from gas, and fossil fuel powered heating through to decarbonize heat.'' (TS18).*

The issue of mapping and its role in high level strategic plans were also highlighted by TS1 and 11. Strategic planning for DH, focusing on new build planning policy and energy master planning for specific sites, proved difficult to implement in practice due to the absence of sufficiently strong planning policies requiring developments to implement DH. Consequently, DH implementation projects were primarily focused on social housing and public sector buildings with high heat loads and where local authorities had already established relationships with decision makers. In this approach the incentive to connect to a DH network is the promise of price stability, energy security, cost security, and cost predictability. This includes financial incentives, carbon reduction and health benefits as a form of environmental incentive, as part of the aspirations to achieve carbon neutrality as set out in the Greater Manchester Environment Plan. Participants identified the following strategic drivers and benefits for DH implementation in GM.

Presence of numerous high-density areas with high heat demand: GM is densely populated and, therefore, presents an opportunity for effective implementation of DH.
TS7 stated.

> *"And I think probably mainly, because of the density of the building. So you know, district heating is suited to high density building. And, and district heating is a kind of technological solution that can be deployed at a wide scale, you know, it can actually have quite a large impact on carbon emissions. I think Greater Manchester can see from other countries, mainly, you know, European countries that have successfully implemented district heating over many years that it can be a big success. And so I think that's why Greater Manchester is looking at district heating (TS7)."* This view was also expressed by TS9, who also indicated the possible integration of hydrogen in DH.

Heat Decarbonisation and Emission Reduction to Achieve the Net Zero Target: Participants TS16 and TS17 highlighted the significant role DH can play in decarbonising heat and delivering carbon emission reduction to achieve the Net Zero target.

> *''The key thing about DH networks is that they are, potentially a good way of actually saving carbon. And because everything for government is driven by becoming Net Zero carbon by 2050. As a country, we cannot do that unless we actually save carbon in terms of our use of heat, because heat accounts for 40% of the energy that we consume. And it has been deemed for a good reason, and a very useful way to actually save carbon within heat is to have DH networks'' (TS16).*

> *''I think it is largely down to the Heat Network Delivery Unit being set up and the background of the Greater Manchester Environment Strategy, I think, because of that document, they had the Tyndall Centre looking at possibilities to reduce carbon emissions, they had to look at the buildings and the heat energy'' (TS17).*

Environmental Benefits: As stated by TS16, DH provides the opportunity to deliver on a variety of environmental benefits that the government is committed to achieving as outlined in numerous strategy documents.

> *''The main driver, of course, is UK net zero target by 2050 as well as* ***GM 2038 net zero target*** *which has created these climate change agendas as well with the declaration of climate emergencies at local authorities. It facilitates a readily available pathway to national government's target to deliver net zero carbon by 2050, air quality improvement and climate change mitigation. It supports the 2008 Climate Change Act, GM Environment Strategy and the Clean Growth Strategy.'' (TS16*).

Energy security: *DH networks enable flexibility and security of supply that would not be possible without the DH infrastructure, due to the diverse range of heat sources that can be integrated with DH.* It also increases energy efficiency and security of supply by generating heat and electricity at the same time, making it less resource intensive, more efficient, and provides greater energy security. TS10 and TS12 emphasised that a significant impetus for DH implementation is to reduce reliance on gas and the need to have an alternative low carbon option in preparation for gas phase out to aid the transition to a low carbon economy.

> *''Gas is likely to be withdrawn from service. So the Committee on Climate Change is recommending that existing boilers should be phased out in the residential sector from 2033. Now, if that happens, what are those people going to do? The likelihood is that they would switch over to the air source heat pumps, which only have a coefficient of performance of 1 to 3. But if there is a heat network available, then they would be able to connect to that.'' (TS10).*

> *''Decarbonisation and energy security, because being dependent on fossil fuel imports, whether they're gas or oil is a risk as well as the carbon question, but risk in terms of security of supply and cost'' (TS12).*

Economic Growth and Development: Local authority desire to have an income stream to attract additional business to the area for increased job creation and to establish a commercial venture for economic growth and development was identified as a driver by TS1.

> *''The drivers include decarbonisation, building critical infrastructure, energy security, stabilizing energy costs, creating jobs and training opportunities, all the economic drivers really'' (TS1).*

Fuel Poverty Reduction: TS9 and TS12 highlighted that fuel poverty reduction is a key driver. According to TS12, one of the initial drivers for DH implementation was to reduce fuel poverty; however, carbon reduction and climate change mitigation are currently the primary drivers.

> *''The driver for actually doing heat networks was primarily focused on addressing fuel poverty. That changed it with the 2008 climate change act. And now the driver is carbon and climate change. So that is what is driving this, the government realizes that heat is an extremely difficult sector to decarbonize, they have thrashed around to try and investigate various alternatives, but it always brings them back to DH networks. DH networks in urban areas is the most cost effective and efficient way of reducing carbon in those areas. And so the policy driver is carbon.'' (TS12).*

> *''DH is one that the local authorities and national government can play a big role in delivering and benefiting from using it as a lever, as an opportunity to deliver other benefits such as, fuel poverty reduction and so on.'' (TS9).*

Availability of government funding for DH network projects: *TS9 stated that available government funding for DH networks has been a key driver for the growing interest and subsequent implementation of DH networks.*

> *I would say very much central government. And that is manifested through HNDU and HNIP funding that has been made available through both of those, I would imagine there has been some other incentives being offered to local authorities…. And fortunately, they put money up to get things moving. And we're seeing the benefits of that now is schemes that started through HNDU funding are now being delivered.'' (TS9).*

Participants generally agreed that these strategic drivers and benefits are the primary reasons that large-scale DH implementation is being explored in GM.

7.4.2. Commercial Approach

Several participants expressed views that this approach which identifies potential anchor load customers to be connected to a proposed DH network was a major implementation strategy endorsed by HNDU funding. It was expressed that a key criteria for accessing HNDU funding was that a feasibility study must provide evidence that DH was a viable solution which often involved the use of heat maps and stakeholder engagement to demonstrate the potential for commercially successful projects. Energy master planning and financial feasibility studies were conducted by consultants to identify opportunities in each area. The ability to generate a commercial degree of financial return on investment was used to decide which business cases were viable. Evidence of the potential opportunities could then be used to attract government funding and private sector investment from

DH companies to deliver DH projects. Participants believe that this approach helps to reduce the burden and financial risk on local authorities.

> *''Anchor loads are so important to making your networks. commercial anchor loads are really the thing that drives it. So we believe that public sector, commercial buildings should be mandated to connect to heat network zones, where zones are the best way to go. And we also support I think, mandatory connections on larger non-domestic buildings as well. So if there's big office blocks, big new developments, kind of commercial real estate going on, they should be eventually mandated or very strongly incentivized to connect to the heat network in the area'' (TS5).*

The vast majority of participants agree that the focus of this approach on increasing revenue generation through the implementation of profit-based DH networks has the potential to drive increased job creation and attract inward investment, which could ultimately drive increased economic growth and development at the local level.

7.4.3. Public funding and low-cost finance approach

TS2 and TS10 highlighted that available access to public funding sources to cover all or part of a project as well as local authority (LA) access to low-cost finance is a key strategy that has aided the development and implementation of DH in GM. Local authorities consider securing public funding to cover all or a part of a project's capital costs to enable a financially viable business model. This reduced investment risk for scheme developers while also allowing them to keep consumer prices low by removing the need to recoup capital investments through heat sales. Some of the sources of funding include Heat Network Development Unit (HNDU), DH Networks Investment Project (HNIP), Public Sector Decarbonisation Scheme (PSDS), Greater Manchester Low Carbon Fund, Public Works Loan Board (PWLB), Renewable Heat Incentive (RHI) and The Industrial Energy Transformation Fund (IETF).

> *''That strategy has been helping local authorities start to build up their capacity and expertise in developing DH networks through the heat network delivery unit, injection into the market of capital funding with Heat Network Investment Project and more recently announced Green Heat Network Funds (GHNF) to try to build expertise, get key projects off the ground, and to get the market going in the UK, in England or Wales more specifically.'' (TS2).*

''Public sector can borrow capital at 3%, the private sector has to pay 10%. So, in terms of having that focus management and ring fence budget with low cost capital, it sort of naturally leads towards a public sector approach.'' (TS10).

TS3 and TS19 believe that HNDU plays a critical role in funding and supporting projects by providing grant funding to LAs for DH development to develop interest in DH as well as connecting and sharing information among key stakeholders in local authorities.

''The Heat Network Development Unit within BEIS. So they are there to help DH networks get identified and develop effectively the idea of DH networks. So they will give money to local authorities to people like myself to sketch out the heat network and show that there is a viable heat network in a certain location, and then they can, then give you more money to design it. '' (TS3).

''HNDU and HNIP have been doing road shows, and obviously a lot of contact with local authorities really trying to encourage them to pursue DH feasibility studies.'' (TS19).

Essentially, participants unanimously agreed that the public funding and low-cost finance approach is a key strategy for establishing a solid foundation of sustainable funding for DH development and implementation for local authorities to deliver on the aspirations to decarbonise heat through the implementation of large-scale DH networks and the wider plan set out for GM within the target of a carbon neutral city region.

7.5. Technical Solutions and Heat Sources

Gas Combined Heat and Power

Several participants highlighted that gas CHP is the most prevalent technical solution in GM because it is the most cost-effective solution for DH schemes and provides the shortest return on investment due to the low price of gas, which is responsible for the commercially viability of most DH schemes. TS19 and TS16 identified earnings from electricity from CHP made the DH schemes a more viable investment.

''Currently it is gas CHP s just for maybe the first five to 10 years. The technical solution is having the infrastructure, which is the pipe works around all our customers, then the engine, which basically drives it does not really matter. …And CHP is perfect because I was saying the heat

element is so low in terms of profitable profits, you put the electricity and suddenly your margin gets a bit better for profit. So that is what we're doing currently. But we have got the deep geothermal and energy from waste plant which are really strong behind which at large scale will be really good as well (TS19).''

''*Gas CHP is often favoured because it delivered the shortest return on investment, and the most certainty is kind of like a very proven technology. But they were thinking about in the longer term, how the Civic court will provide like a central focus, central anchor. …Gas CHP was favoured because it delivered the shortest return on investment, and the most certainty is kind of like a very proven technology.''* (TS16).

TS16 noted that low carbon heat supply options will increasingly becoming an important criteria for securing grants and access to loans for DH network implementation in the near future as more funding schemes are now premised on low carbon sources and carbon savings. These include the Greater Manchester Low Carbon Fund, Public Sector Decarbonisation Scheme and the proposed Green Heat Networks Fund.

''I think there's going to be increasing move towards lower carbon heat networks in terms of what gets funded. And that's what we're seeing with the Green Heat Networks Fund, which should start in April 2022, just a successor to the HNIP grant scheme. So because we do find it is difficult to put together a business case for a low carbon heating network, in a standalone kind of way, in the same way that a gas fired CHP would be probably a self-funding solution. So we're still trying to get to a point where low carbon heat is like rewarded financially for being so but even in the budget this week, there's not really enough leverage and like taxes. incentives for like getting Green Heat, I don't think at this point.'' (TS16).

TS11 and TS14 believe that the best way to drive the transition from the widespread use of gas boilers to cleaner alternatives such as DH powered by low-carbon heat sources is to increase the carbon tax on gas to make DH more competitive. Participants noted that even though most new and existing DH schemes in GM are predominantly gas CHP, DH provides less carbon than individual fossil fuel powered building level solution such as gas boilers, thus providing both economic and environmental benefits, which is why DH has been widely used to alleviate fuel poverty.

''Parallel to that I do believe there is a need in the UK to indirectly support district heating and other solutions like heat pumps, by increasing the CO_2 taxation, to increase the costs of having a gas boiler in homes. The best way of driving people into something cleaner, which could be heat pumps, district heating, or other solutions, solar PV is to make it more expensive using gas. And so therefore, I would expect the government to increase the carbon taxation in coming years.'' (TS14).

TS10 also noted that DH is considered to be a no regret solution that can access multiple sources of heat and the heat source is not a major challenge as this can be switched to low carbon alternatives easily.

''DH can actually access multiple heat sources, both environmental and waste heat, that are not accessible at an individual building level. And so they've completely changed their tune. Essentially, there are five no regrets options, one is heat pumps in in rural areas, another is biogas, retrofit insulation, high standards for new build properties, and the fifth one is DH networks. So this means whatever happens in the future, you should be doing all of these things now and that includes the large-scale implementation of DH networks.'' (TS10).

In relation to imposing a high carbon tax on gas, an opposing view expressed by TS9 was that this could potentially affect the commercial viability of existing gas CHP DH projects premised on the cheap price of gas. Another key concern highlighted by participants was uncertainty around the policy change and its impact on business cases and existing schemes as well as the risk of changes to other regulations that are not necessarily directly related to DH but could potentially have an impact on DH implementation, such as the re-balancing of gas and electricity prices.

''There's also the risk of regulatory changes that aren't directly related to heat networks but could impinge upon them, for example, imposing a massive carbon tax on gas, would have a severe impact on quite a few projects''. (TS9).

TS1 and TS4 noted that Greater Manchester is exploring the recovery of heat from flooded coal mines to feed into district heating networks by repurposing abandoned coal mines is which has many opportunities and potentials to integrate with various energy technologies, sources and demands.

''We've got 23,000 abandoned mines across the UK. My role is to help to decarbonize heat using the water that's contained within our abandoned mines as a source of low carbon geothermal heat. …And then in Oldham, we've done a piece of consultancy work for them, so that's a much more detailed piece of work that says where the resources are, how you could

use it, and basically put together some ideas of where you might drill the bore holes that would be used to extract the energy sources for the heat network, which is in the water in the mines.'' (TS4).

The vast majority of participants identified gas CHP as the prevalent technical solution for new and existing DH networks. This is primarily driven by the relatively low price of natural gas and the use of natural gas for cogeneration of heat and electricity, which makes it the most cost-effective solution for district heating schemes with the shortest return on investment. Participants noted that most existing district heating schemes in operation in GM rely on the use of gas for cogeneration in order to be commercially viable.

7.6. Policy Instruments and Regulatory Framework

Participants noted that the DH network sector is currently unregulated in the UK, which means that DH customers do not have equivalent protections available to customers in the gas and electricity sectors and there are no technical standards, emission standards and broad measures supporting investment. TS5 stated.

''So the heat network market is currently not regulated, there is nothing within legislation or secondary legislation that regulates heat network, customer protection standards, technical standards or emission standards...'' (TS5).

TS2 and TS5 highlighted some of the proposed government policies in the DH sector which is being developed under the BEIS Heat Network Transformation Program and Heat Network Market Framework, which seeks to address the lack of regulation and statutory regulator, consumer standards, technical and environmental standards, and access to the energy ombudsman, which is an alternative dispute resolution mechanism. It also aims to give a clear compliance framework for technical standards for heat networks, as well as some assistance with decarbonizing DH networks.

''The Heat Network Market Framework, where BEIS consulted on last year stated intentions to regulate the heat network sector, and to appoint Ofgem as the heat network regulator, and to give them power over consumer protection standards, such that consumers can feel more confidence that they're going to get a good deal if they live on a heat network. And also said that we want to give them the same statutory powers such that the market can more easily develop the key infrastructure that they need for the heat networks. And then, further key policies against being the heat network zoning, designating areas in cities or towns where heat networks are the default low carbon heat solution, and trying to see whether we can compel

as many new and existing buildings to connect over time, I think it's going to be key to start to get market growth and market size and maturity'' (TS2).

TS2, and TS15 expressed concerns around the challenge of decarbonising DH networks as well as the operating cost versus environmental benefits, particularly how the proposed policy will seek to decarbonise the DH while being commercially viable, given that low carbon alternatives do not stack up financially in comparison to gas. This has been a contentious issue and a major source of disagreement and debate in DH policy development.

I'd say that's probably one of the main areas of disagreement from my perspective, and then the secondary disagreement or debate would be about the pace of decarbonisation in the heat network sector. You know, how quickly should we be pushing the new executive to transition away from gas boilers and gas, combined heat and power plants to low carbon alternatives?" (TS2).

''The biggest conflict and it's not unique, to DH schemes is operating costs versus environmental benefit or carbon saving. And the two, don't necessarily go hand in hand. The challenge you've got is that you can achieve significant carbon savings, but the operating costs to deliver that will be far greater than unfortunately, deploying conventional technologies. Now, until that changes, it's going to be very difficult for individuals and organizations to make that transition.'' (TS15).

TS5 noted that asides from implementing a high tax on the use of gas the rebalancing of gas and electricity prices could also incentivise the transition away from gas.

In general, most participants believe that the reform of carbon taxes and levies is critical to achieving a thriving decarbonised DH sector, however they were concerned about the impact of a high carbon tax on the business case and commercial viability of existing schemes as well as the energy system as a whole as this is a matter that touches on more than just DH networks. Also, while most participants were in support of some of the proposed government policies, such as the heat zoning policy and the BEIS Heat Network Transformation Program, which seeks to address the lack of regulation, consumer protection and pricing structure, as well as the lack of technical and environmental standards to accelerate growth towards a self-sustaining DH market, they were particularly concerned about the enforcement of the heat zoning policy which could potentially lead to policy and regulatory issues.

7.7. Pricing and Consumer Protection

TS9 and TS11 identified that significant price variations and the lack of consumer protection rights in the DH sector was a key challenge stemming from the lack of DH regulation and statutory heat regulator which has led to customers paying high prices and poor service provision. They also highlighted the inadequacy of Heat Trust which is as a voluntary scheme set up to address excessive pricing and lack of consumer protection due to the voluntary design and limitation to residential customers.

> *There's no legal framework for pricing. So for residential, there is this voluntary industry regulator called Heat Trust, as you probably know. And so Heat Trust has a calculator. And so you can put your postcode in this calculation, and it tells you what the fair heat price should be from the heat network. The Heat Trust provides a model, which you can use to compare your price of heat from your heat network provider, with what it would cost you if you had your own heating system. But again, it's not a legally applicable calculation, although you could use it to challenge the pricing.''(TS9).*

A number of issues were raised including actual issues with schemes that are technically deficient, resulting in numerous large heat losses and excessive expenses. Participants stated that this can be remedied simply by following good technical standards, which means having a well-functioning network.

TS8 and TS11 stated that issues relating to price exploitation and consumer protection issues is partly a technical issue as networks aren't well-designed, built, or managed effectively, and as a result, they don't operate efficiently, and customers are overcharged.

> *''This has been one of the problems for the last decade or so. So there hasn't been any consumer protection, and it's had problems. Because people were paying crazy money for district heating systems. So it's been a real problem and the industry knows that. There are real problems of schemes that are technically poor, so they have lots of big heat losses, and therefore the costs are too high.''* (TS11).

TS12 highlighted the pricing and consumer protection are often built-in agreement contract for some existing non-residential schemes.

> *''I don't think there is one on consumer protection as such. However, there are ways that contracts are built up. So heat supply agreements, to customers always include clauses about the responsibility of the heat supplier to the customer, and penalties associated with failure to deliver. So it's through legal contracts at the moment that I think most of the protection is appearing*.'' (TS12).

TS1 and TS6 also identified that DH network customers do not have the same regulated customer protections as domestic gas and electricity customers, which has resulted in excessive pricing and monopoly exploitation, as well as inadequate consumer service quality standards and a lack of competition in the sector.

> *''Then, as a consumer, you pretty much don't have much choice when you connect to a heat network, because you're stuck with whoever operated and you pay whatever they say, whatever you agreed to pay. So it's not like you can go to your switch and find a different operator.'' (TS6).*

TS19 noted that while there is no statutory DH regulator to set a DH pricing structure most DH schemes which are non-residential or not signed up to Heat Trust aim to supply heat to customers at 5 to 10% less than the gas price to order to attract customers.

I know some heat network companies say okay, we'll price for the equivalent of gas less 5% or less 10%. But it is difficult to do that when heat networks are so delicate in terms of their financial return anyway. But certainly, I've worked on projects where we, we started with about 10% or So okay, well, let's make it 5% as an incentive to try and attract people to connect into the heat network, you offer a 5% saving.'' (TS19).

One view expressed TS10 was that according to the customer satisfaction survey conducted by BEIS and CMA, most DH customers on existing networks were broadly happy and had bill savings compared to gas and electricity customers, but there were instances of exploitation and customer dissatisfaction due to a lack of regulation and accountability.

TS12 highlighted that the direct comparison of the DH heat network heat price to the price of gas for a gas boiler does not take into account the actual cost of the gas boiler, annual maintenance costs and the cost of replacing the gas boiler when it breaks down and that the price of heat for a DH network includes these costs, which is why it should be viewed as a service and explained to customers.

> *''So with your gas boiler, the bill you get in the post is just for how much gas you've used. You don't factor in, annual maintenance, you don't factor in how much it's going to cost you to replace your gas boiler when it breaks down. The heat network bill has all that priced in.* '' (TS12).

Most participants noted that the lack of pricing structure and consumer rights protection consumer service quality standards in the DH sector that exists for other utilities in the water, gas and electricity sector has resulted in excessive pricing and monopoly exploitation in the DH sector, which is largely responsible for the lack of commitment trust and buy-in of stakeholders experienced in the DH sector. Participants generally agreed that this can be addressed by the implementation of a DH regulation and the appointment of a statutory regulator.

7.8. Financial Instruments and Incentives

TS15 highlighted that the financial instruments and incentives used for the implementation of DH networks were primarily government funding and incentives through capital and grant funding as well as low interest loans such as ELENA *funding* (European Local Energy Assistance) ,HNIP, HNDU PWLB, *PSDS.*

> *"So historically, they were financed via Elena funding, which was European Investment Bank. And, and if we didn't have that money, we wouldn't have done what we've done. So that's the first thing there. So most of it has been funded by grants funding, external, European or national grant funding. Without that, I don't think most of the heat networks in the UK would have come forward.'' (TS18).*

TS10 highlighted that available government funding through HNIP, HNDU and low interest loans (PWLB) has helped reduce investment risk and incentivise DH.

> *''Typically, these distribution technologies similar to other infrastructures, give a relatively low return on capital. So the Internal Rate of Return the IRR, we call it is usually in a healthy one, somewhere between about 3 and 8%. … Now, commercial organizations seek to recover or seek to get a return on capital in excess of 10% in order for them to meet their costs, but also make a profit. And so, you know, that if they can go to the bank and borrow money is that they're looking to get a return of 10% in order to meet what they call their hurdle rate. In fact, it's, it's generally higher than that, but let's say 10%. Local authorities, on the other hand, can borrow money through what is called the Public Works loan board at 3%. So if they can borrow money at of range between 3 and 8% It can happen.'' (TS10).*

TS18 noted that securing capital funding for feasibility study was not a huge challenge; rather, obtaining a development fund to progress DH projects through the design and construction phases was the significant challenge.

> *''And I think if you've got the right project, and this is irrespective of heat network, or solar farm or whatever, if your project is robust enough, we can finance pretty much whatever we want it putting it bluntly, that finding the money is not that difficult thing. It's finding the money to do the development. So the dev x. So taking it from concept design, to detailed design is where there's a problem, because a lot of these projects are huge network projects, don't make it beyond feasibility study. So that's, that's dead money, you're not going to get return on that. And that's where the challenges, capital funding very easy to get hold of development funding, challenging.'' (TS18).*

TS1 and TS2 were particularly concerned that government funding was primarily targeted at the public sector and that DH schemes are not commercially viable without government funding due to high capital costs, a lack of DH regulation and associated risks. It is believed that continued government funding without third party or private sector investment could potentially affect the growth and development of a mature and self-sustaining DH market.

Many of these projects are financially marginal, and really not attractive enough for the private sector to invest in. And that's where government grants come in, to tip them over into, into viability. However, the government subsidies seem to be aimed mainly at the public sector. And I think that's probably because it's cheaper for the government to give the subsidies to the public sector, because the public sector doesn't require the same rate of return as the private sector.'' (TS1).

''So, I think the major objective has been to develop the heat network sector into a more mature and self-sustaining market. And the main aim of government funding is to try to get the heat network market on a self-sustaining trajectory, so that we can reduce government support for it while enabling the right market conditions for growth.'' (TS2).

TS2 expressed concerns that acquiring funding through private investors was an issue because of the low financial return DH offers as well as the risks associated with lack of DH regulation as a result potential investors are often have low appetite to invest. BEIS has attempted to address this issue by establishing the BEIS Heat Network Investment Vehicle (BHIVE), which aims to connect DH projects with potential investors.

''…one success recently has been the launch of the BHIV. So the BEIS Heat Network Investment Vehicle, so this is part of our heat network investment project. And this is kind of a digital area where we can match, heat network projects with institutional energy investments in a way that facilitates investment in key in heat networks and projects. So we certainly see that as hopefully the beginning of more significant third party investments in heat networks. But then it's about ensuring as well that we create a secure market for those investors.'' (TS2).

A view expressed by TS12 was that list of potential investors provided by BEIS through BHIV has not yielded much actual investment as most investors are often not interested because of the low return on investment and associated risk of implementing DH projects created by the lack of regulation.

''There is a real problem in terms of funding, because these schemes don't actually make much financial return. And then for the funders, who fund infrastructure projects or renewable energy projects, these companies typically would just look Europe wide, or they'll look even globally. So they'll say, well, you know, shall we invest in this heat network scheme in Trafford Park, or shall we invest into a solar farm in Spain, they don't have to invest in in your heat network, and the alternative for them as well, the solar in Spain could actually provide a much higher return. (TS12).

While most participants acknowledged that available government funding through HNIP, HNDU, and low interest loans (PWLB) has helped reduce investment risk and played a role in driving the implementation of DH and incentivizing DH for LA-led schemes, they also pointed out that there was no provision for government funding and low-cost finance for private-sector-led DH projects, which has contributed to a lack of third-party investment in the DH sector. Some participants were also concerned that the procedures for obtaining government financing were too burdensome, which discouraged its use.

7.9. Challenges of DH Network Implementation in GM

This section discusses the additional theme that emerged during the data analysis which was not included in the MLP analytical framework structure. These include the key barriers, challenges and gaps in provision limiting the development and delivery of DH in GM. Participants identified several challenges, risks and barriers associated with implementing DH network projects in GM, which are noted in Figure 48 below.

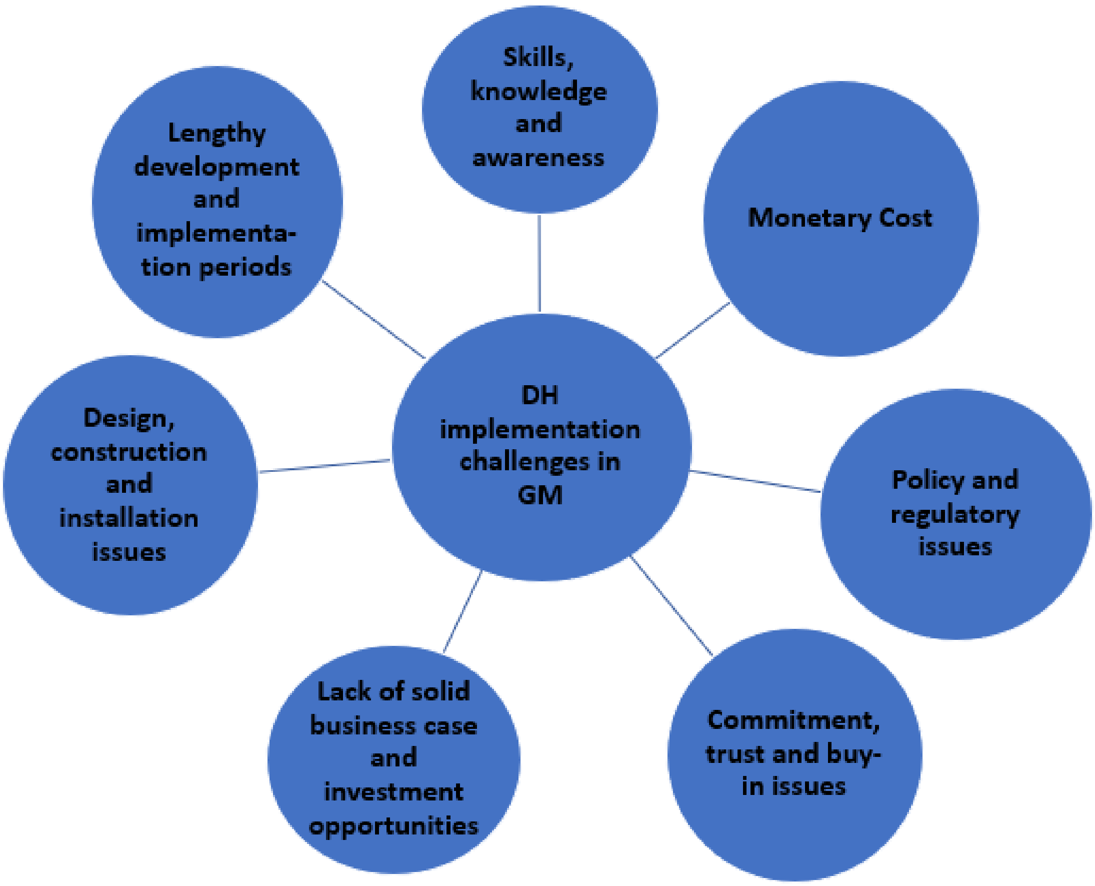


Figure 48:Challenges associated with DH network implementation in GM

This theme could not be explored in the secondary case study cities because DH is widely successful in the Scandinavian cases with documented evidence, as such there was a lack of data on the barriers to DH network implementation in the Scandinavian cities. Largely, participants believe that the perception of risk and threat to DH development and implementation is very high and some of this reasons provided are presented in subsequent sub sections.

7.9.1. Lack of DH skills, knowledge and resources

TS10 and TS14 expressed a lack of widespread DH skills, knowledge, resources and experience in terms of the required skills to design, install, and operate DH networks particularly in local authorities as a major concern which is largely due to the small community of DH practice in the UK as DH currently provides 2% of UK heat demand.

> *" The technical skills in terms of design, operation, maintenance, but also the skills in terms of procuring, managing and operating these systems, there's just a very small number of people within the UK that that have those skills. This is an issue that government, both the Scottish*

*and Westminster government are keenly aware of, and let's like, group them together in what we would say supply chain issues, because it's not only the hardware in terms of the kit that you need to put in the ground, but also the soft tissues in terms of skills to be able to design, install, and operate these networks. This is because we're starting from a low base of only 2%.'' (*TS10).

To overcome the skills gap and achieve 20% of UK heat demand from DH by 2050, TS14 identified some of the trainings, reskilling and occupations necessary to successfully implement a DH network project from vision to operations by training about 100,000 people over the next 7 years. These include training on DH project delivery management, heat network development management, engineer master planning, system control, as well as positions such as legal and financial specialist, and operations and maintenance technician.

"So there will be need for lots of training going forward in terms of developing both the vocational skills, not just the vocational skills in welding excavation, installing electrical equipment, heat pumps and so on. But also the professional skills in strategy, program management, digital solutions, financial planning and so on. We believe that will be a need to train 100,000 people in the next six seven years. To give the UK is chance to reach the 20% market share objective of District energy by 2050.'' (TS14).

TS1 and TS18 identified a lack of local authority capacity and resources to undertake early intermediary activities and establish a common understanding of the benefits of DH as a significant barrier to progressing through the development stages of DH implementation. Highlighting concerns about the limited knowledge of DH implementation compared to gas boiler, a lack of adequate capacity to carry out DH projects, and the burden of taking on DH projects without adequate staff resourcing in local authorities.

''*The availability of officers to actually work on these projects, local authorities are very stretched at the moment, under pressure financially, and, you know, don't have much capacity to actually put into developing this type of project.''* (TS1).

A view expressed by TS9 is that the DH technology as a heat supply solution is not the problem as DH is a well-established technology, it is believed that the lack of DH skills, knowledge and experience is the major challenge in GM.

Technically, all of the equipment and solutions that you require exist, and they're well proven. So in essence, they're not the problem. I think if you're looking at a project, like the one in Manchester, we are putting a building and an energy centre, in a very sensitive part of the city, *which required the designing and build of a very iconic and unique energy Centre. You're also putting pipes and cables through congested city streets, which they are full of services, and then also unknown things you encounter, like sewers, that people didn't realize existed, or abandoned water mains, and things like this. So the challenges are really around, building it in the real environment.'' (TS9).*

TS9 noted that a lack of DH expertise in local authorities contributes significantly to driving up the cost of implementing DH projects, and if the industry was confident lessen the technical errors in the design, construction, operation and maintenance of DH networks.

The lack of procurement experience in local authorities for this type of project and the lack of legal and financial expertise in local authorities is a major challenge, because they have to hire in external consultants which are expensive.'' (TS9).

TS6 highlighted that if the industry had been confident that the demand for DH expertise would increase significantly, it would have established training institutes to train more people in DH skills in order to avoid cost increases as the market develops.

''I noticed that there is currently a shortage of welders capable of welding district heating section steel pipe together, which, along with a few other factors, is driving up the cost of building district heat networks. If the industry had been confident that the step change in demand would occur, it would have trained more people in that skill. And we would not see that increase in costs, because, logically, the costs should decrease as the market expands.'' *(TS6).*

Due to the fact that DH merges three functional aspects of the energy system which include: generation, distribution and demand, TS18 noted that supply chain issues and the shortage of core DH skills puts a lot of pressure on DH companies to offer the services they require themselves.

''There is a shortage of required core skills and there is a shortage of supplies into the supply chain for companies that are looking to implement, they're typically have to do things themselves. So it puts a lot of demands upon an organization to grow to a level that they can provide all the different services'' (TS18).

TS10 expressed concern about the danger of expanding DH in the face of a skills shortage, which could lead to supply and demand issues, as well as cost increases. Another concern raised is that a lack of essential skills could lead to poor network design and maintenance, resulting in project failures that could damage the technology's reputation and undermine stakeholder confidence in DH.

'' The danger for them is that, if DH expands too fast, you'll have more demand for those skills than is available. So, consequently, that will put up the price a classic case of supply and demand situation, but also, there is the danger, that these things will be poorly designed and maintained, leading to failures of the technology, which will undermine customer confidence.'' (TS10).

TS17 highlighted that the private sector had more DH skills, knowledge and expertise, which is critical in bringing additional expertise and experience to the DH implementation process, TS17 and TS8 expressed concern that some consultants were bidding on work for which they lacked the necessary expertise. This could limit the DH potential to contribute to delivering decarbonisation in the heat sector, which in turn could reduce the achievable level of energy system decarbonisation by 2050 which is why much of the DH companies prefer to work with consultants from the Scandinavian countries who have a wealth of DH knowledge and experience.

"We went to Scandinavia, because that's where these people have been doing since the oil crisis in the 70s, in essence, and we went to specifically in in Sweden, and we started working with some operators, so municipality owned district heat network to understand if they were to start today, what will they do on the basis of what they know, but not necessarily for us to replicate that but to actually look at what are the pitfalls what we should not fall but also leapfrog by still starting using the best available technology of today because as you understand these infrastructure projects, when you put the pipe especially into city centres under the highway, you want them to be there for at least 50 years.'' (TS17).

''Technical consultants focus on the designs, but they don't necessarily have the skills to build, operate and maintain DH networks.'' (TS8).

In general, most participant believe that local authorities were overly reliant on national government assistance to address resource and skill gaps, and that national government support mechanisms aimed at addressing some of the challenges faced by local governments did not appear to be achieving their objectives. TS8 noted that while HNDU funding was intended to address the lack of expertise in local governments, however, the focus is limited to consultancy expertise, rather than developing internal local government capacity and expertise. This was mentioned as a key barrier to the development of a strategic approach to DH.

7.9.2. High monetary cost and funding issues

Examining the costs of implementing DH projects, revealed varying perceptions about the investment risks due to high upfront capital cost and long payback periods. Most of the participants stated that a major barrier to DH implementation is the significantly high upfront capital investment costs as well as the high cost of feasibility studies required in advance of any financial return from energy sales. This is believed to be further exacerbated by the uncertainty of securing long term heat supply contracts with key anchor load customers, as well as the low return on capital DH provides.

TS16 identified low cost of implementation alternative heat supply options such as gas boilers compared to DH as a major barrier to DH implementation.

> *'At the moment heat networks lose a lot, as projects don't stack up to get ahead to become a real project from the outline basically because they don't stack up, they appear to be very expensive, the levelized cost of energy efficient low carbon DH networks compared to individual gas boilers or centralized gas boilers solution never make sense economically, because gas is very cheap.'' (TS16).*

TS9,TS11 and TS19 identified the high cost of funding a DH project as a key barrier to DH implementation and the fact that the cost cannot be recovered if the project does not progress to implementation and operation stage as well as limited funding availability.

> *The cost of developing these schemes up to the point where you procure and deliver them is very high. And it has to come out of a revenue account. If you take the total capital cost of a project, then the development cost is going to be at least 10 to 15%. So a 20 million pound project could be to 2 million pounds worth of development costs. Just because they are they are complex, legally, financially complex in terms of getting all the modelling done. It's an expensive business.''* (TS9).

TS19 further elaborated that monetising the benefits of DH was a way to overcome the high cost of DH implementation barrier which could then lead to opportunities for the LA to sell some of the equity and shareholding to get more financial returns

> *…unless you monetize the benefit to society of the CO_2 reduction, the emissions reduction, and there are formulas for doing that. So when I talked to local authorities about the social net*

present value and the social financial return, not just the financial return. And that gets some traction. I suppose in terms of trying to encourage them to actually adopt heat networks scheme, and once you've got your first phase of your heat networks scheme it becomes easier to extend it and then once the whole effects operational you would be on the construction stage, then it's all deemed to be a lower risk investment and there is opportunity for the local authority to start to sell some of their shareholding, some of their equity, to pension funds, whatever, and get a more pleasant financial return out of it. But they got to get through the pain of the construction of the first phase, become successful operational start to look at extending.'' (TS19).

TS17 identified the lack of LA understanding of how to secure government funding as a key barrier to obtaining finance for DH projects.

''HNDU funding it's there for everybody to tap into. And there's a clear direction of travel to utilize it. I think that the issue becomes the fact that people in the local authority don't understand it. And because they don't understand it, the risk, they play a higher risk value. Now, if we had more parties that understood it and could champion it, then there's a likelihood that more of that HNDU funding will be utilized. So the risk will be lower.'' (TS17).

TS6 expressed concern that local authority access to loans with low interest rate has helped to reduce the investment risk on LAs, while the private sector, which possesses substantially greater DH knowledge and expertise and can play a significant role in widespread DH implementation, does not have access to low interest loans. This is believed to be a major reason why private sector developers prefer to implement building-level solutions such as electric radiators, immersion heaters for hot water, individual gas boilers or centralized gas boilers, which are less expensive and much easier to implement.

The private sector has got a role to play, but it just simply can't do this, because of the high cost of capital, because for a private sector developer of a new housing block it is cheaper to put small electric radiators and immersion heaters for hot water in each.'' (TS6).

High development and operational cost

TS11 and TS12 highlighted the high cost of digging up the ground to install DH connection pipes, as well as the significant risks of not knowing what will be encountered in the ground in urban areas despite the use of ground survey technologies, and the risk of affecting other existing utilities in the ground, as major concerns that may drive up construction costs.

You literally do not know what you are going to find, when you start digging up the ground and how much those cost sides is different from a construction site, a construction site, very confined area, typically, you've got very good intelligence about what you're going to find and the problems you're going to encounter.'' (TS11).

TS12 also expressed concern that the high upfront capital development cost of implementing DH networks is unlikely to change due to the need to dig up the ground which could potentially have many obstacles in densely populated areas which are best suited to DH.

We have a very dense urban landscape underground. And so putting pipes in the ground is incredibly expensive. It's not particularly difficult, digging a hole and putting a pipe in it. But when there are lots of obstacles in the ground, then that creates a technical challenge, but most importantly, it's a commercial challenge because every extra hour you spend on every piece of pipe adds significant costs to the installation...'' (TS12).

TS12 highlighted that the perception of risks and threat to DH implementation is very high, which is why most schemes were implemented with the use of public money, and implementation is unlikely to occur without the use of public money due to the high monetary cost of construction and lack of solid business case and investment opportunities to attract private investors.

''The risk and threat to DH implementation is very high, because of those factors again, there isn't a scheme that would work without public money, or I say, there isn't a scheme, most schemes wont. There are some schemes that should be able to work if you've got a virgin development site, and you know, what you're going to build. And you know, from the beginning, that you're going to be laying a district heating scheme, and that everybody is going to be connecting to that scheme. There's no reason why that shouldn't be commercially viable. But the moment you dig up an existing town or city, then you've not got a chance of making it without public investment.'' (TS12).

TS6 and TS19 also mentioned that the lack of a well-established DH market, which leads to supply chain challenges and high material costs, as well as lack of reliable information/uncertainties regarding the actual cost of building a DH network as a key challenge which can be addressed by the appointment of a statutory regulator.

''For supply chain the main thing would be the cost of materials now.'' (TS6).

"…just having recognized cost figures [and] recognized contracts, it would be good, I think to have a formal regulator for heat networks, which is meant to be Ofgem, but it has not gone through Parliament yet. That will make things more recognizable and mainstream, and in turn will encourage other people to connect to heat networks….'' (TS19).

Participants generally agreed that a key barrier to DH implementation in GM was the high monetary cost of implementing DH networks and access to capital and development fund. Participants believed that the high cost of DH implementation was largely due to the need to dig up the ground, a lack of a robust DH market, and the shortage of DH knowledge and expertise which gives rise to the outsourcing of all aspects of DH implementation from feasibility studies to operational stage to expert consultant which is often expensive.

7.9.3. Policy and regulatory issues

A vast majority of participants stated that lack of powers to implement strong planning policies such as heat mapping and heat zoning policy in local authorities was a key challenge, even though they recognised the potential of planning policies, their implementation was not always deemed successful or viable in the absence of national / local DH network planning policy measures and lack of DH Regulations to support customer acquisition and buy in of investors.

DH network planning policy/heat zoning policy

TS11 and TS2 highlighted that acquiring customers and persuading potential customers to see the benefits of connecting to district heating is a key challenge that poses a huge risk to DH implementation. TS11 and TS2 both agreed that this barrier can be overcome by regulation, highlighting that the implementation of a heat zoning policy could potentially enable greater DH take-up and expansion which the government has committed to investigating in the Energy White Paper.

''In the Energy White Paper, the government committed to, looking into a heat zoning policy. And what that policy could do is it could enforce people in a certain location to connect to a heat network. And what that would unlock is the risk of building a system and not having customers. Because it means then if you build a network, then people are forced to connect, and they're forced to stay connected in theory. And that then gives you the revenue stream. … This is why heat networks start quite small and end up in some cases staying quite small, expanding heat networks to the scale that we see in Scandinavia has been that risk of customers connecting to the heat network and a heat zoning policy would solve that.'' (TS11).

Lack of a clear policy position on DH

TS1 and TS18 identified the lack of a clear policy position mandating the implementation of a DH network where appropriate is a key barrier to DH implementation; it is effectively up to market forces and potentially planners to determine whether or not one should be in place. TS17 further highlighted that the policy needs to be clear and supportive to enable DH implementation.

> ''*There are certain elements of the National Planning policy that make it challenging for GM to enforce or put in stricter measures. So for instance, in GM, we want to go faster but National Policy doesn't permit us to go faster. So we are constantly lobbying along with others to be able to set heat zones. So to go to set a zone and say that has to be a heat network or that has to be a particular technology or solution, because we've done, we understand the area, we understand what's right for the area. And equally, we understand how it benefits our low carbon aspirations. But we can't do that I'm afraid.*'' (TS18).

> *The policy needs to be very clear, and very supportive to allow the things to happen.'' (TS17).*

An opposing view expressed by TS19 is that the untimely introduction of a National Planning Policy could lead to implementation failures and supply chain issues due to a lack of a well-established DH market, which is believed to be the reason BEIS has introduced different requirements is to try and grow the SME market and to create market capacity funding for DH networks.

> *''I think it would be helpful if there was national policy, I think maybe what government's been concerned about is if they bring in all the requirements too soon, that actually the supply chain, the SME market or the private sector market, won't have enough resources in terms of capacity to produced pipes, heat pumps, enough technicians to actually install them, the amount of companies to actually run the equipment etc.... So they're sort of relying on certain cities to do, or towns to do their own thing that starts to grow the market in terms of resources, etc. And then we'll get closer to the point where there will be this regulation, there might be National Planning policies that you have to connect to a heat network if there's a network in your area. But undoubtedly, it will be helpful to have national policy. But at the same time, we need the market to be providing, as I say, financing people and skills and all these things sequentially.''* (TS19).

Another opposing view expressed by TS19 as regards having a heat zoning policy was that mandatory connection to DH networks could create a bad reputation for DH.

> *''I think there is a risk also in saying we're going to enforce mandatory connection to DH networks, by saying people must connect to this district heating. It's against the mentality in the UK. And it could create a bad reputation around district heating, if that happens.'' (TS14).*

Lack of DH Regulation and statutory regulator

With regards to regulating DH, TS2 and identified the lack of DH regulation and statutory regulator as a key barrier.

> *''So not having a DH regulation and a statutory regulator is a big barrier, in terms of like future implementation of policy.'' (TS2).*

TS1 and TS12 highlighted that the DH sector should be regulated to reduce risk, sets a consistent standard across the country rather than having local variations, to provide certainty in the DH sector and to prevent monopoly exploitation owing to the monopolistic nature of DH.

> *''Yes, DH should be regulated. It is important based on the principle it is a monopoly supply. So customers need assurances about the reliability of the heat network. And whether that's matching up to their expectations, as well as things about prices as well as carbon factors for heat delivered. So I think, if it's done at a national level, then at least that sets a consistent standard across the country rather than having local variations, according to local planning conditions. So for a company like ours doing projects around the country, it is important to have kind of nationally agreed standards if we can.''* (TS16).

TS9 identified a lack of equivalent statutory rights that exists for other utility developers such as gas and electricity as a key challenge during DH construction in terms of acquiring way leaves to install pipes in the ground. highlighted that DH regulation could be used to overcome this challenge to make DH implementation easier.

> *''From a delivery point of view, you can have issues in getting way leaves to put your pipes and cables in the ground. Now, if you're a statutory undertaking, like electricity company, or gas company or the water companies, you can get the way leaves agreed far more easily....So you'd want equivalence with statutory undertakings that already, exists with other utilities.''* (TS9).

TS10 and TS11 identified that DH regulation would help provide assurance to customers, and gain their confidence around price, customer protection and quality of service to support the heat zoning policy as well as reduce risk by bringing down the return on capital that is required by investors which will make the sector more viable.

> *''DH needs to be on same level playing field as other ways of actually distributing energy. And that will then give customers connecting to a heat network confidence that their interests are being protected. And that will principally be around price and quality of service. So that, if*

there's an interruption, or kind of disconnection from supply for some reason, that that they have recourse to compensation, and so forth.'' (TS10).

''.. Because if you're saying you have to connect to something, mandating connection, you can't force them to connect to something that's, not going to work properly or cost too much, or they've not got any kind of protection against things going wrong, etc. So I think what we have at the moment is weak, albeit that the industry has tried to put this voluntary scheme in place the Heat Trust and it's been successful. What will happen is mandatory regulation, similar to other utilities, will have to be put in place.'' (TS11).

An opposing view expressed by TS14 regarding DH regulation is that DH in GM / the UK should not be based on a regulatory framework to drive up DH implementation, but rather it should be based on lowering the cost of building it, through DH training and skill acquisition, commissioning more DH projects to build DH experience and developing a competitive supply chain over time and by placing a requirement for densely populated areas and new builds to be connected to DH networks through the implementation of a heat zoning policy.

No, I don't think so. I don't think you should build up a model, which is based on the regulatory framework, I think the challenge for district heating in Manchester or in other places, is the cost of building it is currently too costly. And as I said before, you need to learn to build this in a cost efficient way. And that is about training. It's about experience, but it's also about having a competitive supply chain of technologies.'' (TS14).

TS2 identified a lack of investment policy that incentivises third party investment as a key barrier to private sector investment in DH. Highlighting that BEIS is looking to address this by introducing the BHIVE, but also recognises that providing confidence to investors through regulation is a critical step towards driving third part investment in the DH sector.

''I would say investment policy is an area we need to make more progress on. …. So we certainly see that as hopefully the beginning of more significant third party investments in heat networks. But then it's about ensuring as well that we create a secure market for those investors.'' (TS2).

The vast majority of participants agreed that the most significant barrier to DH implementation in GM was a lack of strong policy and regulation, which exposes the DH sector to several risks and challenges.

7.9.4. Technical challenge: poor technical and performance standards

Poor technical, and performance standards in both new and existing DH networks in terms of poor quality DH design, construction, operation, and maintenance was identified as a key barrier to successful DH network implementation. This challenge is closely linked to the lack of DH skills, knowledge, resources and experience in implementing DH projects.

TS15 identified technical difficulties building compatibility with DH networks due to the prevalent high heat temperature requirement in existing buildings and low heat temperature requirement in new buildings as DH networks are often best suited to buildings with high temperature requirements and heat pumps to buildings with low temperature requirement. Despite the fact that high temperature heat networks are more expensive to build than low temperature heat networks, the high capital cost of DH often rules out DH as a viable solution for new builds.

> *''The main technical difficulties or challenges are existing flow return conditions of the heating systems within the individual buildings, as some buildings operate at relatively high temperatures, which then limits the technologies that can be deployed to provide that primary source.'' (TS15).*

> *''However, due to the fact that many buildings in the UK are very poorly insulated, they require high temperatures. And building high temperature heat networks is more expensive than low temperature heat networks.'' (TS14).*

TS18 and TS14 identified the risk of pipe installation in the ground affecting other utilities as DH construction requires the installation of pipes in the ground which can affect existing subterranean utilities such as pipes and wires for gas, sewage, freshwater, telecommunications and electricity systems and can also impact traffic and convenience for residents.

> *''The big technical challenge is to put the pipes in the ground in existing cities, which are very dense in their character. So district heating involves digging trenches and putting pipes in the ground. Unless you do that, you can't build district heating so that will have a big impact on during the building period it will have an impact on traffic and other convenience factors for the residents. So that I would say is the biggest technical challenge to get the pipes in the ground quickly.'' (TS14).*

TS5 and TS17 highlighted the poor design, performance and technical standards in existing DH networks, which has resulted in excessive heat price for consumers and a bad reputation for DH, which BEIS is currently looking to address.

And suddenly all these losses, inefficiency of the system, the operator is still paying for them, and is not going to want to take that from their bottom line, which might actually make them not profitable. So they pass down to the end users, and the end users certainly pay for something which is way more than what they thought it will be because it wasn't designed maybe efficiently, it wasn't installed properly. And it's not been operated and maintained properly. And this is why I think a lot of district networks have got bad names because people think that certainly it's going to cost more almost on standing charge.'' (TS17).

Several participants acknowledged the role of industry representatives in developing the CIBSE Code of Practice for the UK document which aims to address the poor technical and performance standards in the UK DH sector. The Code of Practice provides a set of standards to ensure high quality in the design, build, operation, and maintenance of DH networks as the successful DH implementation requires proper planning and design considerations.

In respect to the last Chartered Institute of Building Services, Engineers CIBSE, that they have instituted a technical manual to help improve the skills of the existing engineering fraternity, and I happen to actually sit on the committee, that, that oversees that particular initiative. So there is a real risk, the government recognizes that risk, and it is endeavouring to manage that risk, but also intervene to address that risk.'' (TS10).

''There is a training course that goes to the Heat Network Code of Practice document as a technical standard for heat networks… it's a pretty key document. and it's been developed by most of the of the key people in the in the industry, and it's hoping to drive up sort of technical performance standards of heat networks.'' (TS11).

TS7 highlighted that DH the consultants, engineering, consultants, designers and contractors have a significant role to play in ensuring that DH networks are properly designed, built, operated and managed to deliver energy efficiency and environmental benefits at a low cost.

''Starting from the consultants, engineering, consultants, designers, contractors, the main role, we all have to place to make sure that we don't sell unicorns to be honest to the client or to local authorities and to provide good and robust designs. So everything from a good design and a good installation then gives a well performing project, both in terms of economical and efficiency measures.'' (TS7).

TS7 identified a lack of technical expertise and resources with regards to DH network implementation in LAs as the key technical challenge.

> *At the moment, I believe the issue is viewed as a technical issue. There are lots of people who can design, supply the parts, and install them. The challenge is simply how to get it all started, and for one thing, local authorities lack the technical resources to do it. And I believe they would benefit from a lot more support. (TS7).*

A concern expressed by TS17 was that the CIBSE code of practice CP 1 document provided details on how to conduct feasibility studies but was inadequate in providing detailed information on how to construct, operate and maintain DH networks. This is believed to have contributed to the lack of continuity following the feasibility study as well as the challenges and risks associated with DH implementation which includes the lack of regulation in the sector and lack of expertise on how to execute DH projects.

> *Another barrier is the skills, the know-how and the strategic view about how these systems should be designed, constructed, operated and maintained. And it's very interesting. I've been on the CIBSE course, when they launch the first CP one, the code of practice for DH network that was about five or six years ago, obviously, the new one has been revealed, not so many weeks ago. And what I will say about that is it's great for feasibility studies is a really good document, it helps really to kind of shape the thinking of people. But when you look at the different aspects and the different chapters, when you look at construction, operational and maintenance, it's probably a 10th of the wall practice book, because everything is focused on currently on the design and the feasibility, but not on the construction and operational manner.*'' (TS17).

Participants generally agreed that a lack of widespread technical expertise on how to successfully implement a DH network project from vision to operations in terms of how to design, build, operate and maintain DH networks was a key barrier to DH implementation in GM. It is believed to be responsible for the lack of continuity of most DH proposals to implementation phase following feasibility studies.

7.9.5. Lack of commitment, trust and buy-in

A vast number of participants cited a lack of commitment, trust, and buy-in from stakeholders as a major barrier to DH implementation in GM, emphasising the fact that the success of a scheme is dependent on having the commitment, trust, and buy-in of stakeholders in order for a project to be viable. Reputational barriers stemming from the experience of DH customers on poor performing networks in terms of lack of pricing structure and protection for consumers, as well as the difficulty experienced by DH developers in delivering existing DH projects were also mentioned by participants. Also, the lack of DH awareness and support, as well as the general perception that DH schemes are difficult to implement and do not provide good value for money and there are/will be much easier low carbon alternatives such as hydrogen or heat pumps which is believed to pose a barrier to private sector investment in the DH sector. Some of the concerns/ challenges raised as being responsible for the lack of commitment trust and buy-in include.

TS10 highlighted the improper comparison of DH networks, which are capital intensive and significantly more complex to implement, to gas networks, which are well-established, less expensive, and easier to implement, which will cease to exist as a key barrier to the implementation of DH networks.

> *Because of the incumbency of the gas networks, the heat network industry, through the ADE Association of Decentralized Energy, set up the Heat Trust, to provide a form of regulation. So, they have a comparative tool, which actually looks at the cost of heat, relative to the price of gas, now, this is going to be a complete nonsense, because gas is going to be gone. So, you know, you're comparing it against something for which that particular competitor will no longer exist. So, consequently, they have to change.'' (TS10).*

T11 and T12 identified the low cost of gas boilers, ease of implementing gas boilers compared to DH and the relatively cheap price of gas as a major challenge. As such, DH powered by low-carbon heat sources struggle to compete with gas powered systems due to the comparatively low price of gas as a result of the low tax rate on domestic use of natural gas in the UK.

> *''At the moment, gas boilers are very cheap. And it is a difficult market then for both heat networks and air source heat pumps to be fair, they both struggle. The problem really is what you're trying to compete against. And what we're trying to compete against with the heat network at the moment is too difficult, because gas boilers are really cheap, to buy really cheap to maintain really cheap to replace, and gas is really cheap. So unless they solve that, then we haven't got an alternative, which is offering somebody something better in terms of bill and carbon savings. ''* (TS11).

TS11 identified the lack of clear plans to phase out individual gas boilers and increase gas prices as a barrier to DH implementation, which could potentially undermine the through heat zoning policy.

''*But if you can say, we're phasing out gas boilers we are making gas incrementally more expensive over time. …It's not clear yet how they're going to kind of phase out or make gas more expensive and make the alternative cheaper.* '' (TS11).

TS15 identified cultural barrier in terms of overdependence on the use of gas boilers and the resistance from gas distribution companies as well as reputational barrier in terms of the general perception that DH schemes are too difficult to implement and do not provide good value for money.

''And I think historically, it was the perception, that DH schemes don't provide value for money. And it's like anything, you can always find examples where that is the case where they don't provide value for money, or in the main if a project has been conceived and developed correctly, it should always provide value for money. I think that perception is changing because they do see district heating schemes as the gateway to decarbonise. So I would just say stakeholder engagement, to commit to the long term and initial capital investment.'' (TS15).

T15 and T12 identified the lack of a solid business case due to uncertainties regarding customer acquisition and securing long term heat supply contracts as well as lack of bankable DH network investment projects due to complicated investment policies, high capital and operating costs and poor financial returns to encourage private sector investment.

''*The main challenges are probably some more commercial challenges in terms of getting commitment and buy in from stakeholders. The success of any DH scheme or community energy scheme is obtaining critical mass, customer base. Now without that critical mass, it's very difficult to build a business case to work to get a project to be developed in the first place.''* (TS15).

TS6 identified the lack of actor networks to support DH implementation as opportunities were still being missed in local authorities due to lack of DH awareness, support, resources, commitment and established stakeholder communication channels.

People to talk to each other within the same organization, so better communication and more. So, for example, in any project that we do with a local authority or even private sector, at the start, we always suggest the creation of what we call a project board or a project team, where not only us and the client we try to bring all the key stakeholders. So, identify which are the key stakeholders within that organization or linked organizations and have them all participating on the project. So, they can all be aware of what is happening and also to see to *understand what they need from a heat network for example, if they don't think that heat network is a good idea, why do they think so maybe we can see what the problems is?''* (TS6).

Actor networks serve a variety of functions, including the transfer of knowledge and key success factors between local areas, the pooling of capacities and resources, and the coordination of multiple local actors to enable project delivery cooperation. For example, the traditional energy system actors interviewed for the study (represented by the energy company actors) emphasised the need for local governments to take the lead in order to make DH more commercially appealing. The housing association actor was also looking to their local authorities to provide leadership in order for projects to move forward. However, a lack of resources and capacity within local authorities to provide this coordination was a major barrier to Implementation. Participants highlighted that establishing strong local actor networks based on trust and cooperation was viewed as an essential component of the DH development process. Quite often, project plans were based on a few large anchor loads that served as the foundation for a reliable and predictable business case. Furthermore, participants identified a knowledge sharing gap and a lack of collaboration among DH delivery companies in the private sector, which is responsible for unequal expertise among DH companies, as knowledge sharing of successful case studies were regarded as an important tool to build a knowledge resource on how to implement DH to establish trust in DH. Consequently, stakeholder engagement was a critical component of the development process in order to establish trust in the project and facilitate the development of an investable business case.

Aversion to debt and risk

TS2 highlighted that the lack of DH regulation, statutory regulator, and equivalent statutory undertaker rights that exists with other utilities creates uncertainties in the DH market, which affects the commitment, trust and buy-in of investors, as DH is considered to be a high-risk investment.

''So one thing I hear as head of policy for investors is they don't want to put their money in a sector that's unregulated. … if we can regulate the heat network sector, it will give investors more security. If we can demonstrate that there's no investment risk from lack of statutory powers and reduce the investment risk through zoning, I think you would start to see more third party investment as they start to see these really compelling kind of investment choice.'' (TS2).

In general, it was perceived that DH is viewed as a risky investment by local authorities and private investors. Numerous projects failed to progress to implementation stage despite the involvement of expert consultants/advisors and a comprehensive techno-economic analysis, owing to a perceived lack of willingness to take risks to ensure the success of a project. Additionally, some local governments had a cap on the amount of debt they could take on at any given time as such were averse to taking risks.

7.9.6. Lengthy development and implementation periods

Due to a distinct lack of DH infrastructure (underground pipes) in GM compared to their European counterparts, the implementation of large-scale DH network schemes requires the deployment of extensive infrastructure. Participants highlighted that the lack of statutory powers statutory powers providing the institutional framework backing the implementation of DH infrastructure give rise to significant challenges for DH developers and operators. These include step by step negotiations with multiple landowners which increases costs, causes delays and organisational requirements. LAs however, do have the required rights and powers to dig up roads to carry out large urban infrastructure development. This is why DH ownership and management structure in GM for new and existing schemes is primarily a joint venture between the private and the public sector as local authorities have a significant role to play in the implementation of DH.

Another important point raised by a participant was supply chain issues, as the UK DH market is not well established, as such most raw materials are imported from other European countries. Additionally, Brexit has complicated and lengthened the importation process, due to the additional paperwork requirement, which causes delays in DH implementation.

> *'' So Brexit has added more complexity because quite a lot of the key materials like the pipe work, the heat generating plant is either fully or partially imported from other countries in Europe. So they're no tariffs on them yet or interest, but there is the extra paperwork and processes that need to go through to get through customs that add extra reflectors and extra costs. So, that also creates different planning in terms of bringing the materials from time for a project.'' (TS6).*

TS19 expressed concern that despite available HNDU and HNIP funding, good DH opportunities often end up as a report on the shelf that never progresses from feasibility to implementation phase due to the lengthy process and challenges associated with obtaining these grants, which includes the requirement to conduct studies on the potential to implement other low carbon technologies. This often leads to the loss of interest in DH implementation; in some cases, energy officers decide to implement a much simpler technology based on the other potential options identified, ignoring the fact that DH would have been a more suitable option for the area, with the potential to offer greater energy efficiency and carbon reduction.

''So last time, I looked over 100, local authorities have had the HNDU and HNIP grants and there's been over 200 projects. But unfortunately, I think in some cases, there might be a good project, but it just ends up as a report left on the shelf, as the energy officers decide that they're going to do something else, or they resign, and then of course, the new opportunity is lost.'' (TS19).

TS12 and TS19 expressed concern that securing government funding takes so long to organise, such that the project fails before the approvals are obtained. Also, HNDU funding requirements to carry out investigation on the potential for the implementation of alternative low carbon technologies makes the process long winded which often takes up to five years. TS12 highlighted that a more flexible approach were projects are considered on a case by case basis with the requirement to only provide evidence for DH opportunity in a given area would be more beneficial rather than a standard procedure requiring the consideration of other potential low carbon technologies alongside DH.

''Unfortunately, I think the HNDU approach to the grants has been too long winded because every stage takes basically a year or so to get through to commercialization that's taking you five years. That's too long. And the way that scheme was created, I think should have been simplified, so that you didn't have to rebuild your, your project team, every stage, you should have been able to select a team.'' (TS19).

Participants identified the numerous challenges and barriers to DH implementation in GM, as well as their perceptions of risk and threats to DH implementation. The vast majority of participants identified a lack of holistic/strong policies and a lack of DH regulation as the most significant barriers to the large-scale implementation of DH in GM. Participants generally agreed that the formulation of strong policies and DH regulation can address most of the challenges, barriers and gaps identified in this study.

7.10. Chapter Conclusion

This chapter explored the early-stage development of a DH implementation strategy articulated by actors actively working to implement DH in the case study using the analytical framework structure derived from the literature review of existing literature. The study focuses primarily on the perspectives of key actors in the case study, who were identified in the literature review as crucial actors in enabling the strategic development and implementation of large-scale DH networks. Although DH is still in its early stage of development and implementation in GM, the vast majority of participants believed in its potential to contribute to delivering the aspirations to decarbonise the heating sector at scale in GM, as well as providing a social return and environmental benefits. In addition, the general perceptions of the participants towards DH are positive.

Examining the costs of implementing DH projects, revealed varying perceptions about the investment risks due to high upfront capital cost and long payback periods, as well as the uncertainty of securing long term heat supply contracts with key anchor load customers, though participants noted that available government funding through HNIP and HNDU and low interest loans has helped reduce investment risk and incentivise DH. Irrespective of the high capital cost of implementing technology, participants acknowledged that DH would yield long-term benefits such as increased energy efficiency and fuel poverty reduction, considering the economies of scale created by connecting key anchor loads to a network, which would create the opportunity to sell heat at lower prices as well as economic growth and development through increased job creation and the reinvestment of the income generated from scheme profits back into the local authority.

The findings reveal that there is a lot of support from the UK government to deliver DH networks, however, there are a number of challenges, including access to funding, poor technical standards, institutional support, and lack of strong policies, regulation, statutory regulator, DH skills, knowledge and experience, and commitment and buy-in and strategic coordination as well as limited interest from private investors. The following chapter discusses the main findings of the study by highlighting similarities, differences, and relationships, using the same analytical framework structure used in the secondary and primary case study analysis, where themes are discussed in greater detail with reference to the previously discussed literature.

8. CHAPTER 8 DISCUSSION OF MAIN FINDINGS

8.1. Introduction

This chapter discusses the main findings of the study and the theoretical implications of the research findings. It highlights the similarities, differences, patterns, and correlations in the primary case study (GM), and secondary case study cities Copenhagen, Stockholm and Helsinki using the themes derived from the MLP framework, where themes are specifically discussed with reference to the literature discussed earlier. This is to gain a deeper understanding of how to successfully implement DH networks in cities and to draw lessons on how to support the development of DH in areas with little history of DH networks in order to deliver increased energy efficiency and climate mitigation objectives. The cross-case analysis of the secondary and primary case study contexts enabled the researcher to identify the gaps in the GM DH implementation approach to provide recommendations that can aid the successful implementation of large-scale DH networks in GM.

The discussion will also draw on the findings of the multilevel perspective on social technical transitions and the insight generated from the interactions between the three layers of structuration - a level of confined technological niches within a socio-technical system that serve as "protected spaces" and a testing ground for new technologies where innovations can emerge free of the selection pressures of the incumbent regime; a level of socio-technical regimes (for example, the energy system) that provide stable structures and a selection environment for innovations; and, thirdly the socio-technical landscape, which includes cultural norms, values, and relatively stable broader social structures that influence niche and regime dynamics, as well as the socio-technical system structures.

The following sections also draw on the findings on both parts of the analysis in order to provide a short discussion of current relevant DH policy along with a series of recommendations to policy makers. These recommendations are aimed at tackling the main factors and barriers identified in the analysis, in order to create an enabling environment for the development and implementation of DH networks.

8.2. Implementation Strategies

DH implementation in the three secondary case studies (Copenhagen, Stockholm and Helsinki) appears to have been stimulated solely by the oil crisis which changed their overall energy policy direction, whereas GM is more motivated by the ambition to deliver increased energy efficiency, emission reduction and climate mitigation objectives. The DH development and implementation strategies in each of the case study cities reflects a mix of regulatory frameworks and strategies put forward to support DH, such as connection requirements, consent regimes, strategic coordination through heat zoning, price regulation, mandating DH planning to local areas, consumer protection, financial instruments regulatory means or market forces such as high taxes on alternative heating legislation. This includes government support and financial incentives through subsidies such as grants, loans or tax credits to incentivise the adoption of DH and CHP. Table 18 provides an overview of the DH implementation strategies in both primary and secondary case study contexts.

Table 18: Overview of case studies

Case study	Regulation	Pricing Structure	Legal Obligations	Points of Interest
Copenhagen	Regulated	Not for profit rule, annual heat tariffs based on actual expenditures (necessary costs plus a set mark-up). DERA is responsible for governing the DH market and ensuring consumer protection.	Heat zoning; Obligation to connect to DH in designated zones (enforced by municipalities). obligation to provide information about pricing and services so that complaints and disputes can be resolved	Well established sector and supply chain Waste heat is a major priority
Stockholm	Liberalised (Light touch regulation)	Voluntary pricing and complaints processes to aid transparency. There are no mandatory connections, and companies rely on good customer relations to grow	None, other than submitting annual accounts	Clear division of responsibilities between local and national governments Mixture of mandated and voluntary consumer protection schemes

		their market share		
Helsinki	Unregulated (no regulation)	Theres is no specific DH legislation. DH is profit-driven, with competitive pricing and complaints processes to aid transparency. Customers connect voluntarily as a result of the competitive price level.	None. There is no obligation for energy companies to connect buildings	Operates a business based DH system. Third-party access to the district heating network is unregulated and there is no obligation to connect to a DH network. DH success is based on customers will to choose DH in a free market.
Greater Manchester	Unregulated	No pricing structure and protection for consumers/ complaints process.	None	GM is at the early stages of DH implementation with limited knowledge, experience and expertise.

The Copenhagen case study employs DH 'heat zoning,' in which local authorities have the authority to require connections to schemes in designated heat zones. This enabled Danish local authorities to plan where DH would be most beneficial to the energy system in the long run and to ensure that these plans were implemented. In the Stockholm case study, the Swedish system of taxes on fossil fuels and incentives for district heating, as well as the efficiency of heating homes with district heating through market forces aided the growth and expansion of the DH sector. District heating in Helsinki has been largely driven by carbon taxation.

Given that the DH sector is currently unregulated in the GM case study, it was essential to investigate the perceptions of key actors regarding how DH is currently being developed and implemented, as well as their perceptions of risks, barriers and challenges associated with DH implementation in GM. Most participants expressed concern that the electricity and gas sectors pose a significant threat to the development and implementation of DH at scale due to the well-established market and stable sociotechnical regime, which reinforces the literature on sociotechnical transitions theory regarding the barriers posed by incumbent regimes, as well as the challenges of niche development and transition. As a decentralised energy technology, DH needs to adapt to the physical and technical context of the local area, however, these regional differences in social and economic circumstances are frequently overlooked during the development process. In GM participants identified a DH knowledge gap between LA and non-local authority (private companies and DH consultants) as well as the need for a coordinated approach to foster increased knowledge sharing and established communication channels between key stakeholders and potential anchor load customers such as university, hospital, and specific officers within local authorities; planning officers or local politicians to enable the widespread implementation of DH networks at scale. However, the actors' agency to implement this approach was constrained by challenges such as a lack of skills, resources, capacity, awareness, commitment, buy-in, strong policies and established stakeholder communication channels.

Ultimately, public and private niche actors are constrained in their actions and general transition strategies by the interplay of these various forms of regime resistance. Within the context of a highly stable regime, niche actors with limited agency have very limited window of opportunities to support niche processes that can cause a radical regime transition (Geels, 2014; Smith and Raven, 2012).

Given that DH projects require significant capital investments prior to securing long term heat supply contracts and building connection, load uncertainty is a major threat to the successful implementation of DH networks. This is why stakeholders seeking to implement DH in GM often opt for funding-driven or commercial approaches to deliver stand-alone projects, with the hope of expanding later. In addition, existing policy measures are not sufficient to address some of the local authorities' lack of commitment, experience and expertise in DH implementation. A narrow focus on commercial viability made it difficult to develop longer-term capacities for achieving broader goals with DH. In Copenhagen the implementation of the city wide mandatory connection policies (heat zoning policy) has been used to enforce the connection to DH schemes while competitive pricing, good customer relationship and complaint process have been used in the Stockholm and Helsinki case study to drive commercial viability.

In GM LAs lacked powers to implement strong planning policies: While local authorities recognised the potential of planning policies, their implementation was not always deemed successful or viable in the absence of national policy measures and lack of DH regulations to support customer acquisition and buy-in of investors. Schemes not progressing to the construction and operational stage due to lack of commercial viability, lack of statutory undertaker rights, as well as lack of technical expertise on how DH networks should be designed, constructed, operated and maintained which was cited by participants as one of the shortfalls of the Code of Practice in providing sufficient details on the implementation, and operation stages. Also concerns that a lack of technical expertise was limiting successful procurement of relevant DH delivery services, resulting in inefficient or more expensive schemes. In addition, the risk of pipe installation in the ground affecting other utilities as DH construction requires the installation of pipes in the ground which can affect existing subterranean utilities, such as pipes and wires for gas, sewage, freshwater, telecommunications, and electricity systems. Poor design and technical standards as the implementation of DH requires proper planning and design. Owing to the fact that the DH sector in Copenhagen Stockholm and Helsinki are well established with well-developed market spanning over 50 years of development long before the installation of other utilities in the ground, DH infrastructure (underground pipes) have either been established or are a key consideration in planning policies. This has also lead to the development of their supply chains, widespread knowledge and expertise on how to design and implement DH networks.

8.3. Technical Solutions and Heat Sources

Most of the proposed and implemented DH schemes in GM are majorly gas CHP, which does not support low carbon. Gas CHP DH networks generate both electricity and heat, which produces less carbon emissions than individual building level solutions using gas, such as individual gas boilers. It is therefore considered a no regret technology and a better solution than using individual gas boilers because with one input you get two outputs in the form of electricity and heat. Essentially, the current approach in GM is to grow the heat network sector by implementing DH networks at scale and then decarbonise along the way by integrating low carbon heat sources.

While the implementation of large-scale DH systems in Copenhagen, Stockholm and Helsinki have been largely successful with all three cities having a significant share of their total heat demand supplied by DH networks, the findings revealed that their DH systems are still largely powered by fuel combustion technologies, which have adverse environmental impacts. The contribution of fossil fuels in the energy supply mix of DH systems must be reduced, otherwise, DH would not be considered a highly efficient heat supply technology if it is not derived from renewably sourced energy at a competitive price which is a key consideration for the advocacy for DH (Connolly *et al.*, 2014). A common feature in these cities is that they all intend to shift away from fossil fuel-based heat generation by seeking ways to improve the energy efficiency of their DH systems, while reducing carbon emissions and lowering costs, to develop a smarter fossil fuel free DH production network within their target plans to achieve carbon-neutrality. The major challenge is that the current landscape for low carbon energy generation in cities is not moving at a rapid pace and direction towards a clean energy future as it requires investments decisions that promotes renewable energy sources with robust short-and long-term energy policy implications (Dahal, Juhola and Niemelä, 2018). As renewable energy policies are one of the key mechanisms required to promote the influx of renewable energy technologies, they need to be properly designed and implemented for effective delivery and to attract the required investments and stakeholders.

The common challenge identified in this study is that, while the secondary case study cities have successfully implemented efficient DH networks, they have not been able to achieve a 100% renewable energy mix for powering DH systems as DH systems are still powered by fossil fuels (coal, oil and gas). Decarbonising existing DH systems is the main challenge in Helsinki, Finland and Copenhagen, Denmark, while Stockholm DH is already almost fully decarbonised (Kerr and Winskel, 2021). GM is seeking to achieve its environmental goal to generate its energy from 100% renewable energy sources by promoting wider usage and integration of DH as part of a low-carbon energy system. There is a need for GM to consider implementing 100% renewable energy-fired DH systems. However, there has been some very poor performance identified in some heat network developers, particularly in the new build sector. As a result, the industry developed a standard to ensure high quality in design, build, operation, and maintenance of DH networks which is the CIBSE Code of Practice CP 1. Following the recommendations in the 2018 CMA report, in 2019 BEIS contacted all DH network operators in the UK to notify them of the forthcoming regulations, and how they can be ready for sector regulation in ways such as improving their technical standards as well as to recommend that they consider signing up to the Heat Trust which is the voluntary consumer protection scheme.

The 2020 consultation to revise the metering and building regulations in the UK was to ensure sure that DH network operators are even more targeted and to work together even more effectively. The Government has committed to enacting legislation to establish the market framework and a statutory regulator. The updated Heat Network Code of Practice for the UK CP1 (2020) was developed to raise standards by establishing minimum project requirements while promoting key success factors. These requirements aim to improve the quality of feasibility studies, design, construction, commissioning, and operation, thereby protecting against inefficient systems. It also seeks to ensure that DH networks provide customer satisfaction, affordability, reliability, safety, and sustainability by providing energy efficiency and environmental benefits, excellent customer service, and promoting long-term heat networks in which customers and investors can trust (CIBSE and ADE, 2020).

However, participants expressed concerns that the CIBSE Code of Practice CP 1 document provided details on how to conduct feasibility studies but was inadequate in providing detailed information on how to construct, operate and maintain DH networks. This is believed to have contributed to the lack of continuity following the feasibility study as well as the challenges and risks associated with DH implementation which includes the lack of regulation in the sector and lack of expertise on how to execute DH projects. Figure 49 illustrates a typical work plan for a heat network project development as illustrated in the Heat networks: Code of Practice for the UK document.

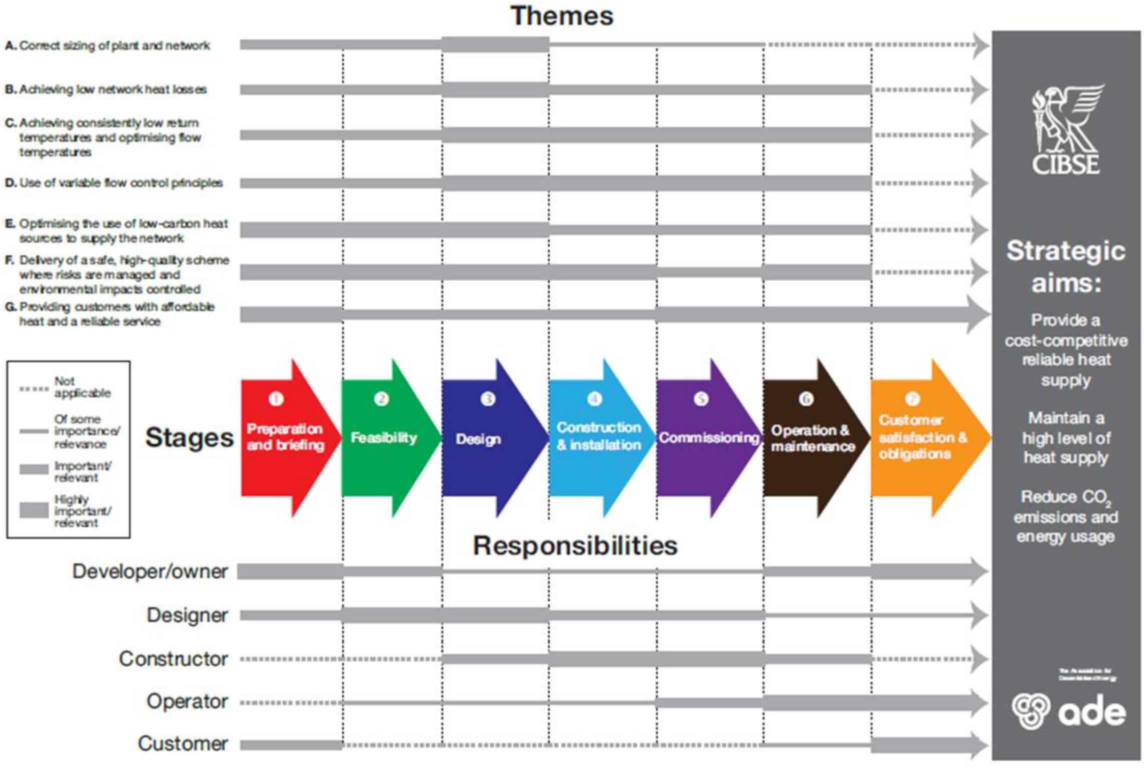


Figure 49: A typical work plan for a heat network project development (CIBSE and ADE, 2020).

The UK government continues to meet with industry representatives to discuss how to support the implementation of technical standards such as the Code of Practice CP1 and how to integrate high technical standards into a longer-term coherent framework for consistent coverage of technical standards across the sector and integration into regulation (CMA, 2018; ADE, 2020; BEIS, 2021c).

- Heat temperature requirement in existing buildings: While DH networks are often best suited to high temperature buildings, the existence of low temperature buildings requires strategic planning to determine the placement of high and low temperature DH networks.
- Technical difficulties relation to the compatibility of buildings with DH networks.

The magnitude of change required, as with most challenges related to the energy transition, is large, with hundreds of thousands of connections required each year. To have a chance of meeting these targets, the UK's skills base must be coordinated and supported to swiftly develop capacity, ensuring that best practise is both attained and progressively improved through innovation and learning.

8.4. Policy Instruments and Regulatory Framework

In Copenhagen, the Heat Supply Act (1979) and national and municipal buy-in helped provide a strong foundation for regulating and expanding DH networks. Direct policy intervention has also benefited DH. Municipalities can enforce forced connections on new and existing structures, which is one of the reasons for the DH success in Copenhagen. To discourage fossil fuel consumption, a higher-than-European carbon price was imposed in 1992, and oil burners were outlawed in new construction in 2013 and existing structures in 2016. Financial incentives were provided to keep DH and CHP viable. Subsidies and levies improved the environmental performance of the Danish heating and electricity systems. Danish heat regulation has a clear responsibility division. Local decision-makers now have complete influence over the design of their heating systems, revising their heating plans, and authorising heating projects in their community.

In Stockholm, there is no specific national government policy on DH, rather they provide an overarching policy agenda to transition away from fossil fuels. These policies are often technology agnostic and will not promote DH over other technologies that provide comparable benefits (e.g. heat pumps). Swedish Government has implemented a comprehensive collection of policy instruments and incentives to promote a sustainable and market-based heat supply to accelerate the transition to low carbon heating (including both DH and heat pumps). The Swedish government introduced the DH Act in 2008 to protect consumers and improve transparency. While municipalities still play an important role in DH development, their responsibilities and powers have decreased since the liberalisation of the energy market.

Helsinki, Finland has no DH act. The Energy Authority promotes energy efficiency through energy audits, consumer education, voluntary energy efficiency agreements, and product eco-labelling and eco-design. The government and participating sectors chose the voluntary approach to avoid introducing new regulations to meet national energy efficiency goals. Similar to Copenhagen and Stockholm, fossil fuels are taxed in Helsinki based on their energy content and CO_2 emissions. Renewable fuels are often tax-free to incentivize renewable heat energy generation. Land use procedures are also considered when assessing the potential for heat production in the Helsinki region. The prohibition on market dominance imposes certain pricing and cost elements on district heating operators. Third-party access to the district heating network is unregulated and there is no obligation to connect to DH networks.

The DH network sector is currently unregulated in GM, which means that DH customers do not have equivalent protections available to customers in the gas and electricity sectors (CIBSE and ADE, 2020). The government plans to introduce legislation in this Parliament to regulate heat networks to provide consumer protection to heat network customers and minimise carbon emissions, as well as to reduce the 90% dependency of DH networks on natural gas. This will require the transition of DH networks to low-carbon fuel sources as part of a natural replacement cycle, hence minimising service disruption to network customers. In addition, the government intends to support local authorities to designate new heat network zones by 2025 (HM Government, 2020a). Participants highlighted that acquiring and persuading stakeholders to see the benefits of connecting to district heating is a key challenge that can be addressed by regulation through implementation of the DH network planning/heat zoning policy to allow for increased DH uptake and expansion. The following section discusses the proposed DH regulation under which GM will operate.

8.4.1.1. Considerations for the Proposed UK DH Regulation

DH regulation in the UK would require wide ranging decisions that would have a significant impact on the DH network sector's ability to grow. There are strategic decisions to be made regarding heat decarbonisation pathways and the ability of industry to invest to make the substantial progress in the 2020s identified in policy.

The UK Government has set a target for DH networks to supply around a fifth of heat by 2050. The infrastructure requirements for a decarbonized heating system in the UK will be vastly different from what is currently available and have had historically. The current policy framework is incapable of delivering on the set targets to grow the DH sector to supply 18% of the UK heat demand. In order to see significant expansion of the DH network infrastructure and shrinkage of at least some of the existing methane gas networks, there is still a significant question about who pays for this and how the costs will be allocated in such a way that does not distort investment decisions or day-to-day energy use, these questions remain unanswered to a large extent. Finally, for the long-term viability of the regulation it is important to consider the points highlighted in figure 50.

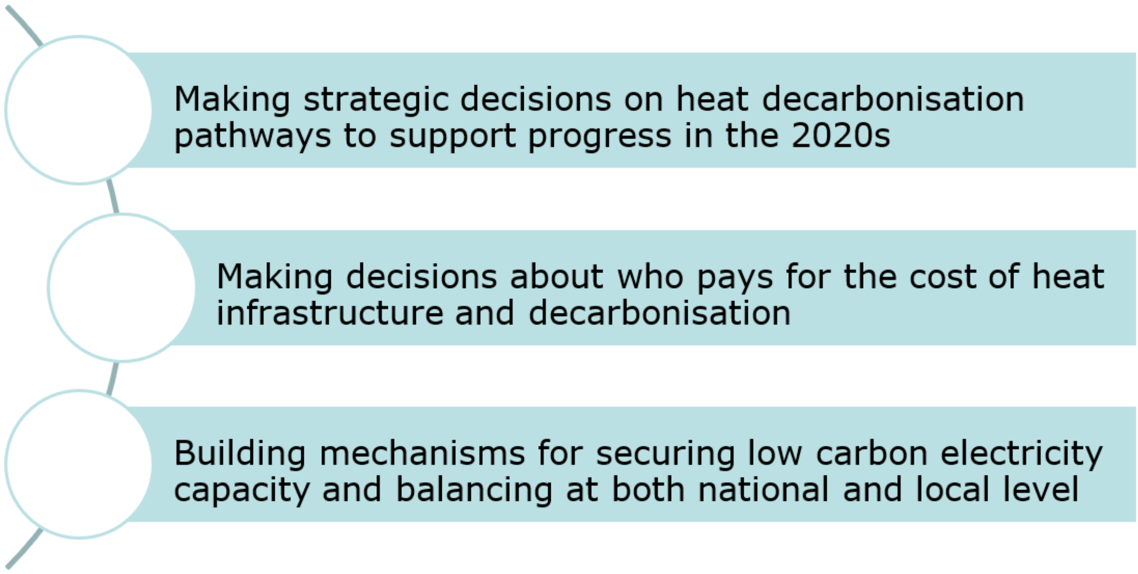


Figure 50: Considerations for the long-term viability of the regulation (ADE, 2021).

The way in which the reserve capacity is procured at the national level as well as the national balancing markets, remain extremely carbon intensive. The decision on how to decarbonise those markets and develop local markets for balancing other network operations without the use of fossil fuel resources are still yet to be made. DH networks, with their flexibility and storage capabilities, should play an important role in decarbonising those markets.

8.4.1.2. Visions and Features of the Proposed DH Regulation governing GM

This section presents a description of some of the key pillars of the proposed DH Regulation and the broader measures that are critical to supporting investment, which will govern DH development and delivery in GM, based on comments from the interviews. It highlights the overall policy picture for DH networks and the industry's ambitions for moving the UK DH sector forward over the next few years. Table 19 highlights some of the key features of the proposed DH regulations.

Table 19: Key features of the proposed DH regulations in the UK (CIBSE and ADE, 2020).

Consumer protection standards	• Heat Trust • COVID-19 Consumer protection statement • Cost and scope of regulation (incl. smaller players) • The Heat Network Industry Council Customer Experience commitments
Technical standards	• Supporting the development of CP1 (2020) • Supporting the future development of assurance schemes
Environmental standards	• The Heat Network Industry Council carbon reduction and forthcoming strategies
Broader measures supporting investment	• Supporting Government's work on the introduction of Statutory Undertaker Rights for heat networks • Heat network zoning (with Government and through the Heat Network Industry Council) • Reform of taxes and levies (including carbon taxation)

Consumer protection standards*:* the industry has been working for some time to put together customer standards as the heat network market remains unregulated and in preparation for regulation. Heat Trust, which is a not-for profit consumer champion for the heat network sector, providing consumer protection standards and independent access to the ombudsman for those heat networks who are registered to it. Over the last year and a half, the industry has taken proactive measures, with approximately 13 companies coming together to voluntarily pledge to a series of commitments, to align with many of the commitments of the gas and electricity sectors. Additionally, the industry is working closely with the government to ensure that the proposed regulatory design is appropriate for the market in its current form and as it grows, and that it is compatible and workable with the diverse range of stakeholders in the market, including very small DH network operators. In terms of long-term goals, the Heat Network Industry Council is also working on a number of provisional but very ambitious commitments covering a number of areas, one of which is the customer experience for heat networks customers which will be refined and finalised this year (2021).

Technical standards: The industry has been heavily involved in the development technical standards, as well as focusing on the future development of assurance schemes and the broader framework that surrounds those technical standards to ensure they have teeth on environmental standards. The 2020 consultation on technical standards gave some indication of widespread support for the development of more mature technical standards, as well as support for the government building on the great work the industry is doing in developing these standards to implement them in regulation and to ensure that minimum technical standards for how heat networks are designed, built, operated, and maintained (DBOM) are included in regulation and those standards are consistent across the sector. The government is expected to announce plans legislation proposals in the coming months, while continuing to support the development of technical standards and consulting with industry representatives on how to develop these standards into a longer-term coherent framework with consistent coverage across sectors and integration into the proposed regulation.

Environmental standards: The industry has been clear that it intends to make ambitious commitments around the leading role that heat networks can play in decarbonising the overall heating sector. The heat network industry council has provisionally pledged to decarbonise all new heat networks by 2030 and all existing and new heat networks by 2035. The strategies that underpin those commitments will be refined and published over the next few months, including how the diverse range of heat networks currently on the market will develop and decarbonise in the future.

Broader measures to support investment: Some of the broader measures that will be important to support and grow investment in this sector, in parallel to regulation, is the statutory undertaker rights that the government intends to include in the regulation as well as the introduction of heat network zoning which is crucial to ensure a much more strategic approach to where heat networks are sited in the UK. This will strengthen the incentives to connect in those areas where they are seen as the appropriate decarbonisation path. The Heat Network Industry Council, as well as the government, have done a lot of work to get the broader measures implemented in last few years and will continue to do so. The reform of carbon taxes and levies is also seen as crucial to getting to a market-led decarbonised sector in the next decade. While this a topic that touches more than just heat networks, it will be needed for heat decarbonisation as a whole. The decisions over the next year in terms of where those taxes and levies sit, and particularly any changes to taxation on gas are important. The UK Government also plans to plan to deliver the net zero transition for existing heat networks by 2035 through BEIS' Heat Network Delivery Unit (HNDU) in partnership with the Association for Decentralised Energy (ADE) and the Heat Network Industry Council (HeatNIC).

8.5. Pricing and Consumer Protection

Participants identified significant price variations and the absence of consumer protection rights in the DH sector as a key challenge stemming from the lack of DH regulation which has led to customers paying high prices and poor service provision. A number of issues were raised including issues with schemes that are technically deficient, resulting in numerous large heat losses and excessive expenses. Participants stated that this can be remedied simply by following good technical standards, which means having a well-functioning network. So, in many cases, it is partly a technical issue: networks aren't well-designed, built, or managed effectively, and as a result, they don't operate efficiently, and customers are overcharged. Another key issue was that DH network customers do not have the same regulated customer protections as domestic gas and electricity customers which has led to excessive pricing and customer exploitation as well as inadequate consumer service quality standards and lack of competition in the sector.

Consumer complaint mechanisms that are both effective and efficient are required for the efficient implementation and regulation of DH, as well as for preventing operators from exploiting monopoly positions. As evidenced in Copenhagen, Stockholm and Helsinki case studies, DH networks can provide comfort to homes at a cheaper cost than alternative technologies, when properly designed, operated and maintained. They have been found to reduce fuel poverty and are well-established in the secondary case study cities. However, public perception, commitment trust and buy-in is critical to the successful implementation of DH networks. This can be achieved through pricing structure, customer rights protection with end users potentially having a powerful collective voice if performance standards are not met and a complaints process to manage disputes. Consumer protection requirements and levels of satisfaction vary depending on how much emphasis is placed on consumer protection during the regulatory design process. Complaints procedures that appear to be efficient and beneficial to customers as well as a fair, consistent and sustainable pricing structure appear to be in place in Copenhagen (the Energy Supplies Complaints Board), Stockholm (Prisdialogen), and Helsinki (the Finnish Competition and Consumer Authority). Participants highlighted significant price variations and the absence of consumer protection rights in the DH sector as a key challenge stemming from the lack of DH regulation which has led to customers paying high prices and poor service provision. DH developers try to address this by setting the pricing structures at 5 to 10% less than the gas price to order to attract customers and incorporating protection for consumers into their contracts, but there were still instances of exploitation and customer dissatisfaction due to the lack of regulation and a statutory DH regulator to monitor accountability.

Additionally, several industry representatives are initiating improvements and advocating for quality developments, however participants have highlighted that this can be addressed by regulating the sector, including increased coordination and collaboration among stakeholders, which are critical to realising the full potential of heat networks and developing the market responsibly, with a clear offering to all stakeholders.

8.6. Financial Instruments and Incentives

In Copenhagen, all investments have been fully financed by low-interest loans. Loans for DH investments are readily available, with interest rates under 2%. The Danish “Kommune Bank” provides competitive long-term debt financing for Danish municipalities, which also funds 100% of its DH investments using these loans. Access to capital is critical to the Danish DH sector's growth. Low capital interest rates (about 2%) allow a financial case to be developed even if the network return is only 4%. Municipalities can also borrow money from the public works funds to fund DH development (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018).

Stockholm's DH projects are primarily funded by investment grant programmes that promote the development of energy efficient technologies. Between 1998 and 2004, only CHP biofuels powered plants were eligible for 25% investment grants (SEK 4000/kW) Grants were also available to convert thermal plants to CHP. Currently, DH network development and investment are currently driven by DH companies, rather than municipalities or the central government. DH companies are investing heavily in interconnecting existing DH networks between cities and towns. This enables systems to accept large amounts of excess heat, thereby increasing energy security and efficiency. The corporative investment, innovation and collaboration among DH companies is perceived as a good outcome of the lack of regulation (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018).

DH in Helsinki has always been for profit-driven with a competitive price level. The investments made to improve operations are financed through profits earned in the free DH market in accordance with free competition. In certain instances, investment in renewable heat sources can be financed through investment funding which may be provided by businesses, municipalities and other organisations to new small heating plants powered by renewable energy (Helen, 2016; MEAE, 2018a, 2018b; City of Helsinki, 2019b).

Participants noted that DH in GM has been largely financed by government funding and incentives through HNDU and HNIP capital and grant funding, as well as low interest loans available to the public sector. Participants raised several concerns associated with these funding schemes, which include the lengthy process and challenges associated with obtaining these grants, such as the requirement to conduct studies on the potential to implement other low carbon technologies. Participants were also concerned that government funding was predominantly targeted at the public sector, and that most DH schemes would not be commercially viable without government funding due to high capital costs, a lack of DH regulation, and the risks that this entails. Continued government funding in the absence of third-party or private-sector investment is thought to have the potential to stifle the growth and development of a mature and self-sustaining DH market. Highlighting that there were challenges with securing government funding due to the requirements and the lack of knowledge on how to secure the funding in LAs.

8.7. Key Barriers to District Heating Implementation

The capacity of DH systems to incorporate energy efficiency improvements with the integration of renewable energy has given new significance to these technologies. However, market barriers to their development and implementation persist, such as lack of knowledge and understanding about the application of the technology, its multiple benefits and savings, lack of integrated infrastructure and land-use planning and lack of expertise and capacity to structure and attract investment. Data analysis and reporting challenges include the lack of sufficient data on municipal heating, the lack of an agreed framework for the assessment of energy savings and environmental benefits, and the lack of agreed measurement methods to develop building efficiency ratings, labels, and standards. Other barriers include restrictions on interconnection and grid access, high upfront capital costs, and heating energy pricing schemes or market structures that put DH systems at a disadvantage compared to other technologies.

To enable the large-scale implementation of city-based DH systems, cities need to address various barriers and challenges. Despite these challenges, cities and countries around the world have successfully developed targeted strategies and policies to support DH systems, promoting significant growth in the sector. The most strategic and effective policy responses will depend on local factors, which include the social, economic, and environmental objectives of the city; population density and size; market structure; credit rating; local expertise; capital availability; energy mix; existing infrastructure.

This study identified the lack of strong policies and DH regulation as the most significant barrier to DH development and implementation in GM, which exposes the DH network industry to several risks and challenges. It is believed that strong policies and DH regulation can address a number of identified challenges which include price exploitation, lack of consumer rights protection and lack of statutory undertaker rights that exists with other utilities. According to a new study by the UK Competition and Markets Authority (CMA, 2018), the heat network industry should be regulated, DH network consumers should have the same rights as customers in the gas and electricity sectors. Defining clearly specified standards of customer support is critical to increasing the uptake of DH networks. The ultimate objectives of any heat network is to provide sustainable heat through a dependable infrastructure that provides customer satisfaction (CIBSE and ADE, 2020).

DH systems can be an efficient method of supplying heat, capable of playing a significant role in the transition to a sustainable low carbon, secure, reliable, and affordable energy system, as it can be powered by renewables from biofuels, waste heat and energy from waste (Connolly et al., 2014). Despite the benefits of DH, the degree of expansion, market penetration and the proportion of households supplied by district heating varies from country to country. The percentage of citizens that have their energy supplied from DH systems varies from 92% in Iceland, to 63% in Denmark, to 52% in Sweden and 2% in the United Kingdom (Euroheat & Power, 2015; Colmenar-Santos et al., 2016). This study reinforces some of the key areas where barriers to DH have been identified in existing literature (DECC, 2013a):

- Difficulties with meeting development and capital costs
- Uncertainties relating to reliable heat sources
- Absence or lack of enabling policies and regulation
- The choices made by heat providers
- Uncertainties regarding longevity and reliability of customer heat demand
- Lack of guidance, support, leadership or political will for planning and implementation
- Lack of established role for local authorities
- Skill and capacity gaps
- Lack of generally accepted contract mechanisms

A successful DH scheme can only be realised when the key design principles have been properly considered and implemented in an integrated manner, from initial briefing and feasibility to operation (CIBSE and ADE, 2020). As a result, the updated UK Code of Practice CP1 (2020) was published to: improve the quality of feasibility studies, design, construction, commissioning, and operation by establishing minimum project standards and defining best practice options. While district heating has the potentials to generate huge carbon savings, it is however a complex system for cities to implement. DH technology merges three functional aspects of the energy system which include: generation, distribution and demand (Wiltshire, 2011; Ratheal, 2013). District heating could turn out to be a burden for decision-makers and consumers when it is inefficiently operated as they are custom-built technologies that require sound social, technological, and economic investigation in order to verify the economic viability of the system. The engineer must ensure the chosen plant capacity can meet the demand requirement of the consumers. Good engineering design and resource optimisation are key factors to be considered in the development of viable DH systems (Kelly and Pollitt, 2010). There are several known cases in Europe where poor consumer focus, low efficiency, excess capacity, lack of investment and inadequate policy framework have led to the inefficient operation of DH systems giving rise to the decline in the uptake of DH systems. Also there are speculations that poor design and operation of DH systems have intensified fuel poverty in Central and Eastern Europe (Tirado Herrero and Ürge-Vorsatz, 2012).

8.8. Key Lessons for Governing DH Implementation Identified in this Study

Evidence has shown that DH can achieve significant reductions in primary energy supply and carbon emissions at lower cost of approximately 15% than other existing alternatives (Åberg *et al.*, 2020). Since DH can help achieve energy efficiency and emission reduction targets, it is important to research in more depth what policies, key success factors, drivers and effective governing measures that can overcome the key challenges and market entry barriers in order to foster the successful development and implementation of large-scale DH networks. DH efficiency indicators are mainly because of the implementation of the identified key success factors, although there is no universal model to develop efficient DH systems, the case study analysis shows that each system has a distinctive design and interplay of local dynamic settings throughout its development. Thus, leading to the identification of partially replicable key success factors that have been combined in various ways.

KSF are critical enablers of efficient DH systems, integrated during the design, construction and operational processes of a DH system. KSF are therefore the main areas where policy makers, cities (or other project promoters), DH operators and other relevant stakeholders should consider focusing on to foster the deployment of efficient DH systems. These KSFs include the main elements constituting high quality, efficient and sustainable DH systems (Galindo Fernández *et al.*, 2016):

Table 21 provides a summary of the important **key success factors** (KSF) contributing to the large-scale implementation of DH systems in Copenhagen, Stockholm and Helsinki are outlined in below (Galindo Fernández *et al.*, 2016):

Table 20: DH Key Success Factors in Copenhagen, Stockholm and Helsinki adapted from (Galindo Fernández et al.*, 2016).*

			Secondary Case Studies Cities		
			Copenhagen	Stockholm	Helsinki
Key Success	1	National and local policy and regulatory framework	✓	✓	–

	2	Flexible DH system enabling the integration of renewable technologies	✓	✓	✓
	3	CO_2-taxation scheme, tax incentives and subsidies	✓	✓	✓
	4	Ambitious environmental targets	✓	✓	✓
	5	Continuous efforts to lower prices and improve service quality	✓	✓	✓
	6	General ban on the use of gas and electric boilers with a few exemptions.	✓	–	–
	7	Consumer protection and competitive prices	✓	✓	✓
	8	Well-developed supply chain	✓	✓	✓
	9	High flexibility operation of the system	✓	✓	–
	10	Coherent urban planning, with high sustainability standards	✓	✓	✓
	11	The upgrade of old heat-only boilers (HOB) to CHP and priority for CHP when constructing new heating capacity.	✓	✓	Operates a combined heat and power DH system
	12	Innovation	✓	✓	✓
	13	Large-scale and constantly expanding system	✓	✓	✓
	14	Collaboration between DH companies	✓	✓	Has only one DH company 100% owned by the city of Helsinki

While district heating has the potential to generate carbon savings, it is a complex system for cities to implement. DH could turn out to be a burden for decision-makers and consumers when it is inefficiently operated as they are custom-built technologies that require sound social, technological and economic investigation as well as an effective regulatory framework in order to achieve its aim (Kelly and Pollitt, 2010). There are several known cases in Europe where poor consumer focus, pricing, lack of guidance, support, leadership or political will for planning and implementation, inconsistency in national and local planning, lack of clear roles between national and local government, uncertainties relating to reliable heat sources, lack of enabling policies and regulation, low efficiency, excess capacity, lack of investment and inadequate policy framework have led to inefficient operation, giving rise to the decline in the uptake of DH systems (DECC, 2013c; Donnellan *et al.*, 2018). Some of the important **key success factors** (KSF) contributing to the large-scale implementation of DH systems in Copenhagen, Stockholm and Helsinki are outlined below (Galindo Fernández *et al.*, 2016; Donnellan *et al.*, 2018):

- Pricing is one of the primary reasons for the introduction of regulation in Copenhagen as pricing regulation is based on capping DH operator profits. Stockholm and Helsinki operate a liberalised DH market with unregulated pricing, which promotes competition between various heat suppliers. Prisdialogen (Stockholm) and the Finnish Competition and Consumer Authority strengthen the position of customers by promoting fair prices, and predictability of DH pricing in order to prevent exploitation. Inflexible pricing can deter developers from entering the market and upgrading existing systems. It may also limit innovation and cause domestic customers to abandon the DH network for cheaper alternatives. Full price deregulation, on the other hand, has been criticized for negatively impacting consumer outcomes by weakening customer service and protections.
- Transparency is another tenet of most regulatory approaches, though it is achieved in a variety of ways and with varying degrees of success. Transparency strategies must be carefully designed and monitored to ensure that consumers benefit from them. A high degree of transparency through a variety of mandatory and voluntary options (such as publishing of DH prices), have proven to be effective in Copenhagen, Stockholm, and Helsinki.
- Consumer complaint mechanisms are critical for the effective implementation and regulation of DH, as well as for preventing operators from abusing monopoly positions. Consumer protection standards and satisfaction levels vary according to the degree to which protection is prioritized in regulatory design. Copenhagen (The Energy Supplies Complaint Board), Stockholm (Prisdialogen) and Helsinki (the Finnish Competition and Consumer Authority) appear to have effective complaints procedures in place, which seems to be efficient and of value to consumers.

- Technical standards are a critical component of efficient DH network delivery, though their implementation varies (e.g. through licensing or voluntary non-binding standards). However, it must be adaptable so that it does not become a major barrier to innovation and sector development.
- In the cities examined, licensing, zoning, and the award of concessions are key regulatory mechanisms. These are widely regarded as important and beneficial because they contribute to market stability. However, excessive administration or application rigidity can create barriers for operators.
- Mandatory connections in which customers are required to connect to a DH network where one is available can guarantee sufficient heat demand. As Copenhagen has shown, this can be a critical factor in driving investment in DH network development.
- Third-party access and the supply of excess heat supply from industries have a high potential to significantly increase market investment. However, many cities have yet to discover a way to fully promote or benefit from the supply of excess heat. While third-party access is prevalent in the cities studied, it can create investment uncertainty for operators. As operators have the right to refuse, and requests can be rejected. It is critical to carefully consider whether and how to "open up" the market.
- As demonstrated in Copenhagen, DH regulation needs to be consistent with national and municipal planning, as planning-related features such as zoning or mandatory connections can have a significant impact on market development. Also, a clear division of national and local government responsibilities is essential for effective market and sector development.
- Effective regulation and broad policy support. The presence or absence of well-designed subsidy schemes or frameworks that enable developers to access development finance has a significant impact on the development of the DH market. Copenhagen, Stockholm, and Helsinki are examples of successful cities in this regard. Tax incentives and subsidies could also act as a barrier and a limiting factor to stimulating successful DH investment, it is therefore critical to plan and account for the broader socio-economic consequences of such approaches.
- The regulatory regime is inextricably linked to the socioeconomic, infrastructure, and historical characteristics of each city. Each regulatory model provides both positive and negative lessons that are useful for informing decision makers. Effective regulation requires long-term planning, buy-in, and collaboration from both industry and political areas. However, given the changes in the market, there is a requirement for flexibility and the identification of regulatory changes in a proactive manner.

- Flexible DH system enabling the introduction of renewable technologies: The Copenhagen, and Stockholm example shows that district heating is an extremely flexible and adaptable method of heat supply in terms of available production plant choices and diversity of heat sources. The integrated structure of the system enables DH supply companies the freedom to choose among the various production plants. The cheapest option in relation to operational delivery and the most compliant with environmental directives are put forward by the government.

While there are no one-size fits-all model to develop efficient DH systems, policy frameworks developed by international, national, and local bodies have significant impacts on the future of research and development in district heating systems. Also, incentives such as subsidies and taxes are required to create enabling environments for the efficient development and use of district heating systems.

8.9. Theoretical Implications

Energy transitions are long-term, (a decade or longer) socially embedded change processes that will inevitably change individual, organizational, and system-level capacities, as well as the policies for capacity development. Consequently, capacity development is no longer considered a simple acquisition of individual skills and competencies or as the implementation of a new "technology. Rather, it is the change process in technology, the economy, institutions, ecology, culture, behaviour, belief systems, change in production and consumption patterns, knowledge, skills, organisational forms, and more specifically established norms of the actors involved.

The significance of place (especially cities) in socio-technical transitions literature has been criticized in the sustainable transitions literature (Eames *et al.*, 2006; Coutard and Rutherford, 2010; Hodson and Marvin, 2010a, 2010b, 2012; Bridge *et al.*, 2013). Although transition theories acknowledge the interaction and interpenetration of various landscape (macro), regime (meso), and niche (micro) levels, the role of the city and regional scale in transition processes has received little attention. According to Markard, Raven and Truffer (2012), studies on socio-technical transitions often focus on national-level systems with little attention on geographical scales of urban or regional contexts. A “spatial turn” in sustainable transition studies has addressed this to some extent in recent years (Coenen and Truffer, 2012; Coenen, Benneworth and Truffer, 2012; Hansen and Coenen, 2015; Sengers and Raven, 2015; Wolfram and Frantzeskaki, 2016; Sengers, Wieczorek and Raven, 2019). However, more extensive analysis of how cities contribute to sustainable transitions is still necessary

(Karvonen and Guy, 2018). This requires a detailed examination of the dynamics of socio-technical interactions across the levels of niches, regimes and landscapes as well as multilevel systems of governance to develop a more geographically nuanced understanding of niche development (Rohracher and Späth, 2014).

Cities, as entities that consume an increasing amount of energy, are viewed as both a significant target of energy transition and a critical 'instrument' in implementing it. Urban energy transition studies provide the opportunity to gain a deeper understanding of the role of cities in socio-technical transitions (Rutherford and Coutard, 2014). The analysis of DH implementation in the cities of Copenhagen, Stockholm, Helsinki and GM seeks to contribute to a growing body of research that emphasizes the importance of spatial perspectives and the crucial role of cities and regions in transition processes. Using the multi-level perspective on socio-technical transitions, it focuses on the specific local dynamics of DH implementation: what instruments and strategies have been employed by the case study cities in the implementation of efficient DH networks for sustainable heat production and consumption? What motivations, visions, logic of actions, and actor coalitions shape these place-related strategies? How are local actions and change capacity interconnected with and dependent on multi-scalar relations such as international regimes and national frameworks? A parallel aim of this research is to acknowledge the critical role of cities and regions in energy transitions through the multilevel perspective on socio-technical transitions.

While most studies on DH have been conducted on already-existing projects, the current study is notable for examining social acceptance of DH projects before they are implemented in urban settings. This is in stark contrast to the previous study, which examined social acceptance of DH projects after they had been implemented. According to Geels (2018), the production, distribution, and consumption of energy involve both human and technological components. As a result, while evaluating energy-related activities, it is important to take into account social and human factors rather than focusing solely on technical and economic aspects. The findings of this study help inform actors seeking to implement DH as part of a low-carbon energy system to properly assessing whether adequate resources exist. Furthermore, the findings of this study can provide guidance to policymakers when comparing different regulations that seek to promote the diffusion of DH networks in urban environments to make informed policy and investment decisions.

This study employed a co-evolutionary perspective on socio-technical transitions (Foxon et al. 2010), identifying niches as potential springboards for developing new ideas and discovering solutions (Kemp et al., 1998; Geels, 2004; Smith and Raven, 2012). This study builds on the work of Geels (2018), who advocated that transition studies should deepen ties with the social sciences.

Despite efforts to research the perceptions of DH projects and the factors that could either drive or inhibit DH network implementation, limited attention has been paid to social resources and their influence in driving DH development and implementation.

8.10. Chapter Conclusion

This chapter has summarised the major findings of the current study by reviewing: (1) the perspectives and experiences of key stakeholders involved in the DH implementation process (2) the challenges in developing DH projects; (3) the comparison of commonalities and differences in DH implementation approaches in the secondary and primary case study cities which represent two contexts with differences in sociotechnical configurations (4) the key success factors instrumental to the development of DH, (5) key lessons for governing the transition to DH and (6) theoretical implications.

The DH network sector in GM is currently small but has the potential to play a vital role in the future of heat delivery. DH can play a significantly larger role in decarbonising heat especially in less efficient and higher density buildings. However, from the perspective of diverse stakeholders in this study, there are numerous requirements that must be met to improve the attractiveness of DH networks, not all of which are met by the existing offerings. One of the most important of these is high capital cost. There will be reduced capital costs and investment barriers if the focus is on innovation. To enable innovations that lower capital costs in heat network infrastructure, the UK central and devolved governments must offer frameworks that facilitate demonstration, knowledge transfer, and skill development in the sector. Elevating heat networks to the Infrastructure and Project Authority will provide impetus for stakeholders to innovate; it will show that the government recognises the need to expand DH network development as a major infrastructure project. The heat supply market will likely grow in the long run due to increased competition from other sources of heat.

Transitions to new technologies can be an uphill task due to the array of elements such as user practices, maintenance networks, infrastructure, and regulations aligned and coordinated to operate with the existing technology. This study affirms the literature in that existing socio-technical systems and regimes often serve as barriers to technological change owing to the lock-in and path dependencies to unsustainable mechanisms which cannot meet the set goals and targets in the heating sector. As such, transitions will involve adjustments in the established order and changes in technology, consumer habits, markets, business models, policies, infrastructure, and cultural significance. It is therefore important that GM considers the implementation of DH systems powered by 100% renewables as a key priority.

It was also discovered that dismantling the configuration and alignment between the elements of a socio-technical system as well as interconnections between production and distribution networks for the replacement and conversion to renewable fuels could affect the security of heating supply during certain weather conditions. Also, time is required for the planning, policy enactment, land use and permit procedures for new technologies as well as the creation of new technology markets. All of these pose significant challenges to the replacement of fossil fuel energy source with renewables in DH systems (as the case in Helsinki). Although fossil fuel is a highly efficient source of energy the use of fossil fuel has become unsustainable due to issues stemming from climate change, energy security and economic concerns. The fact that DH is majorly powered by fossil fuels which is a reliable and efficient source of energy, potent in delivering high-capacity energy supply at all times makes it even more difficult.

One of the main reasons for analysing the development and implementation of district heating in the leading DH cities of Copenhagen, Stockholm and Helsinki is to explore urban policy in DH delivery to draw lessons on how cities implement large scale DH networks and to bridge the knowledge gap on the expertise and resources required to promote the implementation, wider usage and integration of DH systems. This will be useful for actors seeking to implement DH in GM to identify relevant policy design considerations in order to outline strategic directions towards the implementation of large-scale DH networks which could aid in achieving decarbonisation targets in the heating sector in shorter time frames.

9. CHAPTER 9 CONCLUSIONS AND RECOMMENDATIONS

9.1. Introduction

This chapter outlines the main conclusions of the study, it highlight the contributions to knowledge, the policy implications of the research, recommendations, limitations, and opportunities for future research. The study explored the implementation of large-scale city-based district heating (DH) networks from a socio-technical perspective with a view to identifying key success factors and effective governing measures that can overcome the main barriers limiting the take up and implementation of district heating at scale. The MLP analytical framework structure was used to focus the secondary and primary case study using specific research questions to gain an understanding of the implementation of large-scale DH networks considering the interplay between socio-technical elements and heuristic levels.

The analysis of the case studies revealed that large-scale city-based DH systems have mutual characteristics and architecture with replicable key success factors, key steps to development and implementation that can be executed in various ways as well as common key barriers. The lessons learned from their experience in overcoming these key barriers will provide increased understanding on how to implement efficient DH systems which will be useful for actors seeking to govern the transition to DH in cities as well as validation and direction to the implementation of DH in GM. Finally, it reflects on the limitations of this study, highlighting specific areas where further lines of enquiry would be required, as well as potential future research pathways.

9.2. Contributions to Knowledge

This research presents a city scale lens of the unique set of opportunities and challenges that face heat decarbonisation in terms of energy resources, established infrastructure, and policy mix. The study is situated within the wider context of the literature on sociotechnical transitions, which seeks to explore the coevolution of actors, institutions, and technologies involved in energy system transitions. The following presents the contribution to knowledge.

- It is an original data set that captures the DH implementation process in GM at the start of the journey, to generate a set of useful data that could create a model to base future evaluations rather than just a retrospective analysis of DH in successful cities alone.
- It captured a rich analysis of the context in which DH network implementation process develops in the case study cities in a systematic way using the MLP analytical framework structure.

- It provided an understanding of the dynamic interaction between technology, institutions and actors in DH implementation process.

This research provides an applied contribution relevant to actors in regions seeking to promote wider usage and integration of DH as part of a low-carbon energy system by contributing to the development of a richer understanding of DH network implementation for informed policy and investment decisions in cities in the pursuit to deliver energy efficiency, climate mitigation objectives and a clean heat energy future. In general, this thesis contributes theoretically, empirically and contextually to the literature, as summarised in subsequent subsections.

9.2.1. Theoretical Contributions

This thesis contributes lessons on how to implement large-scale DH networks in urban environments. The study explored delivery approaches of key actors in the case studies for governing a transition to DH from a socio-technical perspective. Numerous studies investigating energy systems transitions have focused on technological innovation and economic processes, while neglecting social factors (Shove and Walker 2014; Berkhout et al. 2004; Strachan et al. 2015; McMeekin and Southern 2012; Hillman et al. 2018). According to researchers (Frantzeskaki and Loorbach, 2010; Markard, Raven and Truffer, 2012; Geels, 2018) in the field of sustainability-oriented innovation and technological studies have identified the need for low carbon transitions research to intensify and expand its engagement with social sciences to provide a deep understanding of the ‘’whole system’’ transformational shifts in socio-technical systems. Studies that seek to explain transitions must look beyond the economic and technological factors to consider the social agents involved in the process. Consequently, the decision to take on the primary case study of the development of district heating in Greater Manchester is to understand the perspectives of the participants in the development and implementation of large-scale DH networks to drive decarbonisation in the heating sector. It seeks to provide a detailed account of the development of a low carbon technology such as DH. The early stage of the heat decarbonisation plan and the widespread penetration of DH within the energy system in Greater Manchester makes it a valuable primary case study to explore socio-technical aspects of the implementation processes and the influence of key stakeholders.

It examined the implementation strategies, technical standards, expertise, policies, regulations, pricing, consumer protection and financial instruments in facilitating niche nurturing and empowerment processes vital to the delivery of efficient DH systems, to bridge the gap in policy making and DH transition literature. It demonstrated that there are key success factors, features, design, and policy considerations that could better inform DH strategic planning and support niche nurturing/empowering processes by reflecting on the priorities of the niche actors to support value demonstration and the establishment of new actor networks with associated resources and powers.

While most studies on DH have been conducted on already-existing projects, the current study is notable for examining social acceptance of DH projects before they are implemented in urban settings. This is in stark contrast to the previous study, which examined social acceptance of DH projects after they had been implemented. According to Geels (2018), the production, distribution, and consumption of energy involve both human and technological components. As a result, while evaluating energy-related activities, it is important to take into account social and human factors rather than focusing solely on technical and economic aspects. The study of an early phase development of DH within a city, in this case GM, represents a new series of insights in the developmental stage of DH, as opposed to established DH systems in other studies to improve the perspective of the MLP analytical framework. The findings of this study help inform actors seeking to implement DH as part of a low-carbon energy system to properly assessing whether adequate resources exist.

The study demonstrated that the role of intermediary actors evolves as an innovation develops and becomes established, potentially facilitating both the nurturing and the empowering of niches at various geographic scales. In order to aid the transition to DH, various activities were carried out at various geographic scales that aided the DH implementation, which were not equally recognised or resourced throughout the case studies. Local authority niche actors in GM had a distinct lack of resources to conduct consistent forms of intermediary activities, preventing them from playing an active role in the facilitation of strategic DH project development. There was evidence that the context of the resistant regime influenced the choices of actors on governing approaches, which is consistent with Turnheim and Geels (2012) assertion that governing successful transitions requires both support for innovations through niche processes and balance with existing regime destabilisation processes.

The analysis corroborated the interaction mechanisms of the niche-regime involving actors, governance/institutional structures and technology as explained in transition studies (MLP), such as Geels (2010) and Verbong and Geels (2010) and includes the constructive/interpretive role of actors. The thesis explored these relationships by using the MLP analytical framework to focus the research analysis to identify transition pathways for the implementation of DH networks from a socio-technical perspective in various contexts, which highlighted various viable approaches. As such, the evidence presented in this thesis provides an understanding of the interactions between socio-technical system elements and contributes to academic discussions in transition studies.

9.2.2. Empirical Contributions

The key empirical contribution made in this thesis is the understanding of the socio-technical elements of the DH implementation process in the Scandinavian cites with widespread DH use, knowledge and expertise as well as GM with limited DH use, knowledge and experience. The MLP has been criticised for not providing clarity on how the landscape and regime interact with niches and each other to shape a transition path as well as its focus on completed long-term transition processes (Genus and Coles, 2008; Shove and Walker, 2010). This thesis makes a distinct empirical contribution by analysing the DH implementation process in the Scandinavian cities and in GM at the start of the journey. It is an original data set that provides a set of useful data that could create a model to base future evaluations rather than just a retrospective analysis of DH in successful cities alone. This would be useful for policy makers and key actors in the energy system seeking to govern the transition to DH as part of a low-carbon energy system to make informed policy decisions.

Smith, Stirling and Berkhout (2005) also emphasized that little attention was paid to the detailed characteristics of regimes in empirical examples, which contributed to a perception of the regime as a "monolithic" or "homogeneous'' entity, thereby disregarding significant differences in contexts. The study explores the large-scale implementation of DH systems in Copenhagen, Stockholm, Helsinki and GM. It considered the roles of actors from a variety of sectors, key success factors, features and key lessons to deliver energy efficiency and climate mitigation objectives through wider usage and integration of DH as part of a broader energy system decarbonisation plan. Given the choice of GM as the primary case study, where DH is still in its early stages of development, the analysis focused on developing applicable lessons for governing niche-level processes.

Notable strategies for destabilising the incumbent fossil fuel regime include imposing high taxes on fossil fuel use, phase out of fossil fuel imports (such as the phase out of Russian oil imports which has the potential to destabilise the incumbent fossil fuel regime) phase-out of fossil fuel heating systems such as boilers connected to the mains gas grid, standalone boilers powered by gasoline, liquid petroleum gas, or solid fuels such as coal, and the use of fossil-fuelled systems in DH networks. This would create tensions within the regime that niche actors could take advantage of and exploit. This is likely to necessitate the leadership of national governments in the context of liberalised markets. The purpose of the DH governing activities (DH Transformation Programme) to support niche processes is to develop and prepare niche actors at various geographical scales for the opportunity to exploit tensions in the incumbent regime, particularly at the local level. While regional and national actors can support local delivery, they cannot replace the need for some form of locally led strategic coordination. It is therefore crucial that local actors must be able to adapt DH delivery models to different local contexts to successfully develop and deliver DH networks and reap the benefits of large-scale DH systems. At the local level, niche-focused governing measures must support the systemic embedding of key resources, skills, and actor networks.

Additionally, a process for facilitating more effective and trusting collaboration among public, private, and community-based actors will be required to deliver DH in the context of liberalised energy markets to leverage the distinct capacities possessed by these various sectors. Establishing mechanisms and processes that will enable effective cooperation without undermining the capacity for local strategic coordination for DH has been identified as a significant challenge that would benefit from further research.

The successful implementation of DH is a fusion of governing activities to support niche processes, as well as a need to destabilise the unsustainable incumbent heating regime. Numerous low-carbon energy benefits of DH can only be realised through local strategic coordination which ensures projects are developed at the appropriate scale and in the appropriate locations. As a result, niche processes must build local capacity and agency for strategic coordination while also facilitating cross-sector collaboration among actors with critical skills and capacities to support delivery. To achieve collaboration, coordination and access to critical resources, the inherent politics of governing design and implementation measures call for pragmatism and compromise on the part of niche actors. To facilitate widespread development and implementation of DH at scale as well as to make significant contributions to energy system decarbonisation, national governments must send a clear signal and make a long-term commitment to provide access to funding, resources, and an enabling environment to encourage investment. This can be achieved through policies and regulations that support DH niche processes and the destabilisation of the unsustainable incumbent heating regime.

This research provides empirical evidence to support and contribute to the socio-technical transitions literature knowledge by uncovering the socio-technical characteristics of urban DH implementation as well as in areas of niche empowering processes and actor agency within transition processes towards a decarbonised heat sector. This section summarises the key contributions of the study. The core contribution is the overall findings of key barriers to large-scale DH development and implementation, as well as strategies to overcome the identified barriers. This provides evidence-based guidelines for driving the implementation of large-scale DH networks in urban environments which will benefit actors seeking to govern the transition to DH to make informed policy and investment decisions.

The findings reinforce the literature on sociotechnical transitions theory on the barriers posed by incumbent regimes due to the lock-in to existing regimes which creates resistance to new technology markets and policy failures which inhibit the widespread deployment and diffusion of low carbon technologies in spite of the evident environmental, social and economic benefits of low carbon technologies. In this case, the pressures in the sociotechnical landscape due climate change and environmental sustainability are creating pressures in the regime and DH needs a window of opportunity to overcome the incumbent fossil fuel regime in order to become an established technology, however, the incumbent fossil fuel-driven developmental path has created resistance and a huge barrier which would require changes in the configurations of policy, infrastructure, markets, scientific knowledge, technology, cultural context, and consumer practices. It also highlighted the role of intermediaries in supporting niche development and empowerment processes in transitions, which is an integral part of the transition process, allowing an innovation to diffuse and be embedded into the regime by influencing systemic socio-technical changes.

In summary, the findings affirm the literature that actors, institutions, and sociotechnical systems which are interdependent on each other significantly impact the development and transition to low-carbon technologies. Also, the findings affirm the literature that social and institutional trust have a significant impact on DH development as developers rely on local authorities for implementation, the local authorities rely on the central government to establish the overall heat policy, the overarching framework of requirements, and appropriate incentive mechanisms. Most participants believe that strong relationships exist between local authorities and their community citizens, which can be used as a lever for customer acquisition through communication on the benefits of connecting to DH networks to drive economic viability and the successfully implementation of DH projects. Their involvement in communities, through various projects, has confirmed this trust, allowing those with the capabilities and resources to implement projects. There were many divergent views on the role of government in driving DH implementation, with participants generally believing that local authorities should take the lead with autonomy and discretion through their local heat decarbonisation plans, with the aid of developers, to implement the projects, whereas others believed that this should largely be driven by central government through the implementation of stronger and supportive policies for DH to thrive.

In summary, the analysis of the interactions between actors and multiple factors contributes to a deeper understanding of DH implementation process using the MLP framework structure to analyse the secondary and primary case study cities which represent two contexts with differences in political, technical, financial, social, governance processes and policy approaches to DH development.

9.3. Policy Implications and Recommendations

This research explored how cities implement DH systems to identify/ develop effective policies, strategies and regulatory framework that can overcome key barriers and to facilitate more appropriate decision-making towards the take up and implementation of DH networks in urban environments.

To answer the research questions and to achieve the aims and objectives of this study, this section draws on the findings from both the secondary and primary case study analysis to provide a series of recommendations to policy makers. These recommendations are aimed at tackling the barriers to DH implementation identified in this study in order to enable the successful implementation of large scale DH networks in urban environments. The recommendations to policy makers and implications for future DH network design and implementation is centred around 6 critical components essential for the successful large-scale DH implementation, which are as follows:

- Long-term planning and commitment to DH development through policy and regulation
- Coordination of national, regional and municipal government actors,
- Capacity for local strategic coordination for DH to determine the placement of DH networks
- Increased provision of easily accessible low-cost finance and government funding for public and private sectors as well as incentives for third party investment.
- Effective use of market development and investment tools in the sector
- Flexibility to accommodate innovation and market changes

This study identified the relative lack of long-term policies, regulation, statutory regulator and broad visions for the energy future in the UK as it relates to the implementation of DH networks as particularly concerning, leading to uncertainties in the DH market as well as commitment, trust and buy-in issues. This study asserts that long term policies and regulation in terms of pricing structure and consumer rights protection, technical standards, and incentives to intensify low carbon heat supply is a critical component to the implementation of large-scale DH networks. This is discussed in more details in subsequent sections.

9.1.1. Policy and Regulatory Recommendation

9.1.1.1. Holistic policies in the DH sector

One of the key policy issues related to the somewhat stunted development of DH in GM is tied to the partially integrated nature of the DH regime within the broader UK energy system. Therefore, policies and institutional arrangements are implemented within one of the regimes, with potential unintended negative consequences for other the other regime, which has been identified as a negative factor influencing DH. The lack of holistic policy is closely tied to the lack of holistic visions for the UK energy future: despite general commitments for a low-carbon energy future, there seems to be a relatively little about desirable development trajectories and potential configurations of such a system. Overall, the recommendation to policymakers with regard to this barrier would be to:

- To develop and deploy holistic policies on energy efficiency and sustainable energy generation affecting the entire energy system, while considering potential unintended consequences of policy change on DH and energy generation methods in order to achieve long term goals for heat and energy system modernisation.
- To put forward more specific visions and expectations for the DH systems in the UK, opening spaces which can be exploited and filled by DH networks, with a secondary positive side effect of increasing public visibility and awareness about DH technologies.
- To work with the finance industry to build a platform that can scale and ensure DH projects are bankable to support third party investment in the DH sector.
- To raise awareness and educate members of the public about DH technology and the benefits over other technologies to help recognise and strengthen the role of DH in heat decarbonisation and to help drive cultural and behavioural change.
- To work with stakeholders to strengthen DH customer protection/rights and to review pricing mechanisms to restore confidence in DH network operations in the UK.
- To work collaboratively with the industry to support training in key skills shortage areas and new procurement and entry routes.
- To make DH network implementation a statutory duty
- DH network exemption from business rates policy to aid the growth and development of the DH market.
- Long term policy that is grounded with stable objectives and political buy in irrespective of change in government administration.

These policy recommendations will be beneficial for informing the proposed DH Regulation, which will mark a significant step forward in the development and implementation of DH networks.

9.1.1.2. Statutory powers for DH network developers

Another key policy issue is the lack of statutory powers for DH network developers, which give rise to significant challenges for DH developers and operators. Due to a distinct lack of DH infrastructure (underground pipes) in the UK compared to their European counterparts, the implementation of large-scale DH network schemes requires the deployment of extensive infrastructure. The absence of statutory powers providing the institutional framework backing the development of the DH infrastructure leads to step-by-step negotiations with multiple landowners which increases costs, causes delays and organisational requirements. The recommendation to policy makers is to grant equivalent statutory rights that exists for other utility developers such as gas and electricity companies. These include rights to dig up road, cross railway lines and waterways without obtaining approval from local authorities, thereby reducing lengthy construction periods to aid the development of the DH sector as identified under the heat network market framework. This aligns with the recommendations provided by CMA (2018) heat network market study.

9.1.1.3. Investment policy and structure

To address the implementation gap, which is defined as the difference between the number of potential projects and the number of projects financed, it is important to build capacity on both the demand and supply sides, as well as in the finance industry, to "crowd-in" private investment and increase the volume of projects financed. This thesis recommends the following:

Creation of a Finance Instrument Tool Kit: A key issue identified in this study is the fact that most LA's do not understand how to secure government funding in terms of HNIP and HNDU funding. The creation of a financial instrument tool kit will help create a clear direction of travel on how to secure various government funding opportunities. It will also be useful in building capacity within financial institutions to understand energy efficiency projects and to help financial institutions better value and assess the risk of energy efficient DH projects to provide a common language between local authorities, developers, and financial institutions to identify higher financial values and to simplify requirements for accessing funding for projects as well as the bundling project procurements

Creation of a collection of open source protocols: The establishment of a set of open source protocols for heat network development projects will ensure that low carbon energy efficient DH projects are documented in order to standardise the heat network development process to decrease performance risks and transaction costs due to lack of standardised process, knowledge and experience while increasing the likelihood of project approval and progression to the implementation phase.

Access to low-cost financing and government funding for the public and private sectors: One of the primary challenges to DH implementation identified in this research is a lack of easily accessible low-cost finance and government funding for private sector led DH projects, as well as a lack of third-party investment in the DH sector. This study recommends the provision of easily accessible low cost finance and government funding specifically for the private sector, as well as incentives for third-party investment in public or private sector led DH projects.

Creation of design, place and sector-specific financial instruments and incentives: Design, place and sector specific financing instruments and incentives such as de-risking tools needs to be in place in order to develop a scheme that works and does not expose DH investors to future financial risk. This involves creating an enabling environment with suitable conditions for the successful implementation of DH networks and ensuring sufficient demand to make it economically viable. These include assuring support through transaction enablers such as:

- Funding for heat network training in institutions, universities and colleges to address the technical skill gap by scaling up skill and resource capacity to develop projects as well as the provision of development capital. The will ensure widespread availability of DH knowledge and expertise could potentially reduce cost and also lessen the technical errors in the design, construction, operation and maintenance of DH networks.
- The development of standardised criteria for DH to deliver low carbon, energy efficiency and high technical standards such that it doesn't expose investors to future financial risk. Redefining the business case, revenue model and financing instruments.
- Collaboration between landlords, developers and public and private sector organisations to act as the anchor load to a proposed DH project for a sufficient demand to make it economically viable (to help support the business case and de-risk its delivery) through connection to public sector buildings, the NHS Trust, secondary school or maybe some government offices, the council's estate, social housing, which have a role particularly to act as the anchor load in a network. This will ensure that when a network is proposed by the local authority or a private organization there would be an existing commitment to sign up for buildings to be an off taker on that network.
- Provision of research funding for innovative design and creative engineering on how to deliver DH more cheaply and investment in local capacity to manufacture DH materials such as pipes and heat exchangers to reduce importation and high capital costs. Investment in DH Skill development and training to address shortage of skills, knowledge and capacity gap to reduce

the risk related to lack of skills to deliver projects which is responsible for the high cost of building DH networks.

The focus on building finance industry capacity, as well as the design of location- and sector-specific financial instruments and incentives, such as development capital, transaction enablers, de-risking tools, as well as collaboration with the finance industry from the start to create a platform that can scale to ensure projects are bankable, is essential to drive third party investment in the DH sector.

9.1.1.4. Long term policies, regulation and statutory regulator

Another key challenge connected to lack of holistic policies and broad visions for the energy future in the UK as it relates to the development of DH networks is the relatively short duration of policies, as well as lack of DH regulation and a statutory regulator. The relative lack of long-term policies, regulation, and statutory regulators aimed at supporting DH development, culture, and consumer behaviour, patterns, and desirable configurations of the DH energy system are particularly concerning. The regulation of suitable heating and DH networks will require the establishment of the scope and duties of the regulator, the adoption of heat supply trading standards and rules for participation and service delivery, the implementation of enforceable standards and the reduction of the complexity of the market, with priorities for creating a market that attracts investment and long-term growth to create a self-reliant market for DH network operation. While the government has committed to enacting legislation to establish a market framework and a statutory regulator, it is worth noting the critical role these will play in the development of the DH sector, as this will help provide the sector with much-needed stability to de-risk DH projects. DH networks are generally anti-competitive and monopolistic but with regulation in place this will ensure that there is no monopolistic exploitation. This thesis recommends the appointment of a statutory regulator, it also recommends that DH development is made a statutory duty with clearer incentives, long term policies, clarity on timelines and stable objectives that are grounded irrespective of change in government administration to aid the development of the sector.

9.1.1.5. Regulation of technical standards

The lack of widespread technical expertise on how to successfully implement a DH network project from vision to operations in terms of how to design, build, operate and maintain DH networks was identified as a key barrier to DH implementation in GM. Regular inspections are not practical, and repairs are often very costly and expensive. This necessitates a very high technical standard of installation, both for the steel welding and the outer casing jointing at each stage where the pipes are connected. The network must be installed by trained and skilled heat network specialists, and inspections must be conducted at each stage of the process. This research supports the UK government's proposal to introduce the DH policy on technical standards. The implementation of an energy efficiency and technical standards policy would aid in preventing overdesign, ensure standard processes in DH deployment, ensuring high technical standards, increased use of technology to effectively monitor and manage systems, and improving network efficiencies. Providing consumers with affordable heat and dependable service is determined by the overall efficiency and maintenance cost of DH network. It is recommended that all DH networks adhere to a new set of minimum technical standards, with an emphasis on measurable performance metrics such as operational efficiency, using existing industry knowledge, including CP1, to ensure that quality standards are met. This study recommends stakeholders seeking to develop or improve new or existing DH networks to seek appropriate advice from qualified professionals, and to ensure that DH projects are undertaken by CIBSE registered engineers to ensure that network implementation/improvement works are carried out by reputable companies to a high technical standard.

9.1.1.6. Heat energy source decarbonisation

Access to multiple low-carbon heat sources: A DH network will not be considered an energy efficient low carbon solution unless the heat supply is generated from a low carbon/renewable energy source at a competitive price. As such, one of the ultimate goals of any DH network is to provide affordable and low carbon heat. This can be achieved by exploring more opportunities for low carbon heat generation such as geothermal heat, waste to heat energy, ocean or water source heat energy from waste, renewable heat sources and waste heat from industrial processes.

High carbon tax on the use of fossil fuels: To disincentivise the prevalent use of fossil fuels as a heat source in DH schemes, a high carbon tax on the use of fossil fuels should be implemented based on the carbon content and CO_2 emissions and renewable fuels should be tax-free to incentivize renewable heat energy generation.

DH networks can only fulfil their potential to decarbonise the heat sector if the industry is mobilised quickly in order to produce a low-cost energy system that satisfies the 2050 emissions targets. This thesis recommends the obligation that industries that generate waste heat must sell the heat to a local DH scheme, to ensure DH networks are fuelled by low carbon energy sources as well as the location of DH networks in close proximity to such industries with heat zoning in place for surrounding areas to foster customer acquisition. Additionally, it recommends a high tax on the use of fossil fuels to decarbonise heat and to disincentivize DH networks from the use of fossil fuels as a heat source, to set the path to achieve GM's long-term goal to become a carbon-neutral green city region by 2038 and the wider UK Net Zero target by 2050. It also recommends the creation of a set of tools to identify and value the multiple benefits of low carbon DH projects, as well as the identification of strategic benefits to increase prioritisation.

9.1.1.7. Heat mapping tools

The use of standardised heat mapping tools can be used to estimate the heat demand in a given area, to display a possible DH path, to identify potential anchor loads customers and heat network zones where DH is the most cost-effective low carbon heat solution to inform an evidence base for local strategic planning for DH as demonstrated in the Copenhagen example. The use of heat mapping for local strategic planning could be viewed as a form of niche empowerment process. This type of strategic planning can be used in conjunction with regulatory authority or incentive programmes to drive the development of large-scale, interconnected networks that provide greater benefits and opportunities for decarbonisation, increased energy efficiency and cost-effectiveness in the heat sector as well as the overall energy system (Rao *et al.*, 2017). This thesis recommends a heat mapping policy as well as the requirement for the heat energy usage to be provided by the energy supply company to gather data in a more systematic way to inform the strategic coordination for the implementation of the heat zoning policy.

9.1.1.8. Pricing and consumer rights protection

Lack of pricing structure, protection for consumers and poor consumer focus have led to inefficient operation, giving rise to the decline in the uptake of DH systems in the UK. Transparent pricing and consumer protection are vital to the successful implementation of efficient DH networks as demonstrated in the Copenhagen, Stockholm and Helsinki case studies. The regulation of pricing and distribution grids or a voluntary price agreement initiative to promote transparency and predictability of DH pricing is necessary to prevent customer exploitation due to DH potential for monopoly abuse. One of the main reasons for introducing DH regulation in Copenhagen is to cap DH operator profits. Stockholm and Helsinki have liberalised DH markets with unregulated pricing to promote competition among heat suppliers. while strengthen the position of customers by promoting fair prices, and predictability of DH pricing through their voluntary initiatives to publish terms and pricing structures to prevent exploitation. This aims to strengthen the position of customers in relation to the DH business to increase security and confidence in the pricing of DH suppliers through a fair, consistent and sustainable price change model. The recommendation for pricing and consumer protection to ensure reliable services, customer protection and to prevent exploitation include:

- Establishing clear guidelines for DH pricing, as well as tariff conditions, and promoting competition.
- Consumer protection and pricing policy to include transparency of pricing and a requirement to publish tariffs as well as a minimum of 10% discount on their counterfactual.
- Improved customer experience through standards for how fast consumers must be notified of outages, as well as regulation standards for how promptly they must be compensated. This should also include standards to prevent inadequate heat supply contracts to promote transparency as well as the establishment of an independent complaint handling board to foster fair judgement.
- Incentivise connection to DH networks through financial and environmental benefits.
- The DH sector regulator should require all heat networks to adhere to "principles-based" rules or guidance on price, establish appropriate pricing and tariff mechanisms, which should be referenced to appropriate price benchmarks or cost plus a reasonable profit margin.
- Defining the duties and responsibilities of landlords, property managers, and DH operators.
- The implementation of standard rules for service quality, delivery, and consumer prices
- Policy options for creating a credible path for understanding consumer rights.
- The sector regulator should also rule on cases when it comes to price deviations and disputes between the parties involved in line with the recommendations provided by CMA (2018) heat network market study.
- Standardised heat pricing structure through the development of a heat price metrics based on the DH network energy source as opposed to comparison to the price of gas.

Essentially, this thesis recommends the appointment of a statutory regulator to act against excessive pricing and customer exploitation, as well as to address the inadequate service quality standards in the UK DH sector.

9.4. Limitations of the Study

One core limitation of this study is the research methods employed, specifically the primary data collection method, which was through expert interviews, the primary case study analysis largely relied on interview data and an extensive document analysis with data triangulation used to cross-reference gathered data and validate findings. The amount of data collected was limited by the number of participants with whom interviews could be conducted due to the small community of DH practice in GM and in the UK at large.

Also, the conclusion about the barriers and challenges of the DH transition process in GM were limited by the circumstances that the observed DH development and implementation process is still ongoing. Therefore, the main part of the discussion undertaken on the primary case study could only be done based on the combined findings of a historical review and the state of the moment analysis and does not cover all the aspects of the governance mechanisms as well as the barriers. While this does not represent any hindrance to the multilevel perspective framework on socio-technical transitions, the secondary case study analysis and other published studies were based on successfully completed transitions (Geels, 2002, 2006b; Verbong and Geels, 2007; Raven and F W Geels, 2010; Raven, Kern, Verhees, *et al.*, 2016) or set time periods (Raven and F. W. Geels, 2010; Verhees *et al.*, 2015). Furthermore, the researcher acknowledges that the study's lack of focus on unsuccessful DH implementation case studies due to the dearth of available data could potentially be a limitation.

9.2. Opportunities for Further Research and Future Research Directions

While this thesis established several key findings, significant gaps in knowledge, understanding, and practice remain. Following the summary of research limitations, the author will put forward opportunities for further research derived from this study. These opportunities are either connected to the findings in this study, the main purpose being to further explore ideas put forward by the author or related to the design of the study and applied methods. The first opportunity for further research is to continue the review the critical role of cities and regions in energy transitions through the multilevel perspective on socio-technical transitions: Are cities merely testing grounds for niche experiments? Are local actions a bridge between the niche and the regime? Do they play a unique role in enabling and stabilizing change processes? Or are they essential for entrenching transitions in broader socio-political dynamics that extend beyond the energy system? Further research on the review of transition pathways in multi-regime transitions, exploring the theoretical soundness and practical viability of various pathways. Further research should also be conducted to assess the changes in transition dynamics in the presence of a multi regime environment, drawing on studies of Verbong and Geels (2007) and Raven and Verbong (2007).

The second research opportunity is on the theoretical and empirical assessment of the niche typology, with the aim of solidifying the theoretical grounding, and expanding empirical research through the analysis of additional case studies. A key theoretical challenge will be further review of the niche as an analytical construct in transition studies, to further review the niche definition as well as its structure and processes. This would need to consider the definition of niches as protected spaces with consideration on the potential review of this definition based on the developmental stage of the niche with a focus on specific case studies. Also, further review of DH, heat pumps and hydrogen for heating could be explored.

The third research opportunity pertains to the methodological and design related limitations of this thesis. Further research studies could be conducted to reflect a more representative longitudinal study on DH schemes undergoing development as case studies, with repeated visits to the schemes, expert interviews and focus group discussions. Another possible methodological design could include quantitative data (Bryman and Bell, 2015). The inclusion of the quantitative data would enable researchers to model the dynamics of the DH transition process, to better understand virtuous and vicious cycles as well as the motors of innovation. This approach, in particular will enable prospective researchers to utilise System Dynamics modelling to provide more accurate evaluations of the performance of innovation systems, by connecting virtuous/vicious cycles and motors of innovation (Roald A.A. Suurs, 2009) to system dynamic processes (Walrave and Raven, 2016). Previous studies have shown that after the internal dynamics of a chosen innovation system is modelled as a dynamic system model, this model can be run and evaluated to predict and assess future performance and the viability of the observed system. Quantitative approaches to system dynamics can also be used to test the effects of specific actions and/or policies on the development of a technology, or combination of technologies, provided sufficient data is available. This could be included in the advice to policy makers, by proposing a number of potential policies and actions that simulate the possible impacts on the investigated transition process which is part of the output of a technology innovation system (TIS) based analysis (Hekkert, Marko ; Heimeriks, Gaston; Harmsen, 2011).

The increased use of quantitative research in transition studies is a growing trend in the wider research community, allowing scholars to broaden the primarily qualitative-based analytical approaches to include specific economic calculations based on numerical data and quantitative scenario planning methods (Amer, Daim and Jetter, 2013). Foxon, Hammond and Pearson, 2010 and Foxon, 2013's work on developing and evaluating transition pathways for a low-carbon energy future in the United Kingdom illustrates a mixed method approach to transition modelling.

The use of mixed methods approaches would enable researchers to combine the relative strengths of various approaches in terms of validity, as well as presentation and impact on actors outside the community. MLP-based analysis of a transition process, as an example, provides a holistic view and captures both quantifiable and non-quantifiable factors influencing the development of the focal innovation, however, it may l fall short of providing precise quantitative hard data on the behaviour of specific variables, which is frequently used by policymakers and in communicating with the general public to build an argument in favour of a proposed policy. By including hard quantitative data in transition research projects, researchers can switch between holistic overviews and macro-level images to generate specific meso and macro level data at will, depending on the target audience. This will demonstrate the behaviour of specific components of the analytical construct, such as the projected rate of market diffusion, the price of a particular utility, uptake of a technology, or the projected development of the energy mix in a given country or region. In general, a broader range of available data will strengthen the impact of transitions research, which will advance the studies in the field (Markard, Raven and Truffer, 2012).

The fourth research opportunity pertains to the role of actors in transitions, which can follow multiple lines of enquiry. Although this study has made some contributions to the literature in this area, there are still certain aspects that need to be addressed. DH delivery requires strategic coordination, trust and collaboration among actors across different sectors and geographical scales to leverage their distinct capacities without undermining the capacity for local strategic coordination for DH. Researchers studying the concept of power and agency could further investigate how to establish mechanisms/processes that will deliver a more effective collaboration among public, private and civic actors in DH delivery. This relates to the findings of this study about the absence of powerful actors and lack of strategic coordination, trust and collaboration among DH actors across various sectors. These act as barriers to the development of DH at scale as well as the delivery of multiple systems and niche (nurturing and empowering) functions. Another line of enquiry is to investigate the role of actors in networks as well as the characteristics of the networks drawing on previous research on Social Network Analysis (SNA) by Caniëls and Romijn (2008).

Lastly, an enquiry into how actor power and the ability of niche actors to influence policy making coupled with the role of coalitions in shaping narratives and developing expectations as well as the dynamics of changing coalitions. This has been the focus of various multi-level perspective (Geels and Deuten, 2006; Smith, 2007; Smith, Voß and Grin, 2010b; Kivimaa *et al.*, 2019)and strategic niche management research with several published studies (Meelen and Farla, 2013; Verhees *et al.*, 2015; Raven, Kern, Smith, *et al.*, 2016; Raven, Kern, Verhees, *et al.*, 2016; Barrie, Zawdie and João, 2017).

9.3. Chapter Summary

The impetus for this study began with the researcher’s long-term interest and passion for combating climate change as a response to the challenges faced in decarbonising the heat sector. The analytical framework based on the MLP framework structure, helped to reveal how the secondary and primary case study cities with differences in political, technical, financial, social, governance processes and policy approaches governed the implementation of large-scale DH networks considering the interplay between socio-technical elements and heuristic levels. The study captured the perspectives and experiences of social actors, framings and key factors involved in determining effectiveness, as well as the distinct interrelationships between socio-technical systems, context, and settings in the DH implementation process – an area that has been regarded as underexplored yet can play a key role in decarbonising buildings, which is one of the most difficult sectors to decarbonise. This study was motivated by the researcher's increased interest on how to drive carbon emission reduction and increased low carbon energy generation in the heat sector through the implementation and expansion of low carbon DH networks – having identified the challenges faced by policy makers and key stakeholders in the implementation of DH networks at scale in the UK and in various parts of the world.

To explore DH implementation in urban environments, this thesis has investigated the implementations strategies, technical solutions and heat sources, policy and regulations, pricing and consumer protection, and financial instruments deemed necessary in order to extract meaning and analytical comprehension on how cities implement DH networks from a socio-technical perspective to inform appropriate design and policy decisions for the successful implementation of DH.

After completing the study and analysing the results, the researcher identified key research findings extrapolated from the data and answered the study's research questions. The researcher reflected on the contributions to knowledge, recommendations and limitations of the study. At this point this study is complete, but the researcher has identified opportunities for future research to further contribute to the field of sociotechnical transitions literature.

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11. APPENDICES

Appendix A: Ethics Approval

5 November 2020

Ibukun Adeniyi

Dear Ibukun,

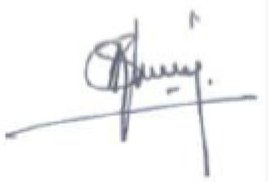
RE: ETHICS APPLICATION–STR1920-35 – Urban District Heating Delivery - A Socio-technical Analysis of Large-scale District Heating Network Implementation in Urban Environments.

Based on the information that you have provided I am pleased to inform you that application STR1920-35 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Ethics@salford.ac.uk

Yours sincerely,

Dr Rosa Arrigo
Chair of the Research Ethics Panel



Dr Levingshan Augusthus Nelson
Deputy Chair of the Research Ethics Panel

Appendix B: Consent Form

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Informed Consent Declaration

PLEASE TICK THE APPROPRIATE BOXES

		Yes	NO
1.	I have read and understood the information sheet associated with this project provided to me by the researcher.		
2.	I have been given opportunity to ask questions to clarify the activity and the nature of my participation.		
3.	I voluntarily agree to take part in the study.		
4.	I understand I can withdraw my contributions without giving reasons and without any consequences. I understand that if I do withdraw from the study, then all the data relating to me will be destroyed.		
5.	I understand that my views, opinions and perspectives may be used in publications, reports, and other research outputs but my name will not be used.		
6	I understand that the interview will be a recorded to capture information for analysis and inference in order to add clarity and value to the data being collected.		
7.	The confidentiality and anonymity of my participation has been explained to me.		
8.	The type of data recorded in the activity and how it will be used has been explained.		
9.	I agree to my data being stored for analysis and I am satisfied that it will be stored anonymously.		

Participant	**Researcher**
Name:	**Name:**
Signature:	**Signature:**
Date:	**Date:**

Appendix C: Information Sheet

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Information sheet

Title of study

Urban District Heating Delivery: A Socio-technical Analysis of Large-scale District Heating Network Implementation in Urban Environments.

Invitation

You are invited to participate in a research project concerning the development of district heating (DH) in Greater Manchester (GM). The study aims to engage 15 to 20 participants for a series of remote interviews. You have been selected for this research because of your involvement in the implementation of district heating in Greater Manchester or in the UK. Please take time to read the following information about the study carefully before you decide whether or not you wish to participate. Although I consider your potential contribution to be very valuable to this research, please be assured that you are under no obligation to take part in this research project.

What is this study about?

The research aims to explore how cities implement large scale district heating (DH) networks from a socio-technical perspective with a view to finding best practices and effective governing measures that can overcome the main barriers limiting the uptake and delivery of district heating at scale. The main focus of this study is to explore effective measures for the development and implementation of large-scale city-based DH networks which provide greater opportunities for decarbonisation, increased energy efficiency and cost-effectiveness in the heating sector.

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It seeks to provide evidence-based guidelines on how to implement large scale district networks in cities through secondary case study research in Copenhagen, Stockholm and Helsinki and primary case study research in Greater Manchester (GM). The study will analyse the institutional, technical, financial, political and governance processes integral to the development of DH networks.

The secondary and primary case studies represent two contexts with differences in political, technical, financial, social, business models and policy approach to DH development. The secondary case studies have well established DH networks which has aided the decarbonisation of their heating sectors while GM is seeking to expand the penetration of DH networks as part of a decarbonisation strategy.

The data collection will cover each of the following key elements: city strategies, technical solutions, expertise, national and local policies, regulations, pricing, consumer protection and financial instruments vital to the delivery of efficient DH systems.

This research seeks to make an applied contribution to the development and delivery of effective policies and to identify appropriate design considerations to promote wider usage and integration of DH as part of a low-carbon energy system. This will be useful for organisations seeking to implement large-scale city-based DH networks to draw lessons in order to make informed policy, investment and strategic decisions, as well as to further the research towards the global drive for emission reduction and environmental sustainability.

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What will happen if I take part?

This study requires participants to provide information on DH development and implementation in GM outlining key instruments, interventions, drivers and barriers to the development of district heating in GM. Interview questions will cover each of the following key elements in the development of DH in Greater Manchester/UK.

- Implementation Strategy
- Technical Solutions and Expertise
- Ownership and Management Structure
- National and Local Policy Instruments Regulation and Incentives
- Pricing and Consumer Protection
- Financial Instruments
- Barriers and Enablers of DH Implementation in GM/UK

This will help the researcher gain insights into the detailed understanding of district heating developments in Greater Manchester in order to be able to deliver on the aim and objectives of the study. Interviews will be taking place over MS Teams and will be recorded to capture information for analysis and inference to add clarity and value to the data being collected. Once the data has been successfully transcribed a full transcript will be sent to participants.

What if I do not want to participate anymore?

Participants are under no obligation to complete the study. Participants have the right to withdraw their contribution without giving reasons and without any consequences if they wish to do so.

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What data are you gathering and who will have access to it?

The data collected will include your views and experiences on the implementation of large-scale district heating systems in cities, both generally and in the specific Greater Manchester context.

The identity of the participants involved in the research will be concealed in all publications. Unless prior consent has been granted by the participant(s) involved, any data that can identify participants will not be published.

At the end of the study, collected data will be stored electronically and anonymously in accordance with the data protection laws. The data will be archived for up to three years from the submission of the thesis and held on a password protected drive that only the researcher and her supervisor will have access to the data.

What if I have any questions?

You are welcome to ask questions if you wish to do so, before you make your decision to participate in the research. Please contact the researcher on i.a.adeniyi@edu.salford.ac.uk +447380224646 or Professor Will Swan on W.C.Swan@salford.ac.uk for further clarifications or more information on the research.

Appendix D: Interview Guide

Table 21:Interview Guide

No	Question	Why ask it?
Introduction - thanks for time, introduce my research (focussed on DH implementation) -Clarify recording, use of data, who else I am talking to. Consent form.		
1	DH networks have had a high-profile in climate policy in the last 5 years. In your opinion what are the main drivers for this? Who have been the key actors responsible for this?	To provide context on the current focus on heat. Has the push come mainly from government or elsewhere?
	How does your organisation support DH implementation in GM?	To understand the role of their organisation
	What do you know about the strategy for GM DH Plan?	
	Why do you think GM has gone down the route of DH? In your opinion is the current approach in GM the right approach. If so, how? If not, what is missing?	To provide insights into the underlying factors responsible for driving the implementation of DH in GM.
	What are the technical difficulties in the implementation of DH in GM and what are your concerns? How much of DH knowledge and skills is widely available? What is the knowledge, skills and capacity gaps?	To understand the technical and resource challenges
2	In your opinion have the organisations involved in DH development changed in recent years. Which organisations have the greatest influence? Do local authorities engage in DH policy debates and development?	To investigate key coordinating groups- where the influence lies, who works together, who competes and why, if any organisations have become more important over time? If local authorities work independently or collaboratively? If they collaborate with other actors?
3	A range of strategies have been put forward by government (and others) to support DH and CHP (mention some relevant country specific policies/activities). In your opinion is the current approach tackling the right things. If so how? If not, what is	To open discussion as to whether some sort of regulation (i.e. Heat Act) or specific DH/CHP strategy is required. Such as connection requirements, consent regime, heat mapping, price regulation, mandating DH planning to

	missing? Should DH be regulated, if so why and how? What is the governing strategy and how does it support and strengthen the development of key processes and policies that will enable DH development?	local areas, consumer protection and financial instruments etc - if these suggestions are made ask how they think it should be delivered/managed (locally, centrally, or other).
4	What are the main challenges/ barriers to DH development (might need to refer to possible topics such as regulatory issues, financial issues, policy, local powers and market issues)?	To discuss broader issues of governance/institutional structures, and the role of sub-national powers in energy.
5	What are the barriers that face the DH companies and the supply chain within the heating sector as well as the perceptions of risks and threats? Are there any specific actions that have already been taken to overcome these? How can these barriers be overcome and what would help in addressing these barriers?	To discuss broader issues of governance/institutional structures, and the role of sub-national powers in energy.
6	How does DH work in terms of consumer protection and how is it priced? What are the key areas of conflict/ disagreement in DH policy-who disagrees?	To discuss the sites of conflict and who is involved?
7	How are DH development projects financed in GM? What role do the public and private sectors play in supporting DH development and integration in GM?	To discuss the value of feasibility funding/focus on LAs.
8	DH is currently under various ownership and management structures in the UK, Copenhagen, Denmark, Helsinki, Finland and Stockholm, Sweden (public/private/private public partnership/community ownership and the separate divisions of	Opener on a number of issues- LA ownership decision making based on (return on revenue -RoR, risk, local politics and control). Finance issues-Are there any problems with local access to

	generation/distribution/supply). What are your views, on the ownership structure that could be dominant in the future? Why? What are your views on the effect of investment policies on DH development projects?	appropriate finance? What are the extra advantages (or risks) of LA ownership?
9	How significant do you consider the current rise of LA's involvement/ownership of energy infrastructure? Follow-up Question... what could be the benefits/risks of more LA ownership/supply, what could this mean for policy? What are DH companies and the utilities saying about ownership?	To explore issues of local ownership and how this links to questions of the role of the local authorities in the energy transition - will LAs take a strong role in DH regardless of government policy?
10	Currently, LA's largely decide on the degree of involvement they want with DH development - is this the right approach? If not, what needs to be changed?	To discuss whether there needs to be some sort of local powers/responsibility for heat planning and DH
	Highlight research explores three other city contexts, do they have anything they want to say or things they think are important to explore? Do they know anyone who's knowledge and contribution would be beneficial to this research?	

Appendix E: Interview Questions

Introductory questions

Could you tell me a little about yourself, your career and the organisation you work for?

How does your organisation support DH development and integration in GM?

What is your involvement with DH in GM?

The interview questions have been divided into seven themes with a headline question and series of follow up questions.

Implementation Strategy

What is the strategy for the large-scale implementation of DH in GM?

A range of strategies have been put forward by government (and others) to support DH and CHP globally such as connection requirements, consent regime, heat mapping, price regulation, mandating DH planning to local areas, consumer protection, financial instruments regulatory means or market forces (high taxes on the use of fossil fuels).

- In your opinion is the current approach in GM the right approach. If so how? If not, what is missing? Should DH be regulated, if so why and how do you think it should be delivered/managed (locally, centrally, or other)?
- What major innovation strategies are in place, or are currently being developed, which are relevant to decarbonising heating?

  What are the decision criteria and approaches used to develop DH in GM?
- Do these approaches support the realisation of local authority targets for DH?
- What is the governing strategy and how does it support and strengthen the development of key processes and policies that will enable DH development?
- What is the business model for DH in GM?

<u>**Technical Solutions and Heat Sources**</u>

What technical solutions and heat sources are currently being considered or have been applied to implement DH in GM ?

- What kind of technical solutions (boilers, CHP, or heat pumps) are being applied to DH in GM?
- What would you say is the main technology or the main technical solution for decarbonizing heat in Greater Manchester is?
- What heat sources have been integrated with DH networks (Energy from waste, Waste heat, geothermal heat, solar thermal, mine water heat energy, ocean and river source heat pumps) in GM and what is the energy mix? Does it support low carbon DH supply?
- What are the technical difficulties in the implementation of DH in GM and what are your concerns?
- How much of DH knowledge and skills is widely available?

- Are there any knowledge, skills and capacity gaps? If yes, what are they?
- What are the risks to heat network deployment in the UK presented by a skills gap in the supply chain?

Policy Instruments and Regulatory Framework

What policy instruments and regulatory framework underpin DH implementation of DH in GM and are these the right ones?

- Heat networks have had a high-profile in climate policy in the UK over the last 5 years. **In your opinion what are the main drivers for this?** Has the push come mainly from government or elsewhere? Who have been the key actors responsible for this and has the policy direction changed?
- In your opinion have the organisations involved in DH policy/development changed in recent years? Which organisations have the greatest influence? Do local authorities engage in DH policy debates and development?
- What is the interplay between national and local policy scales?
- what low carbon heating policies and strategies have been deployed or proposed?
- Does the national planning policy framework support the local planning policy in GM?
- What policy and incentives underpin the delivery of DH in GM and are these the right ones?
- What are the key areas of conflict/ disagreement in DH policy-who disagrees?
- What are your views on heat mapping and the implementation of a heat mapping policy?
- Does the current policy landscape support DH planning and implementation?
- What are your views on the regulation of heat networks? Should it be regulated or not and why?
- What policies would be required to support the heat network market (implementation of more HN, fair pricing structure, ensure consumer protection and heat decarbonization through DH?

Pricing and Consumer Protection

How does DH work in terms of consumer protection and how is it priced?

- Who is responsible for governing the DH market price and ensuring consumer protection?
- What are the legal frameworks for pricing and customer protection?
- Are there published terms and pricing structures for the purchase of heat?
- What protection exists for customers?
- How competitive is the pricing structure compared to other heating systems?
- What are your views on DH pricing and what protection should be available for customers?
- Do you have a view on whether heat network customers should have similar consumer protections to customers of regulated gas and electricity utilities?
- Do you have views on whether regulation of heat network prices to end customers is appropriate?

Financial Instruments

How are DH development projects financed in GM?

- Are there any problems with local access to appropriate finance?
- What are your views on the effect of investment policies on DH development projects?
- What are your views on how DH should be financed in GM? (Loans, grants, investments etc.)

Barriers and Enablers of DH Implementation in GM

What are the main challenges/ barriers and drivers of DH implementation in GM?

Is lack of DH regulation a major barrier?

- What are the perceptions of risks and threats to DH development in GM?

- What are the barriers that face the DH companies and the supply chain?
- Have these barriers been overcome? How were they overcome? What would help in addressing these barriers?
- What are the key drivers/enablers of DH development in GM?