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Utilising Nuclear Energy for Low Carbon Heating Services in the UK

A thesis submitted to the University of Manchester for the degree of PhD in the Faculty of Engineering and Physical Science

2013
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School of Mechanical, Aerospace and Civil Engineering
Abstract

Utilising Nuclear Energy for Low Carbon Heating Services in the UK

Christopher Jones
PhD in the Faculty of Engineering and Physical Science, the University of Manchester
May 2013

If new build nuclear reactors are built in the UK they will provide a large low carbon thermal resource that can be recovered for heating services through heat networks (district heating). There are however questions about the geographic location of nuclear sites relative to heating demand and public/user interpretations of a potentially controversial technology to consider. This thesis includes three research themes that explore these issues. The first is an assessment of potential non-technical barriers to nuclear heat network development. The second is a focus group approach to studying local resident responses to nuclear heat network technology both as potential users, and as public groups. The third theme considers the technical potential for a heat network connecting the Hartlepool nuclear site to local heating demand centres. The research finds that there is potential for nuclear heat networks to take 70,000 existing users off the natural gas in the Hartlepool area. Following series of expert interviews it finds no non-technical barriers that would be unique to nuclear heat networks as opposed to other heat network types. It also suggests that the technology could be acceptable to local residents if it is framed as a local resource that benefits the local area. These findings indicate that there could be similar potential at Heysham and Oldbury nuclear sites.
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1. Introduction

This thesis considers the potential for nuclear energy to be utilised for low carbon heating services through heat networks in the UK. It finds that nuclear heat networks could contribute to the transition to a low carbon energy supply sector.

This research topic was developed as part of the Engineering and Physical Science Research Council (EPSRC) and Economic and Social Research Council (ESRC) funded Sustainability Assessment of Nuclear Power: An Integrated Approach (SPRIng). SPRIng investigated the environmental and economic implications of a new build nuclear power plant programme in the UK. The focus of the SPRIng project was the role of nuclear fission in reducing the carbon dioxide (CO$_2$) emissions from electricity supply. $^1$ The new build nuclear power plants that are planned for the UK will however only be able to contribute 35-37% of their thermal energy output to the energy mix if they are only used for electricity generation. $^2$ This raised questions about how to utilise more of the thermal energy outputs from a nuclear reactor and thereby increase the contribution of new build reactors to a low carbon energy mix.

Heat networks (also known as district heating) offer a way of increasing the utilisation of power plant thermal energy output. They distribute thermal energy from where it is in surplus (energy generators) to where is in demand (energy users) using water $^3$, circulated through a closed loop system of highly insulated underground pipes, as a heat transfer medium. Heat networks enable thermal power plants to operate as combined heat and power (CHP) plants. In a CHP (also known as cogeneration) plant thermal energy from an electricity generation steam cycle is also used to provide heat for a heat network. Because CHP plants can export electricity through a grid and thermal energy through a heat network, up to 64% of the thermal energy produced by a nuclear reactor can be

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$^1$ Emissions of carbon dioxide (CO$_2$) over the life time of a nuclear reactor and the nuclear fuel cycle are low relative to the unabated natural gas, coal and oil thermal power plants operating in the UK. See Chapter 3.

$^2$ This is because of the efficiency limits of the steam condensing cycle used for electricity generation and the steam temperature achieved by the reactor types that are being discussed. This explained in Chapter 3.

$^3$ In some cases steam or oil may also be used.
utilised for energy supply (Diamant and Kut 1981). Heat networks offer a means of exploiting a low carbon energy resource that will become increasingly valuable based on current trends in UK energy policy.

1.1. UK Energy Policy Context
Increasing the contribution of nuclear reactors to the energy supply mix is significant in the context of the drivers that are changing energy generation in the UK. The UK faces challenges to improve energy security and reduce fuel poverty. Of particular relevance to nuclear thermal energy output however, is the requirement to completely decarbonise heating supply by 2050 (Committee on Climate Change 2008).

The International Energy Agency (IEA) stated in 2008 that “current global trends in energy supply and consumption are patently unsustainable - environmentally, economically and socially” (IEA 2008, p.37). The Intergovernmental Panel on Climate Change (IPCC) reported with ‘high agreement and much evidence’ that anthropogenic green house gases are the primary cause of a global warming effect and that this has had, and will have, profound effects on the earth’s climate (IPCC 2007). The IPCC states that ‘between 1970 and 2004, global emissions of [green house gases] CO$_2$, CH$_4$, N$_2$O, HFCs, PFCs and SF$_6$, weighted by their global warming potential, have increased by 70%.’ Carbon dioxide (CO$_2$) emissions in particular have grown dramatically and in 2004 accounted for 77% of anthropogenic GHG emissions (IPCC 2007). Global mean temperatures have risen by 0.6˚C since pre-industrial times (Warren 2006), and this will continue as atmospheric concentrations of GHGs increase (IPCC 2007). A rise of 3˚C above the world’s pre-industrial temperature is projected to have a dangerous impact on the environment and human society (Schellnhuber, Cramer et al. 2006). The IEA, however, has warned that in a ‘business as usual’ case (whereby present trends and practices are followed over the coming decades) an increase of as high as 6˚C may occur (IEA 2008). According to a 2009 UK Government report such an increase would “make extreme weather events such as flooding and drought more frequent and increase global instability, conflict, public health-related deaths and migration of people to a level

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beyond any of our recent experiences. Heat waves and droughts would affect the UK too.” (DECC 2009, p.5).

Avoiding these dangers requires stabilising global concentrations of GHGs a level that prevents further temperature rises (IPCC 2007). Doing so will involve reducing energy consumption and replacing energy technologies which emit large amounts of CO₂ with ‘low carbon’ technologies (decarbonisation). In response to this challenge the UK passed the Climate Change Act (2008). The act is a;

“a legally binding target of at least an 80% cut in greenhouse gas emissions by 2050, to be achieved through action in the UK and abroad. Also a reduction in emissions of at least 34% by 2020. Both targets are against a 1990 baseline.”

The targets set by the Act are intended to be the UK’s ‘fair’ contribution to avoiding a global mean temperature rise of over 2°C above pre industrial revolution levels, by stabilising atmospheric GHG concentrations at 450ppmCO₂e (Anderson, Bows et al. 2008).

According to the Committee on Climate Change, the Government’s independent advisory group, to achieve this reduction the UK would have to decrease its GHG emissions inventory from 695MtCO₂ per year (as in 2006) to 159MtCO₂ per year by 2050 (Committee on Climate Change 2008). This implies a major decarbonisation of the UK’s energy supply sector (Committee on Climate Change 2008).

The UK Government’s decarbonisation strategy includes supporting the construction of around 16GW of nuclear electricity generating capacity by 2050, through streamlined planning and a potential subsidy support mechanism (DECC 2011). There is also an

5 Description of the Climate Change Act on the DECC Website. See http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx (accessed 20/06/2011)
6 There is however no indication in the Act about the likelihood of not exceeding 2°C at 450ppmCO₂e (Anderson, K., A. Bows, et al. (2008). "From long-term targets to cumulative emission pathways: Reframing UK climate policy," Energy Policy 36(10): 3714-3722..
indication that the Government will seek to incentivise the development of heat network infrastructure as part of a plan to decarbonise heating services (space and water heating, drying and industrial processes) (DECC 2012). This follows advice from the Committee on Climate Change that;

“District heating [heat networks] based on use of waste heat from low-carbon power generation (e.g. nuclear, CCS) could be viable from technical and economic perspectives, based on a preliminary and high-level assessment. Further analysis is required to develop the evidence base on district heating, with the possibility that this could complement or substitute heat decarbonisation in buildings from heat pumps or resistive electric heating” (Committee on Climate Change 2011, p.112).

Heating services are the largest component of UK energy consumption, accounting for around 44% (~700TWh) of total UK energy demand annually (DECC 2009). As of 2012 less than 1% of heating services were provided by low carbon technology, with direct combustion of natural gas accounting for the majority of supply (DECC 2011);

![Figure 1: UK Heating Supply by Fuel and Sector. Adapted from (DECC 2009).](image)

The challenge of decarbonising heating services makes any low carbon thermal source valuable. Although the possibility of nuclear heat networks contributing to the UK energy supply mix is mentioned in policy documents such as Department of Energy and Climate
Change’s ‘The Future of Heating: A strategic framework for low carbon heat in the UK’ (DECC 2012), research on this subject is limited. High level assessments of the potential for nuclear heat networks have been conducted in James and Bahaj (2009) and Dolman, Abu-Abid et al. (2012). These reports however do not address key questions about nuclear heat network development in the UK (see Chapter 2). James and Bahaj (2009) estimate 2.9TWh of heating demand within 10km of the Hartlepool nuclear site, however the analysis in this thesis shows that when demand density and network constraints are considered 1.2TWh is likely to be the upper limit for demand met by a nuclear heat network in this area. Dolman, Abu-Abid et al. (2012) did not conduct analysis on the potential for utilising nuclear energy for heating on the basis of perceived public perception and energy distribution barriers. This thesis therefore is the first in-depth assessment of the potential for utilising nuclear energy through heat networks in the UK.

1.2. Structure of Thesis
The thesis is organised around three research themes; the non-technical factors that influence nuclear heat network development, energy user and public responses to nuclear heat network technology, and the suitability of potential new build nuclear sites in the UK for heat networks. The thesis includes a research framework and technology overview before presenting research on each of the three themes.

Chapter 2 presents the research framework for the thesis. It describes the scoping work that was undertaken to identify key research questions relating to nuclear heat network development in the UK. Three questions are identified:

- What are the non-technical issues relevant to nuclear heat networks and how may they affect the potential to utilise nuclear energy for heating services?
- How might energy users and members of the public respond to a nuclear heat network development?
- Are potential new build nuclear sites suitable for heat networks?

Each question is discussed in relation to relevant existing literature and knowledge gaps are highlighted. The theoretical perspectives that were used to frame the research - Science and Technology Studies, interpretivist approaches to energy infrastructure
controversies, and interpretations of risk - are discussed. This discussion explains the reasons for the research methods that were used and the theoretical framework within which the analysis takes place.

Chapter 3 provides an overview of nuclear heat network technology. It describes nuclear fission reactors, with particular reference to the reactor types proposed for the UK; the Westinghouse AP-1000 and the Areva European Pressurised Water Reactor (EPR). It then explains how thermal outputs from a fission reactor can be used for electricity generation (as currently planned) and for supplying a heat network through a combined heat and power (CHP) process. This chapter presents examples of nuclear heat network application in Europe and Russia that demonstrate the technical feasibility of this approach.

Chapter 4 presents research on the non-technical issues that influence the potential for nuclear heat network development. It describes the interview method that was used to gather data and presents the research findings.

Chapter 5, and two chapters that follow, present the work undertaken for the second research theme on energy user and public responses to nuclear heat networks. This chapter describes the focus group method that was used to obtain qualitative data from residents living near to a nuclear power plant about their interpretations of nuclear heat network technology.

Chapter 6 presents analysis of the focus groups outlined in Chapter 5 that explores how local residents might respond to nuclear heat network technology as energy users. This chapter uses concepts from the Science and Technology Studies literature to consider how responses to offer of heat network connection might by influenced by how users interpret the technology.

Chapter 7 presents findings from the focus groups that relate to public responses to nuclear heat networks. This chapter uses theoretical perspectives from studies of renewable energy controversies and the literature on interpretations of industrial risks to
understand the possible effects of nuclear risks on public responses to a nuclear heat network development.

Chapter 8 and Chapter 9 present work on the third research theme. In Chapter 8 the approach to studying the suitability of potential nuclear sites for heat networks is explained. It describes the scenario method that was used to develop a range of twenty seven quantitative nuclear heat network scenarios. It explains the use of the Hartlepool nuclear site as a case study. The scenarios consider the suitability of the Hartlepool site for heat network development in relation to different user heating demand, network geographic coverage and user connection rate variables. The process of developing and varying different datasets to explore alternative future contexts is outlined.

Chapter 9 is the analysis of outputs from the Hartlepool nuclear heat network scenarios in Chapter 8. The analysis is used to assess the suitability of the Hartlepool site for heat network development in terms of the increased utilisation of reactor output, how efficient the network would be and the financial implications of different scenarios.

Chapter 10 summarises the findings from the research. The findings are used to draw conclusions about the potential for utilising nuclear energy for low carbon heating services in the UK. This chapter also includes a discussion of further research.
2. Research Framework

This chapter outlines the research framework used to investigate the potential for utilising nuclear energy through heat networks in the UK. It describes the initial scoping exercise that identified three key questions relating to nuclear heat networks in the UK that the research aims to answer. It provides an overview of the inter-disciplinary nature of the project and how the social and technical aspects of the work relate to each other within a broader theoretical framework.

2.1. Identifying Research Questions

The research began with a scoping exercise to identify the key research questions relating to utilising nuclear energy for low carbon heating services in the UK. This took the form of a technology review (presented in Chapter 3) and expert interviews (discussed further in Chapter 4). This process highlighted three areas of particular interest where knowledge gaps were identified, namely: the non-technical issues influencing the development of nuclear heat networks, energy user and public responses to nuclear heat networks, and the suitability of potential new nuclear sites for heat networks.

The technology review covered nuclear fission technology, heat networks and existing examples of nuclear heat network development. It highlighted studies and reports, such as Margen (1978), Diamant and Kut (1981), Barnert, Krett et al (1991), Wenxiang and Dazhong (1995) and Handl (1998), Pierrès, Luo et al. (2009), which demonstrate the technical feasibility of extracting heat from nuclear reactors for heat network application. The Beznau nuclear heat network in Switzerland for example transports thermal energy from a reactor site to users within a 9km radius (Handl 1998). Although this example shows the potential viability of nuclear heat networks, it is the only such scheme developed since 1987. The potential for nuclear heat networks is not being exploited, despite increased interest in energy technologies with low greenhouse gas (GHG)
emissions and renewed interest in nuclear fission in the UK (DECC 2011). Interviews with experts who have experience of nuclear heat networks, existing UK heat networks and UK nuclear regulation highlighted potential reasons for this. Firstly, concern that potential users, as well as local publics, would respond negatively to a nuclear heat network in their area. Secondly, that the locations of potential new nuclear sites in the UK are not suitable for heat networks:

“There are different reasons why they [heat networks] might not be do-able. In the case of nuclear it’s public perception.” (UK Energy Industry Trade Body Policy Advisor)

“Since nuclear power stations tend to be sited in relatively sparsely populated areas, one potentially major issue would be the distance of the heat source (i.e. a nuclear power station) from any heat consumers (whether industrial, commercial or residential and particularly any high heat-density areas that offer the best chance of viability for a district heating scheme).” (UK Heat Network Operations Manager)

“Thereoretically you could connect [a heat network] to a nuclear power station, but as they are so far away from the centres of population, for understandable safety reasons, [that] the cost of piping the heat would be extremely challenging. It could be done, but I don’t know how people would feel about being heated by a nuclear power station.” (UK Heat Network Company Director)

These views are echoed within a subsequent report commissioned by the Committee on Climate Change by Dolman et al (2012) on heat networks connected to low carbon heat providers, including nuclear power plants. This report suggests that reactor location and negative public responses would be the key challenges for nuclear heat networks, although no empirical analysis was carried out on these issues (Dolman, Abu-Abid et al. 2012).

In addition to reactor location and public responses, issues that relate to the nuclear component of the technology, the scoping interviews also suggested a number of other barriers that apply to any heat network. They suggest explanations for the low penetration of heat networks in the UK (4% of heating services in 2009 (Koehler 2009)) relative to other northern European countries (8% in France, 14% in Germany and 61% in
Denmark\(^8\)). These barriers include the current UK energy market structure and how organisations make decisions about the heating systems they adopt. Interviewees suggested that these factors had a significant role in shaping past developments of UK heat networks and could be influential in determining future developments.

The three research areas identified by the scoping exercise, relating to the potential for nuclear heat networks in the UK can be summarised as:

- Understanding the non-technical issues that may shape nuclear heat network development. This includes barriers that limit all heat network development in the UK and identifying whether there are unique features about nuclear heat networks that should be considered.
- Exploring local resident responses to nuclear heat network technology as potential network users and as public groups reacting to nuclear heat network infrastructure in their area.
- Assessing the suitability of potential new nuclear sites in the UK for heat networks.

To develop the research framework further, a literature review of theoretical approaches to studying new technology developments was undertaken. This review helped to identify a theoretical perspective that influenced the research methods that were used and informed the analysis of research outputs. This review also highlighted relevant previous studies and knowledge gaps relating to the three research areas. This is discussed in the following section, firstly in terms of an overarching theoretical perspective, but also with specific reference to the research questions.

### 2.2. Research Framing

The research questions outlined in the previous section portray nuclear heat network development as being shaped by several factors that include broader social and

economic conditions, such as market structure and public opinion. The scoping exercise suggested that assessing the potential for nuclear heat networks in the UK would require a holistic view of technology development that takes into account social and economic contexts as well as an assessment of technical viability. There is a significant literature on how to conduct research on technology in social and economic contexts, frequently defined as ‘socio-technical’ approaches (Bhupatiraju, Nomaler et al. 2012) that was used to inform the research framework.

Socio-technical approaches build on critiques of how classical and neo-classical economic theories describe innovation and the diffusion of technology by evolutionary economics theorists (Bijker, Hughes et al. 1993; Beinhocker 2007; Geels and Kemp 2007; Geels and Schot 2007; Reason, Coleman et al. 2009). Within this approach technology development is conceptualised as a process shaped by pre-existing social, economic and technical contexts rather than a pre-determined pathway of linear technological improvement (Moore’s law for forecasting computer innovation and diffusion is a common example of the technological determinism approach socio-technical studies reject (MacKenzie and Wajcman 1999)).

The term ‘socio-technical studies’ captures a diverse field of research, comprising of approaches with a strong economic focus (typically defined as Innovation Studies) and approaches with a particular social focus (often grouped as Science and Technology Studies), which draw from economic and sociological research traditions respectively (Bhupatiraju, Nomaler et al. 2012; Martin, Nightingale et al. 2012). Socio-technical approaches have underpinned numerous studies of technology change, including approaches to studying transitions to low carbon energy systems; for example Unruh (2002), Elzen, Geels et al. (2004) and in Foxon and Pearson (2008).

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While the field of socio-technical studies is diverse, often with different typologies employed for similar concepts (Bhupatiraju, Nomaler et al. 2012), two particular theories of technology change are specifically relevant for this research. Firstly, socio-technical approaches see the outcomes of technology development as being more flexible and uncertain than may be assumed when looking at technological development with hindsight (Bijker, Hughes et al. 1993). Secondly, technology user and public responses to a technology are not considered to be the result of a rational and objective decision making processes. In socio-technical theories, in particular Science and Technology Studies (an interpretivist sociological approach to technology and science), users and other ‘actors’ have the power (agency) to respond to technologies in a number of different ways; a process which shapes technology outcomes itself (Bijker, Hughes et al. 1993).

These theories have been influential for the studying of processes of technology change and answer questions about why some apparently superior technologies (in a technical sense) fail to emerge while whole societies can be ‘locked-in’ to apparently inferior alternatives (Cowan 1990; Unruh 2002). Non-technical barriers to new technology developments, such as energy market structure and organisational decision making, that are highlighted in the scoping interviews for this research, are a particular focus of this form of research.

Theoretical approaches, that have developed from the Science and Technology Studies branch of socio-technical perspectives also address energy user and public responses to technology; specifically the agency of users and the public to interpret technologies in different ways also inform studies of user adoption of energy technologies such as Bijker (1995) and Hommels (2000) and public responses energy infrastructure including Devine-Wright (2005), Walker and Cass (2007) and McLachlan (2010). Socio-technical, 

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11 The definition of a ‘superior’ technology can itself be queried as this depends upon factors such as criteria and what has been invested and by whom. See MacKenzie, D. A. and J. Wajcman (1999). The Social Shaping of Technology. Buckingham, Open University Press.
'interpretivist' approaches to studying low carbon energy prospects have increasingly augmented, or been used as an alternative, to perspectives concerned with attitude and behavioural concepts of individual and groups responses to technology (Shove 1998; Shove and Walker 2007; McLachlan 2009; Nye, Whitmarsh et al. 2010). This study takes an interpretivist approach because it has also been shown to be very useful in understanding public responses to the risks posed by nuclear reactors in local areas in studies by Bickerstaff and Simmons (2009) and Parkhill, Pidgeon et al. (2010). They suggest local residents can have a different response to nuclear technologies than people who do not live with a potential hazard in their area. The focus on the influence local geography (proximity to nuclear reactors for example) makes this approach particularly appropriate because nuclear heat networks would be place specific (as new build is only planned for existing reactor sites and heat networks are localised).

In the next section the influence of socio-technical and interpretivist theoretical perspectives on the research framework is discussed in relation to each research question. This provides a rationale for the methods used to answer the research questions.

2.2.1. Non-technical Issues Relating to Nuclear Heat Networks

The initial scoping for the research framework suggested that the barriers to heat network infrastructure in the UK were non-technical; in the sense that social and economic factors rather than the performance of the technology restricts heat network development. These interviews identified similar financial barriers (particularly structural elements of the current energy market that act as a barrier to heat networks) as in reports by Macadam, Davis et al (2008), McNaught et al (2011)and Koehler (2009) and

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several non-financial barriers related to social, organisational and institutional factors. For example the interview responses highlighted possible inflexibility of some organisations such as supermarkets and hotel chains in adopting technologies that deviate from their standard building design to accept heat network connection (see Chapter 4).

The literature on socio-technical approaches to technology presents a well developed knowledge base for exploring the non-technical barriers, such as market structure, that were highlighted in the scoping exercise interviews. Concepts from the socio-technical studies literature have been used in various studies of technology change, such as Foxon, Gross et al. (2005), Geels (2002) and Elzen, Geels et al. (2004), that identify barriers and opportunities for technology change. This includes a study on heat extraction from large power plants for heat networks in the Netherlands that used as a historical case study to explore technology transitions (Raven and Verbong 2007) and a review how of UK and European social and economic contexts led to different outcomes for heat technology (Werner and Cutler 2004). More specific to this research framework, Reason, Coleman et al. (2009) used socio-technical theoretical approaches in a case study of the Southampton heat network in the UK that explores non-technical issues. There are, in addition, studies that specifically address the difficulties presented by organisational decision making towards new technology adoption, including Anderson and Tushman (1990), Coombs, Harvey et al. (Coombs, Harvey et al. 2003) and Dewick and Miozzo (Dewick and Miozzo 2004).

This previous work in the literature on these subjects helped to define and group interviewee responses on non-technical issues that are influential for heat network development. The initial interviews from the scoping exercise were supplemented by further interviews with participants involved in other heat networks. The aim of this was to investigate whether the type of thermal energy input used for a heat network influences these non-technical issues and alters how they shape the development of the infrastructure. The additional interviews covered a broader range of heat networks with geothermal, natural gas, waste incineration and nuclear energy inputs. This research
2.2.2. Energy User and Public Responses to Nuclear Heat Networks

Energy user and public responses to nuclear heat network technology were highlighted in the scoping interviews as highly significant issues to consider. The role of energy users in shaping technology outcomes is a particular focus of the Science and Technology Studies literature (Bijker, Hughes et al. 1993; MacKenzie and Wajcman 1999). Public responses to infrastructure development been identified as a very significant factor in the UK for causing controversy and opposition to new low carbon energy projects (Owens 2002; Devine-Wright 2005; Walker and Cass 2007). Nuclear heat network technology may be expected to be especially sensitive to public responses given the unique safety risks that are associated with nuclear fission (Pidgeon, Lorenzoni et al. 2008).

Energy user and public responses to energy technologies are often studied separately and inhabit separate although complimentary literatures. This may be because there is not often a direct link\textsuperscript{13} between energy infrastructure developments, which cause public responses, and technology adoption by energy users in the UK. Energy generation developments, such as onshore wind turbines, do not typically have a direct link to new technology adoption by energy users. Even if the development is directly connection to a local grid as opposed to the national grid, it does not necessitate local residents to adopt new technologies as part of the infrastructures development. Similarly when energy users adopt a new end use technology such as heat pump or a biomass boiler there is not necessarily an associated local energy generation development with broader impacts. A public response to heat pump installation is less likely because the direct impacts on the

\textsuperscript{13} It could be argued for example that a new onshore wind turbine will impact energy users in a local area indirectly through its impact on the electricity mix in terms of climate change mitigation and energy bills.
local residents are expected to be limited. For example, heat pumps can be installed in Manchester and supplied by new offshore wind turbines on the Welsh coast.

With nuclear heat networks new technology users have to be local to the new energy development. If a scheme is successful, the publics local to the infrastructure will also become technology users. User connection to heat network involves adopting a new technology (a heat network interface replacing a gas boiler etc) and connection has an impact beyond the user’s premises that affects the wider community. Installing heat distribution pipelines entails disruption to whole streets, and possibly towns, while the actual and perceived risks of nuclear heat networks are shared by the wider public and not limited to the energy users who opt for connection. Consequently the research for this theme required an approach compatible with both aspects of local resident responses.

In addition to considering local residents as potential public opposition and technology users, it was necessary to accommodate an understanding of the unique risk issues that apply to nuclear technologies into the research approach. Nuclear energy is considered controversial in the UK, particularly on grounds of public health risks (Pidgeon, Lorenzoni et al. 2008). It is noted in studies of the risk perceptions of UK residents however, that proximity to an existing nuclear facility can lead to different responses to nuclear risks (Bickerstaff and Simmons 2009; Parkhill, Pidgeon et al. 2010). These studies suggest that individuals and social groups attach different meaning to the same technology and that this informs their responses to nuclear technologies. They suggest that, for a number of reasons, energy users and publics with a local nuclear facility may respond differently to nuclear risks than those in other areas. This is particularly significant as new nuclear reactors are only proposed for sites adjacent to existing reactors in England and Wales. Sites without existing nuclear facilities were dropped from the list of new build options after public consultations (DECC 2011), perhaps reflecting the role of different public responses to the same technology. This research therefore applied an interpretation risk perspective when analysing research outputs.

14 There may be neighbours who object to a visual impact etc.
As the paragraphs above highlight, an interpretivist, sociological approach was adopted to studying local resident responses to nuclear heat network technology. Interpretivism underpins the three complimentary approaches that are useful for examining local resident responses to nuclear heat network technology and nuclear risks; Science and Technology Studies, energy infrastructure controversies, and interpretations of risk. These literatures are now discussed in greater depth.

Interpretivism implies individuals and social groups have the power to construct their own meanings of technologies based on past experience and social context (Bryman 2001). This concept is at core of Science and Technology Studies approaches to energy user technology adoption (Bijker, Hughes et al. 1993). Bijker (1995) discusses the interpretation of a technology as a ‘technological frame’ that defines the positive and negative responses users have to new technologies. The attributes of a technology, according to Bijker, may provide a solution or a problem for users depending upon their context and needs. For example if a heating technology requires additional space within a house (compared to a current system) and this is an issue that for a user that outweighs other benefits, this would negatively frame the technology. Hommels (2000) develops this concept further and focuses more firmly on how existing technologies affect the technological frame of users, by informing their expectations and acting as a reference for related problems and solutions (for example; how will this new technology compare to what I have now?). This is discussed as the ‘obduracy’ of existing socio-technical systems in the Science and Technology Studies literature, referring to how ingrained technologies and their associated routines and practices, become in everyday life (Hommels 2000).

Interpretivism also informs studies of energy infrastructure controversies, such as Devine-Wright (2005), McLachlan (2010) and Walker and Cass (2007). These studies emphasis the meanings local publics (the ‘public’ is not seen as a homogeneous group in this literature) assign to technologies and the locations they are being developed as very significant for understanding responses to infrastructure that include widespread
As discussed earlier, interpretivism has also been influential in studies of public perceptions of risk in the UK; for example in Parkhill, Pidgeon et al. (2010). They use examples from qualitative sociological studies of interpretations of nuclear risk to consider how risk perceptions may be affected by existing nuclear hazards in local areas (Parkhill, Pidgeon et al. 2010). This draws on work by Zonabend (2007), Bickerstaff and Simmons (2009) that use a case study approach to explore the role of proximity to industrial hazards such as nuclear power stations on public responses to technologies. In particular they suggest that local residents can ‘absent’ risk from their minds and not think about persistent dangers in their day-to-day lives (Bickerstaff and Simmons 2009).

To research local resident responses to nuclear heat networks from these three perspectives, a set of focus groups, with residents living near to an existing nuclear power station, were conducted. The focus group approach provides the type of qualitative research data required by interpretivist analytical perspectives (Bryman 2001). They allow a researcher to question participants about their responses and to ‘unpack’ particular answers to try and explore the thinking and assumptions behind them.

2.2.3. Suitability of UK Nuclear Sites for Heat Networks

The suitability of a particular site for a heat network depends upon a range of factors. The energy efficiency and financial viability of a heat network, which are important indicators of suitability, is dependent primarily upon the spatial distribution of connected users, their proximity to the thermal energy source and the annual connected demand (see Chapter 3). Socio-technical approaches portray the outcomes of energy technology development as uncertain and multi-directional (Bijker, Hughes et al. 1993). From this perspective, nuclear heat networks, if developed in the UK would be subject to a range of opposition (Devine-Wright 2005; Walker and Cass 2007; McLachlan 2009; McLachlan 2010).
different social and economic contexts that will shape the technical aspects such as which potential users connect and their annual energy use, in a variety of ways. To address this, a scenario approach which considers several different future outcomes from heat network development was used.

Scenarios are common in energy research, and the term covers a wide range of approaches and methods. Often, in relation to energy scenarios, three broad categories are used to differentiate approaches; predictive (forecasting), explorative (foresight) and normative (backcasting) (Berkhout, Hertin et al. 2002; Börjeson, Höjer et al. 2006). Börjeson et al suggest that the type of scenario that is chosen for research stems from the question being asked; "what will happen? (predictive [forecast]), what can happen? (explorative [foresight]) and how can a specific target be reached? (normative [backcasting]) (2006, p.725).” Typically predictive approaches involve carrying forward past trends with different assumptions that lead to a range of end points (McDowall and Eames 2006). Exploratory scenarios may have a similar ‘forecast’ approach to predictive scenarios, but focus on how events in the future may change these forecasts at different points. (Börjeson, Höjer et al. 2006). Normative approaches establish endpoints first and devise numerous pathways to reach them (Berkhout, Hertin et al. 2002; McDowall and Eames 2007).

A foresight scenario approach was considered most applicable to the research aims of this project. It accommodates uncertain future social and economic contexts by testing a range of different possible outcomes (Berkhout, Hertin et al. 2002). The ability to explore different outcomes is significant when assessing the suitability of new build reactor sites because different social and economic contexts can alter the performance of heat networks in terms of energy efficiency and costs (outlined later in this section). This approach fits with previous studies on heat network suitability. The scenarios build on research in James and Bahaj (2009) which used potential thermal output from nuclear reactors at the Hartlepool nuclear site to estimate the proportion of local heating demand a new build nuclear power station could supply based on thermal energy demand within a 10km radius. This work was a high level investigation that did not include in-depth analysis of individual sites or explore different future contexts. Studies
of UK heat network potential by McNaught, Williams et al. (2004) and Parsons Brinckerhoff (2009) (which omit nuclear CHP) however include detailed assessments of potential heat network sites in Scotland that consider different technology outcomes. They take an exploratory foresight approach by considers different user connection rates (the proportion of potential users in an area who opt for connection to a heat network) and geographic coverage areas (how far a network extends from the heat source). Both studies show how these variables affect the outcomes of heat network viability studies, by changing cost, revenue and efficiency indicators.

The studies by McNaught, Williams et al. (2004) and Parsons Brinckerhoff (2009) do not however include different outcomes from changes to energy use for heating (both use baseline historical data). Annual and peak user heating demand is a significant variable for heat networks (see Chapter 3) (Zinko, Bohm et al. 2008) and energy use for heating is expected to change over time as Government policies to improve energy efficiency continue to be applied (Committee on Climate Change 2008). The actual impacts of these policies on energy use cannot be predict accurately, particularly with regard to the ‘real world’ performance of energy efficiency measures (Shipworth 2011) and user practices (Chappells and Shove 2004), which have been shown limit actual energy efficiency improvements (Shove 2003; Shipworth 2011). This suggested a need to develop scenarios that account for different average heating use outcomes.

Exploring the suitability of potential nuclear sites in the UK for heat networks requires a full analysis of heat network function under a range of different annual and peak energy use, geographic coverage and user connection rate scenarios. In James and Bahaj (2009) the spatial distribution of heating demand was not considered, which limited the usefulness of the study as demand density is a crucial factor in determining heat network viability. To address this issue, a detailed heat network scenarios were developed for the Hartlepool nuclear site in the Teesside area of England. A single site was chosen given the depth of research required. James and Bahaj (2009) identified Hartlepool as a new build reactor site with the greatest potential for heat network application. This research theme included producing a heat demand density map using ArcGIS (a geographic information systems programme) that would show the distribution of energy users near the reactor
site and identify the clusters of high heating demand density best suited for heat networks. The map had to be adjustable in order to test different future energy use outcomes. This research project began before the Department of Energy and Climate Change (DECC) released an online heating demand mapping tool\(^{15}\) in 2011. Consequently a heating demand density map for the Teesside area, where the Hartlepool nuclear site is located, was developed specifically for the scenarios based on natural gas consumption data (see Chapter 8). This map could be altered to show changes to heating demand and graphically show changes in heating demand density. The demand density map allowed hypothetical heat networks to be drawn using ArcGIS. This allowed pipeline lengths in different geographic coverage and connection rate scenarios to measured, which informed cost and energy efficiency analysis.

As part of this research peak energy demand for users under different heating demand change assumptions (such high levels of demand reduction) was estimated to inform pipeline specifications (particularly pipe diameter) which was an important input for determining the maximum number of users that could be connected in a scenario and improved cost estimates (which vary by pipe diameter) that could portray heat networks under different energy use, geographic coverage and user connection rate variations.

High, medium and low cases for each of the three key variables (user energy demand, geographical coverage and connection rate) were used to produce twenty seven heat network scenarios. Each scenario resulted in heat networks with different attributes including annual thermal energy supplied to users, the efficiency of energy distribution (i.e. heat lost in the pipe network) and cost estimates. These outputs were compared to assess the suitability of the Hartlepool site under different conditions in terms of the low carbon heating they would supply, their efficiency (in distributing energy) and financial implications. This research feeds into the discussion of the potential for the utilisation of nuclear energy for low carbon heating in the UK in Chapter 10.

2.2.4. Interdisciplinary Approach to Research

The research approach is novel in that the specific research questions asked about nuclear heat networks in the UK cross physical and social science disciplinary boundaries:

- What are the specific barriers, technical and non-technical, to nuclear heat networks in the UK?
- What might be the response from local residents, both as possible technology users and as public groups be to a nuclear heat network?
- Given the spatial relationships between proposed new build nuclear sites and potential heating demand centres, how might nuclear heat networks perform against energy efficiency, CO₂ mitigation and financial indicators under different socio-economic development scenarios?

To answer these questions a unique combination of research methods were applied in a single, integrated interdisciplinary work programme that included GIS spatial analysis, quantitative energy scenarios, focus groups and expert stakeholder interviews. This approach required developing competency in the different research methods through training and working with experienced practitioners. A course on using ArcGIS in research was completed in the first year of the project and there was participation in a complimentary research project (Process Industry Thermal Energy Management PROTEM) to develop focus group and interview skills. The research framework, outlined above, used Science and Technology Studies theory to conceptualise how social approaches were embedded in the scenario development process and inform the later analysis. By using the focus group and expert interview data to determine the variables applied in the technical scenarios the distinct research methods were aligned into a single body of work that is cognisant of social and technical aspects of the technology.
3. Review of Technologies

This chapter provides an overview of nuclear heat network technology. It provides a background for the technical aspects of the technology discussed in later chapters. It begins by describing the new build nuclear reactors planned for the UK, the technical attributes that make them suitable for low carbon heat supply and the aspects that make the technology controversial. This is followed by a description of combined heat and power (CHP), whereby reactor thermal outputs can be utilised through heat networks. It then presents how heat networks distribute thermal energy to users and gives examples of nuclear heat networks in Europe and Russia.

3.1. Nuclear Fission Reactors

Nuclear fission has been used to provide energy (typically electricity) since the 1950s (Tester, Drake et al. 2005). Although it is a low carbon energy source (Fthenakis and Kim 2007; Weisser 2007; Manfred 2008), and a well developed technology (supplying 16% of world electricity demand in 2006 (Sims, Schock et al. 2007)), the potential risks associated with it make increasing nuclear capacity a contentious issue. While countries such as the UK (DECC 2011) and China\(^{16}\) have plans for significant new nuclear developments in the coming decades, Germany (Umweltbundesamt 2011) and Japan\(^{17}\) are currently considering pathways that will close existing nuclear power stations and prohibit new construction. This section discusses nuclear fission technology in terms of its benefits and risks. It provides an overview of the features that make it an attractive option for lowering national greenhouse gas emissions and the negative attributes which prompt opposition to new build programs.


3.1.1. Nuclear Fission Process

Nuclear fission is the splitting of a heavy atomic nucleus (a collection of neutrons and protons) into smaller (lighter) atomic nuclei. A nuclear fission reaction is initiated when ‘free’ (i.e. not paired with a proton) neutrons are made to interact with an atomic nucleus that is susceptible to fission (fissile material). When a neutron ‘strikes’ a fissile atomic nucleus the nucleus becomes highly unstable causing it to split apart. Uranium-235 ($^{235}\text{U}$) is the only naturally occurring, terrestrial element currently suitable for sustained fission reactions, (although man-made fissile material can also created\(^{18}\)) (Hewitt and Collier 2000).

During fission some of the heavy atom’s mass is converted to energy in the form of ionising radiation (alpha, beta and gamma) and kinetic energy (Hewitt and Collier 2000).\(^{19}\) Gamma radiation and kinetic energy manifests as thermal energy, which can be used for energy services. Fission also liberates additional neutrons that can cause further fission reactions if they interact with neighbouring fissile material. The result, if correctly controlled, is a nuclear chain reaction, which continues until the available fissile material has been ‘burned up’ or there is an intervention to prevent further neutron interaction (for example inserting control rods, as discussed later) (Hewitt and Collier 2000).

3.1.2. Nuclear Reactors

Controlled nuclear fission is enabled by a reactor that sustains and regulates the fission process. Reactors have four main components; a fuel assembly, a moderator, a coolant and control rods. Different variations and combinations of these components can be used depending upon the reactor design concept, as shown in Table 1:

\(^{18}\) Plutonium 239, a product of nuclear fission, is also useable fissile material and Thorium- 232 isotopes can be used to ‘breed’ fissile Uranium- 233. These fuel cycles are currently more expensive than natural uranium fuel cycles and not currently used commercially. See IAEA (2005). Thorium Fuel Cycle; Potential Benefits and Challenges Vienna, International Atomic Energy Agency. IAEA-TECDOC-1450.

\(^{19}\) Neutrinos (a sub-atomic particle) are also released, but have no noticeable effect on the fission process within a reactor core. They do however transfer energy from fission out of the core (this energy is not included in the reactor’s thermal output rating). Tester, J. W., E. M. Drake, et al. (2005). Sustainable Energy: Choosing Among Options. Cambridge, The MIT Press.
<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Specification</th>
<th>Fuel</th>
<th>Safety Issues</th>
<th>Cost Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Water Reactor (BWR)</td>
<td>Light Water Reactor</td>
<td>Water coolant and moderator. Single loop system where core heated coolant is fed directly into steam condensing cycle.</td>
<td>Enriched uranium oxide fuel with zircaloy cladding</td>
<td>Common moderator and coolant means a loss of coolant slows fission to mitigate core melt down. Single loop coolant systems mean radioactive tritium from the reactor core is circulated through the turbine, leading to corrosion.</td>
<td>The Reactor must be shut down to refuel, which can take 6 weeks, reducing revenue.</td>
</tr>
<tr>
<td>Pressurized Water Reactor (PWR)</td>
<td>Pressurized Water Reactor (PWR)</td>
<td>Water Coolant and Moderator. Heavy steel pressure vessel. Steam generators separate from reactor vessel.</td>
<td>Enriched uranium oxide fuel with zircaloy cladding</td>
<td>A common moderator and coolant to mitigate core meltdown. Secondary coolant loop system to prevent radioactive steam circulating through steam turbines.</td>
<td>Capital cost is relatively low. The Reactor must be shut down to refuel, which can take several weeks.</td>
</tr>
<tr>
<td>EPR (European Pressurised Water Reactor)</td>
<td>EPR (European Pressurised Water Reactor)</td>
<td>Evolution of the PWR design. Four loop cooling system.</td>
<td>Enriched uranium oxide fuel with zircaloy cladding</td>
<td>As with PWR but with additional core meltdown mitigation measures such as double containment with ventilation and filtration, core cooling area, containment heat dispersal, water reserve inside containment and four redundant safety systems.</td>
<td>High electricity output, and improved thermal efficiency from earlier PWR designs. Lower uranium consumption.</td>
</tr>
<tr>
<td>AP1000</td>
<td>AP1000</td>
<td>An evolution of the PWR design</td>
<td>Enriched uranium oxide fuel with zircaloy cladding</td>
<td>As with PWR, but including 'passive' safety features that use gravity for coolant circulation replacing 'active' electrical pumps.</td>
<td>Reduction in components (pumps and pipes etc) leading to potentially faster construction period and lower costs.</td>
</tr>
<tr>
<td>Heavy Water Reactor</td>
<td>Canadian Deuterium-Uranium Reactor (CANDU)</td>
<td>Heavy water is used as the coolant and moderator. Individual fuel bundle pressurized coolant channels.</td>
<td>Non-enriched uranium oxide fuel with zircaloy cladding</td>
<td>Short (6month) refuelling cycle enables a consistent core environment that prevents build up of hazardous fission products over long time. Individual fuel rod pressure vessels have safety benefits over single high-pressure vessels.</td>
<td>Can be refuelled without shutdown. Fuel does not need to be enriched. Heavy water is very expensive and energy intensive to produce.</td>
</tr>
<tr>
<td>---------------------</td>
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<td>---------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Advanced CANDU Reactor (ACR 1000)</td>
<td>Light water coolant, heavy water moderator.</td>
<td>Low enriched uranium oxide fuel with zircaloy cladding</td>
<td>Similar to CANDU.</td>
<td>Similar to CANDU, but by using light water instead of heavy water as a coolant costs are reduced.</td>
<td></td>
</tr>
<tr>
<td>Graphite-Moderated Reactor</td>
<td>Magnox</td>
<td>Graphite-moderated reactor and CO2 coolant.</td>
<td>Non-enriched uranium oxide fuel in magnesium alloy casing.</td>
<td>Low energy density in reactor core means thermal output changes take longer, giving an operator longer to respond to core problems, than with light water reactors. Corrosion issues related to fuel casing and CO2 coolant interaction with graphite.</td>
<td>Fabricating specialist fuel and managing graphite corrosion issues.</td>
</tr>
<tr>
<td>High-Temperature Gas Cooled Reactor (HTGR)</td>
<td>High temperature (850°C) Helium coolant, graphite moderator.</td>
<td>Highly enriched U-235 oxide coated 'kernels', arranged in a 'pebble bed' configuration</td>
<td>Helium coolant removes graphite oxidisation problems, design prevents pressurised steam explosions. Potential risks include graphite becoming flammable; a reactor fire would release radioactive iodine-131.</td>
<td>Can operate at higher temperatures and is therefore more efficient. There have been examples of this type of reactor failing to work as expected.</td>
<td></td>
</tr>
<tr>
<td>Boiling Water, Graphite moderated Direct Cycle Reactor (RBMK)</td>
<td>Graphite moderator, water coolant.</td>
<td>2% enriched uranium oxide in zircaloy casing.</td>
<td>Problems identified with motor driven shutdown rods and core flooding system. Reactor unstable at low output (below 20%)</td>
<td>No longer a viable design</td>
<td></td>
</tr>
<tr>
<td>Fast Breeder Reactor</td>
<td>Liquid Metal Fast-Breeder Reactor (LMFBR)</td>
<td>Fission using 'fast' neutrons. No moderator. Liquid sodium coolant.</td>
<td>Highly enriched uranium fuel produces plutonium - 239 which also undergoes fission</td>
<td>Liquid sodium does not require high pressure, reducing steam explosion risk, but burns in contact with air. The fast neutron fission process can lead to rapid power build up, leading to potential nuclear explosions.</td>
<td>More fission material can be 'burned up', reducing fuel input and waste. High construction and operating costs mean it is uncompetitive with other reactors.</td>
</tr>
</tbody>
</table>

Table 1: Overview of Reactor Types. Sources; (Hewitt and Collier 2000; Framatome ANP 2005; Tester, Drake et al. 2005; Abram and Ion 2008)

The following overview of key nuclear reactor core components focuses on light water technology, in particular the pressurised water (PWR) variant. PWRs are most common reactor type in the world (Tester, Drake et al. 2005), and this reactor concept underpins the two reactor designs that are undergoing the UK Generic Design Assessment\(^{20}\) for deployment in the UK; the Westinghouse AP-1000 and the Areva Evolutionary Pressurised Reactor\(^{21}\) (EPR).

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\(^{21}\) Sometimes referred to as the European Pressurised Reactor.
3.1.2.1. Fuel Assembly

Uranium dioxide (UO$_2$) fuel is used in reactor designs such as the AP-1000 and the EPR.\textsuperscript{22} Fissile $^{235}$U isotopes are found in uranium ore with the non-fissile Uranium-238 ($^{238}$U) isotope.\textsuperscript{23} $^{235}$U constitutes only between 0.25%-3% of naturally occurring uranium ore (although high grade ores of 1-3% are increasingly rare) (Sovacool 2008). For light water reactor designs natural uranium ore is not suitable for nuclear fuel. The uranium ore is milled to produce a uranium oxide, then enriched to make a UO$_2$ compound that is typically 3% $^{235}$U and 97% $^{238}$U (Hewitt and Collier 2000). This material is then formed into pellets that are placed into zirconium alloy\textsuperscript{24} fuel ‘rods’ which are bundled together for insertion into a reactor core (Hewitt and Collier 2000). A reactor core contains hundreds of fuel bundles (the number varies based on reactor design) that are typically replaced at 6-18month intervals after the $^{235}$U in the fuel bundle has undergone fission (Tester, Drake et al. 2005).

3.1.2.2. Moderator

Successful, stable chain reactions require control of the speed of neutrons moving through the nuclear core. This is done by using a moderator to slow the movement of free neutrons within the reactor core. If neutron movement is too fast there is not sufficient interaction with fissile material, which halts the chain reaction process (Tester, Drake et al. 2005). A moderator slows neutrons as they pass through it making them more likely to be absorbed by fissile nuclei (Tester, Drake et al. 2005). Graphite and water are commonly used moderators with water used in both the AP-1000 and EPR reactor designs.

\textsuperscript{22} Alternatives include a mixture of uranium oxide and plutonium oxide (mixed oxide, or MOX fuel).

\textsuperscript{23} Isotopes are variations of the same element with different numbers of neutrons. Uranium 235 has three fewer neutrons that Uranium 238, causing it to be less stable Hewitt, G. F. and J. G. Collier (2000). Introduction to Nuclear Power. New York, Taylor and Francis.

\textsuperscript{24} Zirconium provides a durable casing that does not significantly infer with the movement of neutrons within the reactor core Ibid.
3.1.2.3. Coolant
Coolants transfer thermal energy from the reactor core. This maintains core temperature at a safe level and provides thermal energy to generate steam\textsuperscript{25} for power generation or other thermal applications, such as water desalination and hydrogen production (Kupitz and Podest 1984; Utgikar and Thiesen 2006; Naterer, Suppiah et al. 2009). Coolant types range from water, which can be used in lower temperature reactors (\(~260^\circ\text{C}\)) to CO\textsubscript{2} gas and molten salt compounds used in high temperature reactors (600°C to 850°C) (Tester, Drake et al. 2005; Abram and Ion 2008). The coolant is circulated through the reactor core, either by a pump or natural circulation as in the AP-1000 and EPR reactor concepts (Framatome ANP 2005; Sutharshan, Mutyala et al. 2010).

Light water reactors have water for cooling and moderating. This means a loss of coolant from a leak also means a loss of moderator, which interrupts the nuclear chain reaction; a feature that mitigates the potential for a core melt down (Tester, Drake et al. 2005).

3.1.2.4. Control Rods
Control rods act as a neutron ‘poison’. They are made of an element which can absorb high numbers of neutrons without undergoing fission, such as boron (Hewitt and Collier 2000). Control rods can be inserted and retracted to control the neutron population in the reactor core as a means of altering energy output (Hewitt and Collier 2000). When they are fully inserted they can halt the nuclear chain reaction, stopping further reactions and leaving only thermal energy outputs from residual fission reactions and radioactive decay in the core (Hewitt and Collier 2000).

3.1.3. Nuclear Fission as a Low Carbon Technology

Nuclear fission reactors are classed as a low carbon energy technology (Fthenakis and Kim 2007; Weisser 2007; Manfred 2008; Sovacool 2008). The direct GHG emissions attributed to nuclear reactor operation are negligible (Manfred 2008), however there are emissions associated with the nuclear fuel cycle and the reactor building. Emissions from the nuclear fuel cycle are attributed to the mining, milling, enrichment and fabrication of nuclear fuel as well as its storage and long term disposal or reprocessing after use (Manfred 2008). The emissions from the reactor building pertain to the emissions associated with the energy used in the construction process, particularly the large quantities of concrete that are used, and the decommissioning of a reactor site (Manfred 2008; Sovacool 2008).

![Diagram of the nuclear fuel cycle](image)

**Figure 2: Life-Cycle Emissions for a Reactor with a Once Through Fuel Cycle (without fuel reprocessing).**

Life-cycle emission estimates for new build reactor types range from 2.8gCO$_2$e/kWh to 24gCO$_2$e/kWh (Weisser 2007). This compares favourably with unabated natural gas, which ranges from 360gCO$_2$e/kWh to 575gCO$_2$e/kWh and is within a similar range as onshore wind (8gCO$_2$e/kWh to 30gCO$_2$e/kWh) (Weisser 2007). All of these estimates are based on lifetime electricity generation potential of each technology. The long operating periods expected for nuclear power stations (up to, and in some cases, over 60 years) contribute to low life-cycle emissions (Sovacool 2008).
The range of estimates for nuclear life cycle emissions is broad as a result of different assumptions when calculating emissions for key processes. Reactor type, the quality of uranium ore and the enrichment process used are the main variables in life-cycle emission estimates (Weisser 2007; Sovacool 2008). Reactor type influences how efficiently nuclear fuel is used (the useful energy outputs achieved for the fuel consumed) and the embodied emissions in the reactor construction (Weisser 2007). Uranium ore quality affects the emissions from mining and milling. Low grade uranium ore (with low concentrations of $^{235}\text{U}$) requires more mining and milling in order to meet the level of enrichment needed for nuclear fuel in comparison with high grade ore (Weisser 2007; Sovacool 2008). If centrifuges or laser techniques are used for enrichment instead of gas diffusion processes, energy inputs for enrichment are reduced (Weisser 2007; Sovacool 2008). Emissions from enrichment can be reduced if the electricity consumed to power the enrichment process comes from a low carbon electricity grid in the future (Sovacool 2008).

### 3.1.4. Nuclear Waste, Safety and Cost

While nuclear fission offers the potential to generate large amounts of low carbon energy, the processes involved can pose significant risks to human health and the environment. Fear about the harmful effects of ionising radiation from the nuclear process is a key reason for opposition to nuclear technology (Pidgeon, Lorenzoni et al. 2008). Furthermore the need to manage these risks, in terms of safety features incorporated into reactor design, insurance, securing long term storage of hazardous waste and safe decommissioning, increase the costs of associated with nuclear energy (Sims, Rogner et al. 2003).

The fission process releases large amounts of radiation that under normal operating parameters is contained within the reactor building. A breech in containment poses immediate risks to the local environment and human population and can result in significant health, environmental, social and economic detriments. An example of this is
the Fukushima Daiichi nuclear disasters in March 2011. Containment was breached at three reactors on the Fukushima Daiichi nuclear site in Japan as the result of a large tsunami destroying the operator’s ability to control reactor core temperatures. The core meltdowns and an explosion in one of the reactor containment vessels released radioactive fission products into the air and water (leading to land contamination also). This led to mass evacuations within 25km of the reactor, displacing around 100,000 people. It took several months to bring the reactor cores under control. This highlights the immediate risks from nuclear reactors for local residents.

The Fukushima event also shows the potential economic damage a nuclear incident can do, both in terms of the costs of dealing with a disaster (such as relocating large numbers of people and decontamination) and in lost electricity generating capacity. The overall cost of the Fukushima nuclear disaster will include disaster response costs, compensation to affected individuals and organisations, and higher energy bills from increased energy imports.

In addition to operating risks, nuclear reactors produce hazardous wastes that have long term impacts. A number of fission products are produced within reactors including medium-lived products such as caesium-137 that pose a radiation risk for decades after fission, and long-lived products such as iodine-129 which remain a radioactive biohazard for millions of years (Hewitt and Collier 2000). Long-lived ‘high-level’ waste is a relatively small proportion of overall nuclear waste (Gilchrist 2006). The UK’s current inventory of high-level waste is 0.067% of total waste produced by UK reactors since 1954 by volume (Gilchrist 2006). It does however require long term secure storage to prevent safety and security hazards as fission products like Plutonium-239 have the potential to be made into nuclear weapons (Hewitt and Collier 2000). Long term storage is likely to require the construction of a secure geological vault (DECC 2011). The long lived nature of the risk

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27 Ibid
28 Ibid
29 As of September 2012 accurate figures on total costs were not available. A possible cost of $1billion (~£616million) is estimated. See Aaron Sheldrick, (2012), Japan to Take Over Tepco After Fukushima Disaster, Available at: http://www.reuters.com/article/2012/05/09/us-tepco-idUSBRE84802220120509, (Accessed 12 September 2012).
posed by this waste raises inter-generational equity issues, as the legacy of nuclear waste will outlast the people who benefited from nuclear energy (Pickard 2010).

The proliferation of nuclear weapons is another risk of current fission technology.\textsuperscript{30} Nuclear reactors such as Calderhall, the UKs first nuclear power station, were initially developed to produce materials that can be used in nuclear weapons (Hewitt and Collier 2000). The risks of increased nuclear weapon proliferation is a key concern of the International Atomic Energy Agency (Kang 2005). Although public surveys in the UK suggest fears of nuclear weapon proliferation have decreased since the end of the Cold War, Pidgeon, Lorenzoni et al. (2008) suggests this still influences perceptions of nuclear energy.

Cumulatively, these issues may lead to apprehensions about nuclear fission technology. The location of new nuclear reactors in the UK has been limited to exiting nuclear sites in England Wales after new sites at Kirkstanton and Braystones in England were rejected on the grounds of public opposition (DECC 2011). Similarly, the Scottish Government oppose new nuclear reactors, meaning the four existing nuclear sites in Scotland will not have new build reactors (DECC 2011).

3.1.5. Summary

Despite the risks posed by nuclear energy, it is significant low carbon resource. As a thermal power station it can provide constant ‘baseload’ electricity output that is complimentary to more intermittent renewable energy sources (DECC 2011). The risks posed by the technology do however mean that new build reactors are unlikely on sites other than those with existing reactors, many of which are not optimally located for heat networks (Dolman, Abu-Abid et al. 2012). The following sections provide an overview of the way in which the thermal energy produced by reactor cores can be utilised for heating services.

3.2. Combined Heat and Power

This section provides an overview of combined heat and power (CHP) technology. CHP, also known as cogeneration, is the process that would be applied to new build nuclear power plants in the UK to enable the utilisation of nuclear energy through heat networks. It is an alternative to the electricity only design currently proposed for the AP-1000 and EPR nuclear facilities that increases the proportion of nuclear energy recovered for energy services. This section describes how CHP can enable greater use of a low carbon resource and improve the overall efficiency of a nuclear power plant.

3.2.1. Condensing Steam Cycle

The most common application for nuclear energy is generating pressurised steam (Tester, Drake et al. 2005). Although there are different options for using this thermal energy output, such as water desalination (Kupitz and Podest 1984) and hydrogen production through the thermochemical decomposition of water (Naterer, Fowler et al. 2008; Orhan, Dincer et al. 2009), electricity generation is the common application for nuclear energy (Barnert, Krett et al. 1991; Hewitt and Collier 2000).

Nuclear power plants produce electricity through a condensing steam cycle;
High grade heat (able to do work, such as move turbine blades), in the form of steam, passes through a series of turbines which generate electricity. Upon leaving the turbines the steam cools and condenses to water. A heat sink, such as sea water or a cooling tower, is used to lower the water to a temperature suitable for return to the steam generator. A low return temperature ensures that the water can transfer the maximum amount of heat from the reactor core cooling loop possible in the steam generator (Tester, Drake et al. 2005).

At high temperatures (over 600°C) condensing steam cycles can convert up to 42% of the thermal energy in the steam cycle to electricity (thermal efficiency) (Harvey 2006). Steam at this temperature requires high temperature nuclear reactor technology (such as the Advanced Gas Cooled reactor on Table 1). The light water reactors planned for the UK only reach temperatures sufficient for thermal efficiency of between 35-37% (Framatome ANP 2005; Sutharshan, Mutyala et al. 2010). This means that almost two thirds of reactor thermal output from new build reactors in the UK would not be utilised.
3.2.2. Heat Extraction from Steam Cycles

Condensing steam cycles can be adjusted to operate as combined heat and power plants by extracting heat from the cycle to be used for heating services through a heat network. As discussed in the following section, heat networks typically require operating temperatures of 90-120°C (Skagestad and Mildenstein 2011). The temperature of steam condensate leaving the low pressure turbine of a power plant is therefore too low for this application. Steam with sufficiently high temperature has to be diverted from the turbine stage of the steam cycle to achieve the required temperature for a heat network:

In the CHP process a proportion of thermal energy is diverted from the turbines and passed through large heat exchangers (HE1 and HE2). Removing this energy from the turbine reduces electricity output; how much depends on the temperature and quantity of steam that is extracted (Harvey 2006). For example an 80°C extraction temperature means 0.11 units of electrical energy are lost per unit of thermal energy, whereas 0.35 units of electrical energy are lost when extraction happens at 240°C (Harvey 2006). The
number of thermal units recovered for heat network application per unit of lost electrical output is referred to as the Z-factor (sometimes the heat to power ratio). Multiple stage extraction, at different points in the steam cycle, as shown in the above figure, can minimise the loss of electricity output. The extraction of high temperature steam is reduced by using lower temperature steam, less useful for electricity generation, from a low pressure turbine to pre-heat water for a heat network. This results in a Z-factor of 8.3, meaning 8.3 units of thermal energy are obtained for heat network distribution for every unit of lost electricity output (Harvey 2006). Multi-stage extraction increases efficiency by 20% over single stage extraction (Handl 1998).

3.3. Heat Networks

Heat networks are a transmission infrastructure that link thermal energy sources to heating services users. Hot water is circulated by pumps through a closed circuit of highly insulated underground pipes. The pipes deliver heat to a user’s heating system and return the water at a lower temperature for reheating.

Heat exchangers facilitate the transfer of thermal energy between different stages of a heat network system:
The consumer interface for domestic and commercial end users has developed from a passive system in which heat users had no control over their space heating and hot water temperature, to a programmable and variable interface (Skagestad and Mildenstein 2011). The interface includes two heat exchangers so that space and water heating within the consumer’s building can be separate loops and a control panel to set temperature and programme when the system operates. The exchangers transfer heat from the district heating network to building space and water heating systems and uses a thermostat to stop the transfer of thermal energy when the required outflow temperature is reached.

Figure 5: Simplified Diagram of a Nuclear Heat Network
3.3.1. Heat Network Performance

Heat network performance, in terms of energy lost in distribution and financial viability is dependent upon the configuration of the network. The following section outlines how factors such as the spatial distribution of users and their heating demand characteristics affect network configuration and performance.

Thermal energy loss in a heat network may be as low as 5%, but in some cases as high as 50% (Zinko, Bohm et al. 2008). The thermal energy wasted in distribution impacts on the...
efficiency and the financial viability of a scheme. Thermal loss ($Q_c$) in a heat network can be expressed in a simplified way as;

$$Q_c = \text{temperature difference} \times \text{heat transfer coefficient}$$

Here, the temperature difference is between the internal temperature of a closed system (e.g. a heat network pipe) and the surroundings (e.g. the ground the pipe is installed in). The heat transfer coefficient takes into account the thermal conductivity of the boundary material (separating the system and the surroundings, in this case the pipe), how thick it is and its surface area (the length and diameter of the pipe) (Harvey 2006). This shows how heat loss increases with the length of distribution pipe (an increase in surface area for heat loss to take place) and the importance of insulation in the pipe network and the benefit of a low distribution temperature.

The distance between the energy source and end users determines the length of the main distribution pipe. While close proximity is desirable there are examples of large main distribution pipes conveying heat hundreds of kilometres. In some Danish cases a heat source may be 15km from the first end user. Greater heat loss occurs however as the length of service pipe (that links end users to the main distribution pipe) increases (Zinko, Bohm et al. 2008). Linear line density is used to describe the units of heat delivered per meter of pipe (kWh/m), this figure is high where demand is dense and low in sparse demand areas:

![Figure 7: High Linear Line Density](image-url)
Line heat density means that heat networks perform better when connected users with high annual energy demand are grouped closely together. This is influenced by annual demand of users, the proportion of users within an area who connect and the how large an area the network covers. Reductions in annual user heating demand, low connection rates (effectively lowering the concentration of connected users) and large coverage areas have the effect of reducing line heat density and therefore heat network performance.

3.4. Nuclear Heat Network Application

Nuclear heat network technology has already been applied in a small number of cases. Very little published work on these nuclear heat networks is available in English, and no scheme has been developed since 1984. This section provides a summary of nuclear heat network examples based on available data.

The world’s first nuclear district heating project was the 10MWe Agesta reactor that supplied the Farsta suburb of Stockholm with 70MWt between 1964 and 1974 (Margen 1978). Agesta was a reactor situated 15km outside of central Stockholm that was designed for combined heat and power use (Margen 1978). A state company, Vattenfall AB, operated the reactor and the heat network until the reactor was closed and alternative thermal sources were added to the heat network (Margen 1978).
In the 1980’s energy planners in the Soviet Union used the principle that “nuclear plants, as thermal power stations, can provide heat to consumers where there is a concentrated load” (Markov, Beschinsky et al. 1987, p. 945). Heat for industrial and domestic use was supplied from the Bilibino and Beloyarsk WWER (light water cooled and moderated) reactors in Russia (Panasenkov, Sychev et al. 1984). Following the collapse of the Soviet Union no new nuclear heat networks have been developed in Russia.

There are two Swiss examples of nuclear CHP. The Gösgen nuclear reactor started supplying industrial process steam (at 220°C) to a nearby card factory in 1979 (Handl 1998). In 1983-1984 two PWR reactors at Beznau were equipped with heat exchangers to supply 141GWh of heat to a district heating scheme, which by 1997 served 2,160 customers on a 35km mains network (plus 85km of smaller distribution pipelines) (Handl 1998). Westinghouse pressurised water reactors (PWR) were retrofitted with heat exchangers (Handl 1998). The AP-1000, planned for the UK is an evolution of the same reactor design. The Beznau site has two reactors with separate steam condensing turbine halls. Heat extraction is applied to both units for the heat network meaning that during scheduled shutdowns for maintenance, one reactor is supplying heat while the other is offline. In case both reactors go offline back-up oil boilers are maintained. The system includes a central pumping station, pumping substations, heat storage reservoirs, the network piping and customer heat exchangers.

The Beznau case is the most useful example of nuclear heat network technology. It has been functioning for over two decades, covers a relatively large area and shows the potential to retrofit PWRs with heat exchangers for use with heat networks. As a currently operating example of the technology participants of the Beznau scheme were interviewed as part of the non-technical issues research theme. Other examples, such as Agasta in Sweden have been decommissioned for decades, while there is very little information available about the Bilibino scheme in English.
4. Non-technical Influences on Nuclear Heat Networks

This research theme addresses social and economic (non-technical) factors that may be influential in determining the outcome of nuclear heat network development in the UK. It assesses heat networks firstly as an input neutral energy distribution technology to understand the generic challenges for heat networks in the UK. It then considers the role of thermal input technology in shaping heat network systems, something currently absent from the existing literature. This research aimed to determine whether significant non-technical barriers might exist that would constrain the potential for nuclear heat networks in the UK.

Nineteen expert interviews were conducted and analysed. They identified energy user and public responses to nuclear energy as the only non-technical particular to nuclear heat networks (an issue discussed as part of Chapters 6 and 7). The interviewees did not believe that the nuclear component of the system would necessarily lead to additional regulatory, institutional or financial barriers.

The research findings also complement and expand upon the findings of previous studies on the role energy market structure and local authorities in providing barriers and opportunities. These findings have implications when considering the suitability of potential new nuclear sites for heat network development. They point to social and economic contexts that could facilitate large network developments, and those that could limit development.

4.1. Research Context

There have been previous studies that have attempted to understand why heat networks represent a low proportion of the UK energy mix in comparison with other northern
European countries (4% of heating users in the UK (Koehler 2009) compared to 8% in France, 14% in Germany and 61% in Denmark\textsuperscript{31}). Reason et al. (2009) apply a socio-technical perspective to a case study on the Southampton heating and cooling network. Babus'Haq and Probert (1994), and Werner and Cutler (2004), include historical comparisons of UK and European energy markets to explore the reasons for the low penetration of heat networks in the UK. Toke and Fragaki (2008) discuss the impact of liberalised energy markets on limiting heat network development in the UK. These studies all suggest that the UK energy market structure and the institutional governance of energy systems in the UK are key issues that define heat network development. Reason et al. (2009) go further and also identify energy user decision making, when heat network connection is offered, as an important consideration.

The pathway of energy policy in the UK is seen as a significant underlying factor that explains the lack heat network development in Babus'Haq and Probert (1994), Werner and Cutler (2004) and Toke and Fragaki (2008). These studies suggest that nationalisation of the UK energy sector in the 1940s and the related centralisation of decision making, then the rapid (relative to the European context) transition to a liberalised energy market model during the 1990s produced unfavourable economic and institutional frameworks for heat network development (Babus'Haq and Probert 1996; Werner and Cutler 2004). A contributing and enabling factor may also have been the availability of resources, firstly coal, then North Sea gas which did not incentive energy efficiency policies, which have in other cases promoted heat network development. In the Netherlands for example, heat networks were promoted by the national government because they enabled a more efficient use of Dutch natural gas at a time when energy security was a major driver (Raven and Verbong 2007).

All studies, with the exception of Raven and Verbong (2007), emphasise the role of local governance institutions (municipal authorities) in promoting heat network development in the leading European examples of heat network uptake such as Denmark and Germany (Babus'Haq and Probert 1996; Werner and Cutler 2004). The importance of

local authorities in providing leadership as well as financial and administrative support for heat network development in the UK is supported by Reason et al. (2009). This study points out that successful examples of heat network development in the UK, such as Sheffield, Southampton and Nottingham have all had significant local authority involvement (Reason, Coleman et al. 2009).

4.2. Research Method

The interviews carried out as part of this research began as a scoping exercise to define the key research questions relating to nuclear heat networks. Ten interviews were conducted with experts on UK heat networks, a nuclear heat network in Switzerland and UK nuclear regulators (the Health and Safety Executive’s Office of Nuclear Development and the Environment Agency). This was expanded to include nine more interviews with eight interviewees (one interviewee was interviewed twice further clarification) who have experience of heat network development.

In total twelve individuals with direct experience of developing and operating heat networks in the UK and two experts with experience of nuclear heat networks were interviewed. This was complimented by interviews with two government agencies (the Environment Agency and the Health and Safety Executive) involved in nuclear energy regulation regarding specific regulatory issues that might arise from a nuclear heat network development in the UK. In addition there were also interviews with two local authority representatives involved with developing new heat networks in their administrative jurisdictions. The first ten interviews were carried out between March and November 2010. The additional interviews were conducted between April 2011 and June 2012.
<table>
<thead>
<tr>
<th>Job Title at Time of Interview</th>
<th>Role</th>
<th>Interview Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Technical Advisor</td>
<td>Network operations manager for large nuclear heat network in Switzerland</td>
<td>09/03/2010</td>
</tr>
<tr>
<td>2 Strategy Manager</td>
<td>Policy manager for a combined heat and power/heat network industry trade body</td>
<td>26/03/2010</td>
</tr>
<tr>
<td>3 Regulator</td>
<td>UK nuclear energy regulation</td>
<td>29/03/2010</td>
</tr>
<tr>
<td>4 Academic</td>
<td>Leading figure in the development of one of the UK's largest heat networks</td>
<td>20/04/2010</td>
</tr>
<tr>
<td>5 Maintenance Manager</td>
<td>Liaison with social housing tenants connected to a heat network</td>
<td>26/07/2010</td>
</tr>
<tr>
<td>6 Sustainability Policy Manager</td>
<td>Liaison between local authority and heat network operator</td>
<td>24/08/2010</td>
</tr>
<tr>
<td>7 Emergent Technology Specialist</td>
<td>Operations manager for a large UK heat network</td>
<td>07/09/2010</td>
</tr>
<tr>
<td>8 Director</td>
<td>Director of non-profit collaboration with Aberdeen City Council. Involved with several other heat networks in the past.</td>
<td>13/09/2010</td>
</tr>
<tr>
<td>9 Compliance Officer</td>
<td>Responsible for environmental compliance of emerging low carbon technology</td>
<td>02/11/2010</td>
</tr>
<tr>
<td>10 Operations Manager</td>
<td>Operations manager for a recent UK heat network development</td>
<td>04/04/2011</td>
</tr>
<tr>
<td>11 Sustainable Energy Development Manager</td>
<td>Local authority funded advisory group to support heat network development</td>
<td>23/05/2011</td>
</tr>
<tr>
<td>12 Local Activist</td>
<td>Leader of an opposition group opposed to energy from waste derived heat networks</td>
<td>03/06/2011</td>
</tr>
<tr>
<td>13 Manager</td>
<td>Manager of energy from waste facility that supplies heat to a large UK heat network</td>
<td>05/07/2011</td>
</tr>
<tr>
<td>14 Manager</td>
<td>Manager of a large UK heat network</td>
<td>26/07/2011</td>
</tr>
<tr>
<td>15 Administration Manager</td>
<td>Client liaison for a nuclear heat network scheme in Switzerland</td>
<td>08/08/2011</td>
</tr>
<tr>
<td>16 Principal Project Manager</td>
<td>Project manager for large, public sector led heat network initiative in the UK</td>
<td>19/08/2011</td>
</tr>
<tr>
<td>17 Senior Project Manager</td>
<td>Consultant at a large Danish heat network company</td>
<td>13/10/2010 and 02/08/2011</td>
</tr>
<tr>
<td>18 Environmental Strategy Manager</td>
<td>Project manager for large, public sector led heat network initiative in the UK</td>
<td>21/05/2012</td>
</tr>
</tbody>
</table>

**Figure 9: List of Interviewees**
The interviews were based on a semi-structured interview template as proposed in Bryman (2001). A core group of questions were used to frame the discussions and ensure comparable topics were covered by interviewee responses. The rest of the interview structure aimed to allow flexibility so that respondents could focus on issues of particular interest (Bryman 2001). This was done by constraining the number of core questions:

- Could you please give an overview of you/your company’s involvement with this heat network?
- What do you believe are the advantages and/or disadvantages of heat networks for customers?
- Are there customers who are more likely to be receptive to heat network connection?
- What barriers/difficulties did you/your company face when developing the network?
- What contributes to successful heat network development?
- The uptake of heat networks in the UK is often viewed as low in comparison with other European countries. Do you think this is correct? If so why do you think this is the case?
- What is the effect of government policy on heat networks, and could heat networks be incentivised?
- How is the heat price set?
- Does the source of heat impact on the success or viability of a heat network?
- In your opinion would there be nuclear specific impacts on such a scheme?

The interview questions were not altered as a result of changing from scoping key issues to identifying non-technical issues. This was to maintain continuity, and it was felt that the core questions enabled interviews to discuss socio-technical issues without being specifically prompted. The interview structure was however changed for the two regulator interviews. Several core questions, such as heat price, were dropped and interviewees were invited to discuss nuclear heat networks in relation to existing regulations and give their opinions on changes that may be required to comply. Similarly, the questions were also adapted for an interview with a local activist associated
with an existing UK heat network. For this interview questions about heat cost, customer receptiveness, and government incentives were replaced with a question about the reasons for opposition to their local heat network.

Fourteen of the interviews were conducted by telephone, while four were in person and one respondent preferred to reply in writing (thereby providing a structured interview reply). The duration of interviews varied from 20 minutes to 1 hour 40 minutes, depending upon the respondent’s willingness to talk beyond the core questions. Responses to the initial nine interviews were recorded on response sheets, while later telephone interviews were recorded on a digital recorder.

The data was analysed by reviewing audio recordings and response sheets. Responses were grouped into four analytical themes. The first three are concerned with UK heat networks in general and expand upon themes identified in previous studies. The fourth theme considers the potential significance of using nuclear energy to supply heat networks as opposed to ore established technologies such as geothermal, natural gas and waste incineration.

4.3. Analysis

The interviewee responses are discussed as three themes; market structure and finance, energy user responses to connection and governance structure. Analysis of these themes is followed by a discussion of the impact of using nuclear energy as a thermal resource on these and other non-technical issues. Where interviewee responses are cited in the text, they are numbered in relation to Table 2.

4.3.1. Market Structure and Finance

The importance of market structure and securing finance for heat network development is highlighted in Toke and Fragaki (2008), Macadam, Davies et al (2008) and a 2009
report by DECC (Koehler 2009). These studies suggest that the liberalised energy market currently relied upon to deliver new energy infrastructure limit heat network
development. Toke and Fragaki (2008) frame this as a lack of incentives for combined
heat and power (CHP), with the energy efficiency improvements of CHP not being
internalised in the market value of electricity sold to the grid. Macadam, Davies et al
(2008) suggest that in the current energy market context heat networks, regardless of
thermal input source, are unlikely to successfully compete with natural gas and electric
heating prices for heating when private sector discount rates are applied. This is because
the supply infrastructure for gas and electricity is already established (Macadam, Davies
et al. 2008).

The interview responses elaborate on this further. They suggest that having to access
private capital for heat network projects, as required by the current market structure, is
difficult and expensive. This was seen as the result of heat networks having high front-
end capital costs and relatively long payback periods, of typically around 15-20 years
(Interview #2, Interview #8, and Interview #14), a point echoed in Macadam, Davies et al
(2008). Although heat network infrastructure is long lived and may be expected to
perform well financially over medium to long term timeframes, these characteristics are
seen to be in conflict with the current energy market preference for stronger returns
over shorter timeframes. Interviewees #2 and #8 suggested that heat networks, as long
lived infrastructure, were not currently of interest to private companies:

“When you have a private energy sector, energy companies look at return on
investment and that is all they are interested in, for shareholders. Therefore unless
government intervenes the best return option will be built.” #2

The long payback periods and high upfront capital costs mean heat networks face
significant financial barriers in the liberalised energy markets without intervention from
institutions that have social as well as commercial aims (Toke and Fragaki 2008).
Consequently three interviewees remarked that raising sufficient capital at a manageable
cost was the most significant challenge for UK heat network development (Interviewee
#7, Interviewee #8 and Interviewee #14).
Even when investment capital can be secured, some interviewees consider finance costs to be prohibitively high. The high cost of capital is thought to relate to the length of the payback time, which is unattractive to private investors (#2 and #8). Interviewees #7 and #8 suggested that the cost of finance was also high because of the risks associated with investing in UK heat networks that currently lack the financial (such as tariffs and tax breaks) and legal, (including mandatory combined heat and power application for thermal power stations) support that encourages investment in heat networks in other parts of Europe (#8). This is not unique to heat network development. Foxon, Gross et al. (2005) note the high cost of capital for other low carbon energy projects as a result of them being perceived as higher risk than established technologies. This may stem from the long term financial performance of technology being unproven in a particular market, particularly where changes to Government regulation and incentives could alter financial dynamics (Foxon, Gross et al. 2005).

The influence of these financial barriers has been reflected in how heat networks have developed in the UK so far. Additional costs are associated with connecting existing buildings, because roads have to be excavated and heat exchangers retrofitted into properties. Some of these costs can be avoided when new buildings are connected, leading reports such as Macadam, Davies et al (2008) and McNaught, Williams et al (2011) to suggest new build properties should be prioritised for heat networks. Interviewees associated with large existing heat networks in the UK stated that their enlargement strategies also focused on new building developing because of higher costs in connecting existing users (interviewees #11 and interviewee #18).

The interviewee responses and the recommendations from the literature suggest that the current energy market structure prohibits heat network development. A change in the market structure would therefore be required to create a favourable socio-technical context for nuclear heat network development. Furthermore the type of market reform, such as more public funding for low carbon heating infrastructure, is likely to determine the scale of a future nuclear network, in terms of its geographic coverage and the supply of low carbon heating services by affecting the availability and cost of capital for initial pipeline installation. As discussed in Chapter 6, the price at which a heat network can
provide energy is likely to determine connection rates. This highlights the impact of market structure and finance on the outcome of heat network technology.

4.3.2. Governance Institutions
The significance of governance institutions is raised in Babus’Haq and Probert (1994), Werner and Cutler (2004), Toke and Fragaki (2008) and in Reason et al. (2006). This theme was expanded upon by the interviewees who have been, or are currently involved with heat network development in the UK;

“Where feasibility studies identify potential schemes, ‘political will’ from a local authority can be central to implementing a scheme effectively.” Interviewee #7.

Local authorities have frequently played a pivotal role in the development of heat networks. Historically heat networks have benefited when local (or in the European context, municipal) authorities have had a strong role in energy policy and infrastructure development (Werner and Cutler 2004). This can seen in the governance structure of Sweden, Denmark and Germany during periods of heat network expansion in these countries (Werner and Cutler 2004; Holmgren 2006; Toke and Fragaki 2008). In the UK, energy planning was taken largely at a national level. While this is not necessarily an impediment to heat networks it did mean fewer local authorities were involved in establishing energy infrastructure. Where heat networks did develop in the UK, for example in Sheffield, Southampton and Nottingham, city councils had a significant role.

Heat networks are a good fit with local level governance. Their development is linked to local conditions, such as the availability of local thermal resources and the distribution of heating services demand. For example, the Southampton heat network was developed as a response to finding a large geothermal energy resource near the city centre (interviewee #6, interviewee #7, and interviewee #8), while Nottingham and Sheffield

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schemes were developed in line with waste management strategies that led to large waste incineration facilities near city centres (interviewee #4, interviewee #8, interviewee #11 and interviewee #12). In the past, heat networks have been entwined with other local issues such as social housing and boosting economic competitiveness (interviewee #4, interviewee #6 and interviewee #8). In Southampton heat networks had a role in the redevelopment of the city’s quayside area (interviewee #5, interviewee #6 and interviewee #7). In Nottingham, heat networks were connected to new social housing as part of a fuel poverty strategy integrated with the waste management system (interviewee #11, interviewee #13 and interviewee #14).

During a period of energy sector privatisation in the UK, local authorities were dissuaded from participating in energy infrastructure development. This coincided with a period of low natural gas prices and lead to very few heat network developments in the 1990s and 2000s (Toke and Fragaki 2008). However more recently some local authorities have taken voluntary steps (such as the Merton Rule and the Nottingham Sustainable Energy Strategy) to develop low carbon energy strategies that have included heat network planning, for example the Association of Greater Manchester Authorities (interviewee #16 and interviewee #18). The Committee on Climate Change (2012) advocate making such interventions by local authorities in local energy planning mandatory.

The interviews suggest that local authorities in the UK can provide support to heat networks in a number of ways:

- Planning support. The planning process can be used to promote the user connection in the local area. Heat networks can be integrated with other local authority strategies such as regeneration of urban centres and establishing commercial enterprise areas. Although they cannot currently make companies

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obliged to connect to heat networks, they can use the planning process to encourage non-domestic users to connect when new building or, changes to existing buildings are made by stipulating certain energy efficiency and environmental criteria are met (interviewee #6 and interviewee #16). Simply requiring non-domestic users to fully consider a heat network connection at the planning may be enough to encourage connection (interviewee #6, interviewee #5 and interviewee #8).

Council planning offices can also work to provide “class based planning actions” (#16). These are more generic and flexible than case-by-case planning applications and streamline the planning process (#16). This can help reduce risks arising from planning regulations, for example having to resubmit applications if heat network routes change, thereby potentially saving time and reducing costs (#16).

- Resolve Access Issues. Ordinarily heat network operators are not granted the same statutory rights as electricity, gas and water utilities to excavate roads and public areas for installation and maintenance of pipe networks (interviewee #8 and interviewee #14). However local authority planners can grant operators Statutory Utility Status within their administrative area (interviewee #7).

- Provide Demand: In several interviews, local authorities were described as providing important ‘anchor loads’ for heat networks (interviewee #7, interviewee #8, interviewee #11, interviewee #16 and interviewee #18). This means large buildings owned by local authorities, including offices and in some cases sport centres, schools and colleges, can serve as initial user demand. This guarantees some demand, sends a strong signal of support and may encourage other users to follow (interviewee #7, interviewee #8, interviewee #11, interviewee #16 and interviewee #18). This point is also made in Reason et al. (2006).
Co-ordination. In theoretical approaches to infrastructure development, successful alignment, or configuration, of actors is seen as very important for enabling the realisation of technological systems, like heat networks (Bijker, Hughes et al. 1993; Latour 1996; Rip and Kemp 1998). This is echoed in the interview responses and in a study of the Southampton heat network by Reason, Coleman et al (2009). In examples from Southampton and Nottingham, the local authority was a point of consistency when other actors, such as network operators and thermal resource providers changed. They served to bring in new partners at important moments and mediate relationships between network operators, thermal energy providers and users (interviewee #6, interviewee #7, interviewee #8, and interviewee #11). In the case of heat networks being planned in London and in the Greater Manchester area, local authorities have worked to undertake feasibility studies, tender for private and community partners and begun the process of attracting users (interviewee #16 and interviewee #18). Local authorities can provide ‘champions’ who maintain project momentum throughout the development process and coordinate different aspects of network development (Reason, Coleman et al. 2009).

4.3.3. User Responses to Technology
Interviewee #15 commented that during network development mechanical and electrical (M&E) professionals involved in designing or retrofitting building heating systems had little knowledge of heat networks and preferred to “stick to what they know” when deciding upon technologies they install. A similar perspective was reported in Reason, Coleman et al (2009) in their study of the Southampton heat network. This study identified the influence of standard commercial practice on heating system design when multinational firms locate to an area with a heat network and have a generic approach to building function and technology use (Reason, Coleman et al. 2009). Conversely the study also reported that in the Southampton case, when a French hotel chain were approached for connection they were receptive as heat networks as they brought
experience and knowledge from France and other markets they operate in with higher heat network penetration.

Some interviews considered it highly unlikely that heat network connection will replace natural gas heating in existing buildings, particularly in the domestic sector (interviewee #7, #8 and #14). Interviewees have had experience of struggling to convince users to look beyond a short term view on costs (five years and less) which has tended to favour natural gas and electric heating options (#6 and #14). One interviewee noted that a lack of choice in heat network provider, in contrast with the option of several natural gas suppliers, deterred some potential heat network users (interviewee #14). However think this might be changing. Firstly, “natural gas prices have risen significantly, reducing consumer confidence in it as the “cheapest fuel” (interviewee #14). New policy mechanisms such as a carbon price and the Carbon Reduction Commitment (CRC) for larger non-domestic users may encourage commercial and industrial users to “look beyond short term financial targets and consider long term sustainability” (interviewee #8).

4.4. The Impact of Nuclear Energy on Heat Networks
A particularly significant output from the interview process was impact of the type of thermal resource on the non-technical barriers and opportunities for a heat network. In particular there was a contrast between different connotations relating the thermal supply technology; for example between a ‘geothermal heat network’, and an ‘energy from waste heat network.’ The positive environmental connotations of the geothermal heat source of the Southampton heat network were seen as an important factor in the early development of the scheme (interviewee #5, #6 and #7, also see (Reason, Coleman et al. 2009)). The ‘local’ nature of the resource and it’s ‘clean’ attributes stimulated support and interest within the local authority to promote Southampton as a leader in low carbon technology (interviewee #5, #6 and #7). The ‘green’ credentials of the heat network were aligned with the corporate social responsibility of several of the schemes early connected users (#7). Despite geothermal now only providing a small proportion of
heat to the Southampton network, relative to natural gas CHP, investment to keep the geothermal well online is considered important to the appeal to the network (#6 and #7).

While the geothermal heat source proved an advantage in growing the Southampton network, interviewees associated with the Nottingham heat network suggested that the negative environmental image of waste incineration in the UK has adversely affected the heat network (interviewee #11 and #12). The waste incineration facility that supplies the heat network is considered to have a poor public image in the city, and is seen as polluting and a danger to public health by some groups (interviewee #11 and #12). There are established local resident groups oppose the expansion of the heat network in the city because they feel it might legitimise a continuation and expansion of the waste incinerator (interviewee #12). The network is currently attempting to enlarge, but unlike in the Southampton example its marketing as a ‘green’ alternative is more controversial (interviewee #11 and #12). The impact of this on connection rates is difficult to access until the network enlargement is fully implemented (interviewee #11).

Not all interviewees agreed about the importance of thermal input to a heat network:

“In respect to the end consumer, although they would like the idea of it being clean and low carbon, at the end of the day what they are more concerned about is the price.” Interviewee #8.

When asked specifically about nuclear energy as a thermal input technology, the UK based heat network interviewees suggested that public perception of nuclear energy would be significant barriers:

“Theoretically you could connect to a nuclear power station, but as they are so far away from the centres of population for understandable safety reasons, the cost of piping the heat would be extremely challenging. It could be done, but I don’t know how people would feel about being heated by a nuclear power station.” (Interview #8)

“There are different reasons why things might not be doable. In the case of nuclear it’s public perception.” (Interview #2)
This however is not the case with the Beznau nuclear heat network, where local residents not only opted for connection, but invested personally in the development of the network by buying shares in the network operator, of which local communities own 51% (Interviewee #1).

The interviewee #1 considered the basis for this response to be based on a pragmatic financial calculation:

“One kind of advantage is the price level [which] is very constant and not coupled, at least with us [the network operator], with oil prices. So you’re independent from import of oil or gas so you have a local resource, a local source of heat. And what we have seen as well is really a very low...very low cost in operating the house stations [hydraulic interface units], very low maintenance cost of the district heating stations for the customer itself.” (Interviewee #1).

The development of the Beznau heat network happened in 1983 to 1985 at a time when oil prices were relatively low, but past experiences with oil price volatility in the 1970’s may have driven user preference for a slightly higher yet more stable heating supplier (interviewee #1). This corresponds with the assertion of Interviewee #8, quoted above, that energy users may be more concerned about the price they pay for heat rather than the source of their energy.

In the experience of the Beznau nuclear heat network technical advisor, the nuclear aspect of the system was not particularly problematic (interviewee #1). This view was re-affirmed by a customer liaison manager for the network operator interviewed four months after the Fukushima Daiichi nuclear disaster in 2011. Community support was integral to the development of the network as individual towns and villages were required to invest in their own connections (#1, also in Handl (1998)). As nuclear energy was a long term feature of the area many residents were apparently comfortable about the nuclear component of the network (#1). Interviewee #1 stated that the mountainous topology of area, which requires high pump capacity, was a bigger challenge than the nuclear heat source.
In addition to interviewing UK heat network experts, representatives of the UK Health and Safety Executive (HSE) nuclear office\(^{36}\) and the Environment Agency (EA) were interviewed about potential regulatory barriers to a nuclear heat network. While there is no existing guidance relating to the use of nuclear energy through heat networks, the interviewees were asked to consider what the requirements would be. From a HSE perspective, a change in use from an electricity generating nuclear site to a combined heat and power nuclear site would most likely require an investigation to determine risks (interviewee #3). However, because the modification required is made to the steam turbine plant, which is distinct from the ‘nuclear island’ this would not affect the nuclear operator, as the reactor design and planning application would not have to be reconsidered. The interviewee stated that an independent investigation of the risks of radiation contaminated water in the heat network may be necessary. Learning would also be taken from Swiss counterparts on the operation of the Beznau nuclear heat network. Despite these possible requirements, the interviewee did not see other regulatory barriers to nuclear heat network development. The EA representative thought there would not be additional compliance measures, relative to other heat networks, provided a very low risk of radioactive contamination of heat network pipes can be verified (interviewee #9).

### 4.5. Summary and Conclusions

The interviews highlight key non-technical issues relating to nuclear heat network development. They support the finding of Toke and Fragaki (2008) and Macadam, Davies et al (2008) that the current market based approach to energy supply infrastructure is unlikely to facilitate new heat network developments without greater government intervention. The ability of network developers to access finance will shape the scale of network development and the cost of finance is likely to affect the price of thermal energy for users, which in turn may affect connection rates. This is therefore key barrier limiting the potential for utilising nuclear energy through heat networks. Domestic user

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\(^{36}\) Now the Office for Nuclear Regulation.
responses to nuclear heat networks are considered fully in Chapter 6, however there are also challenges in ensuring the connection of non-domestic users. The interview responses identify distributed nature of decision making within companies as a key issue, but one that may change over time with legislation that promotes long term sustainability practices in UK businesses. Once again this is a potential barrier that could constrain development. The interviewees did however support an enhanced role for entities with an explicit social concern such as local authorities, charitable body or community associations. A greater role for local authorities in particular could lead to heat networks being incorporated into regional development strategies, which may facilitate the development of networks with large geographic coverage.

A more surprising finding was the suggestion that nuclear energy as thermal input is not necessarily extraordinary. It does not for example appear to entail additional regulatory, institutional or other development barriers. The comparison of waste incineration heat networks with geothermal heat networks does however indicate that interpretations of the thermal supply technology can influence public and user responses to a heat network. In particular it can alter whether heat networks are seen as environmentally benign or dangerous, and therefore whether its expansion is positive or negative. User and public responses to nuclear energy could be significant given the controversial nature of the technology (see Chapter 3). However there are also indications from this analysis that price of energy may ultimately be more significant. The next chapters investigate user/public responses to nuclear heat networks and the technical potential for utilising nuclear energy at proposed new build nuclear sites in the UK.
5. Focus Group Methodology

This chapter describes three focus groups on nuclear heat networks held with twenty three residents in the Teesside area of England in March/April 2011. The data from these groups is used in the Chapters 6 and 7 to explore how residents with a local nuclear facility might respond to nuclear heat networks as domestic energy users and as public groups. The rationale for undertaking this research and the use of the focus group method is discussed first, followed by a detailed description of how the focus groups were carried out.

5.1. Rationale for Focus Groups

This thesis takes a socio-technical approach to understanding how nuclear energy can be utilised for heating services through district heating networks in the UK. Such an approach sees technology users and publics as internal parts of an energy system that affect its form and function, as opposed to being external actors merely effected by it (Bijker, Hughes et al. 1993; MacKenzie and Wajcman 1999). In the case of nuclear district heating in the UK local residents in the vicinity of an existing nuclear facility would be the anticipated technology users and constitute public groups. Local residents will therefore interact with nuclear district heating in two modes – energy user and public. The scoping exercise described in Chapter 2, and the additional interview responses in Chapter 4 highlighted these responses as significant issues for determining the potential for utilising nuclear energy through heat networks in the UK.

Energy users can directly determine the scale and effectiveness of a heat network (unless mandatory connection is enforced) by opting for long term connection to the network and recommendations to neighbouring energy users. In addition to this role as individual households, local residents may interact with the system collectively. Walker and Cass suggest public interaction with energy infrastructure can be diverse and suggest that the ‘public’ is mix of heterogeneous ‘publics’, inferring local residents can respond
collectively in different ways to resist or enable new energy infrastructure in their area (Walker and Cass 2007). Public interactions with energy infrastructure can be influential in determining where, when and if a development happens, particularly through opposition at the planning approval stage (Bell, Gray et al. 2005; Devine-Wright 2005; Walker and Cass 2007; McLachlan 2009). The interactions between local residents and a nuclear heat network therefore must be constructive to ensure energy user connection and to enable the necessary infrastructure to gain planning consent (Owens 2002). Researching these potential interactions provides insight into whether local resident responses to nuclear heat networks prohibit heat network development, or whether there is an opportunity for a network to be considered as a positive option.

To research local resident responses to nuclear heat network technology, focus groups were used to identify and explore interpretations of the technology. Many socio-technical approaches to energy systems use an interpretivist research lens to study energy user and public interactions with energy infrastructure. The Science and Technology Studies approaches have since the 1980’s considered energy user interactions with technology (Bijker, Hughes et al. 1993; MacKenzie and Wajcman 1999), while subsequently there has been a focus on using this approach to study the interactions between publics and energy infrastructure (Devine-Wright 2005; Walker and Cass 2007; McLachlan 2010). These perspectives considers interpretive flexibility as central to understanding interactions between social actors and technology in an energy system (Bijker, Hughes et al. 1993). They suggest that the meaning of a technology is not fixed, and that there are potentially multiple interpretations of a technology that vary over time and between stakeholders, especially during initial development (Bijker, Hughes et al. 1993).

Responses to the nuclear energy component of the network are of particular interest in this research and potentially highly influential in guiding energy user decision making about nuclear heat network technology. Large quantitative surveys of public opinion in the UK routinely show nuclear energy as a contentious issue, predominately with regard to reactor safety and high level radioactive waste products (Pidgeon, Lorenzoni et al. 2008). It has however been suggested that people with a nuclear facility in their area
may interpret the technology differently than those without a nuclear facility, because their understandings and responses to nuclear risks are shaped by experience of, and proximity to the facility (Bickerstaff and Walker 2001; Zonabend 2007; Bickerstaff and Simmons 2009). This distinction is important because existing nuclear sites in England and Wales are the proposed locations for new build nuclear reactors and therefore nuclear heat networks. For this reason, the Teesside area of England was chosen as the location for the focus groups. It is a suitable area for district heating in terms of demand density and is in close proximity to the Hartlepool nuclear power plant (NPP).

5.2. **Strengths and Weaknesses of Focus Groups**

Focus groups are facilitated group discussions which aim to obtain participant views and opinions about a designated subject (Bryman 2001). This method is useful for in-depth qualitative research that seeks to ‘unpack’ participant responses to explore the reasoning behind answers to research questions. The following section outlines the strengths and weaknesses of the focus group method and assesses its appropriateness for this research.

Four features of focus groups make them a useful method for researching interpretations of nuclear district heating. Firstly it is possible to observe how individuals in the groups form opinions of a topic they are presented with as a group. Participants can contest or confirm each other’s views so that a researcher can obtain more ‘realistic accounts of what people think, because they are forced to think about and possibly revise their views’ (Bryman 2001, p.338). Secondly, the facilitator can probe more deeply into answers given by individual group member to better understand what is meant by a response and invite other group members to comment on this. Greater elucidation of a response by a participant may cause other group members to reconsider whether they agree or disagree, particularly if they had taken it to mean something different. Thirdly,

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the participants can take greater control of what is discussed, in comparison with research methods without direct interaction (such as online questionnaires), revealing what they may collectively rank as more important and of greater concern. Although this is also often the aim of an individual interview Bryman suggests because the interviewer in the focus is group acts as a facilitator/moderator they have less of a decisive role in determining how the discussion will flow (Bryman 2001). Fourthly, the participants are given an opportunity to ask questions and seek clarification about the information they receive and the questions they are being asked. With methods that have no face to face, interaction such as postal or online questionnaires, it is more difficult to ensure participants have received (i.e. read through the supporting document or preamble) and understood the information that is presented before responding.

The focus group approach therefore can be an effective way of obtaining interpretations of a subject through discussion and by further questioning the reasons for these interpretations can be explored. The method does however have limitations. Group sizes range from 4-10 participants and the number of groups may only be as many as twenty for large studies (Bryman 2001). For this study there were three groups with a total of twenty three participants, which is a small sample relative to quantitative survey methods, diminishing the relevance of the results to other parts of the country where nuclear heat networks may be developed (Bryman 2001). Secondly the group discussion can be influenced by the facilitator/moderator – sometimes inadvertently – and it is likely that some of the more vocal group members will exert more influence than others in the discussion (Stewart and Shamdasani 2007). This could have the effect of masking the opinions and views of some participants, particularly less extrovert group members (Stewart and Shamdasani 2007). It is the facilitator’s responsibility to take a limited role in the discussion and to attempt to engage all the members of the group if possible to overcome this. In addition individual questionnaires can be included in the sessions to catch views and opinions not expressed in the group discussions. Thirdly, there is no way
to replicate the study, although it can be argued this may be the case for all social research methods (Bryman 2001).³⁸

Focus groups were an appropriate method for this research theme relative to the research goals. The aim of this research was to identify and explore interpretations of nuclear district heating and how this may be framed by the proximity of local residents to the Hartlepool nuclear power plant. To address issues relating to group dynamics, such as facilitator influence and dominant personalities individual, open ended questionnaires were included in the focus group sessions.

5.3. Focus Group Method
Twenty three participants residing in the Teesside area were recruited for three focus group sessions; four private rent tenants, nine social housing tenants and ten home owners. The private rent group was held on the 13th March 2011 and the social housing and home owner groups were held on the 19th and 20th of April 2011 respectively.

The difference in date between the private rent and other two groups is a result of a change in recruitment method. The initial attempt to recruit for the focus groups did not provide sufficient participants. In the first attempt at recruitment I acted as recruiter, travelling to Middlesbrough to place posters and hand out flyers, while also advertising on social networking and internet forums. Participants were offered £20 high street shopping vouchers for a two hour discussion on a topic relating to heating in the home. Although eight private rent tenants from the local area confirmed attendance, only four attended the session. This was a low, yet adequate number of participants with which to hold a focus group with. The numbers for the proposed social housing and home owner groups however appeared less promising and these groups were cancelled. While lower than expected attendance is a well known risk when arranging focus groups (Bryman 2001), it was clear that a different recruitment approach was needed. A market research

³⁸ Bryman points out that to successfully replicate a survey of any scale, all the environmental factors that might influence responses have to be replicated as accurately as can feasibly be achieved, which may not be possible. See Bryman, A. (2001). Social Reseach Methods. Oxford, Oxford University Press. Chapter 16.
company (DJS Research) were employed to provide social housing and home owner participants for the remaining groups. At the agency’s suggestion the voucher value for attendance was increased to £30. Although the change in recruitment method delayed the social housing and home owner groups, it did provide more participants for the groups.

The three groups differed in ways other than recruitment strategy and participant numbers. Following a review of the private rent group session, an additional questionnaire for individual responses to the key topics and a research feedback form, were included in the social housing and home owner groups at the end of their sessions.

Apart from the additional questionnaire and research feedback form, the session structure was the same for the three groups. The sessions were in two one-hour halves, each proceeded by a presentation. On arrival participants were given a questionnaire to complete individually. This questionnaire asked for opinions about current heating systems and the participant’s knowledge of alternative heating technologies including district heating. The session was introduced as a discussion on alternative heating options for the home. I explained the structure of the session and that the discussions were being recorded and the data would be used as part of a PhD thesis.

The first presentation aimed to provide background on the key reasons for replacing existing natural gas and oil based heating systems. Equal weight was given to climate change, declining domestic natural gas and oil reserves and the health impacts from under heating a building. The presentation outlined the demand side options for reducing consumption and supply side alternatives to fossil fuel combustion heating, including district heating. A discussion on the issues raised was then stimulated using the following pre-determined questions:

1. What are your views on the environmental impacts of heating in the home?
2. What are your views on affordable heating and health?
3. What are your views on declining domestic oil and gas reserves?
4. Are there any issues affecting heating in the home that were not covered in the presentation and should be added?
5. How would you rank these issues in terms of their importance to you?
6. What are your opinions of the demand and supply side solutions shown in the presentation?

Following this discussion, a second presentation was given. The presentation provided an overview of nuclear district heating and how it could be applied in the Teesside area using the Hartlepool nuclear power plant. Participants were shown a map highlighting areas of heat demand in local area near to the Hartlepool NPP. This presentation was also followed by a discussion stimulated by the following prompt questions:

1. Is nuclear energy a concern in any way?
2. Do you have any particular concerns about radiation?
3. What is your opinion of a long term energy contract with a supplier?
4. What are your views on disruption in the home and to the local area during installation of the network?

At the end of the social housing and home owner sessions the participants were given a questionnaire and a research feedback form to complete. This questionnaire aimed to capture opinions that were not shared in the group discussion and obtain comparable data about whether participants would consider connection to a nuclear district heating network if it were offered and on what basis. Two questions relating to the Fukushima nuclear disaster, asking if opinions to nuclear energy had changed in the past year (not mentioning Fukushima directly) were also included. The research appraisal form completed anonymously by the participants and collected in by a volunteer from the group. Although one respondent remarked there had been too much information and they ‘lost track’, the other participants’ feedback on clarity of the presentation and the opportunity to express opinions suggested they had understood the content and felt comfortable engaging in the discussions.

5.3.1. Sampling
The target sample for the focus groups was up-to thirty residents from the Teesside from a broad stratification of socio-economic backgrounds with even spreads of age and
gender. This was to capture a broad range of experiences and perspectives within the groups. Participants were required to have lived in the area more for more than three years (this was to avoid recruiting students only temporarily living in the area, who would not be representative of local residents). The advertisements deliberately avoided terminology such as ‘nuclear’, ‘district heating’, ‘energy security’ and ‘climate change’ to avoid special interest groups. The advertisement phrasing aimed to prevent participants from preparing for the discussions by doing their own research.

The sample for the first focus group, with private rent tenants, was random; based upon advertisements posted on the internet and in Middlesbrough. The sample for the social housing and home owner groups was carried out by DJS Research and was a more targeted approach, using contacts with organisations such as the housing association for social tenants. In only one case, in the social housing group, did the participants know each other prior to the sessions.
A good distribution of age and socio-economic background was achieved, considering the relatively small sample size (n=23). However, the 18-24 age group was underrepresented and no over 65s took part. Although there were more men than women in the private rent and social housing groups the overall male to female ratio was 14:9.
Social classification data for the home owner and social housing groups was provided by the participant recruitment firm DJS Research, and their methodology was applied retrospectively to the private rent group based on occupation/employment status. Although this classification is based on an older system of social classification it is broadly in line with the current Office for National Statistics Socio-economic Classification (NS-
SEC\textsuperscript{39} and can still be used to illustrate the range of socio-economic backgrounds represented in the focus groups.

Social Classification

![Social Classification Chart]

Figure 13: Social classification by main household earner

<table>
<thead>
<tr>
<th>Social Grade</th>
<th>Occupation of Main Earner</th>
<th>NS-SEC Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>High Managerial, administrative or professional</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>Intermediate managerial, administrative or professional</td>
<td>2</td>
</tr>
<tr>
<td>C1</td>
<td>Supervisory, clerical and junior managerial, administrative or professional</td>
<td>3,4,5</td>
</tr>
<tr>
<td>C2</td>
<td>Skilled manual workers</td>
<td>3,4,5</td>
</tr>
<tr>
<td>D</td>
<td>semi and unskilled manual workers</td>
<td>6,7</td>
</tr>
<tr>
<td>E</td>
<td>State pensioners, casual or lowest grade workers, unemployed with state benefits only</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 2: Socio-economic classification by main income earner (Source: DJS Research).

Lower income households are over represented in the groups, however this compares favourably to general trends for the Middlesbrough Local Authority area in which most of the participants are resident:

\textsuperscript{39}The Office for National Statistics now uses a 1-7 scale, however this is similar to previous ranking system referred to in the focus group sampling. See \url{http://www.ons.gov.uk/about-statistics/classifications/current/soc2010/soc2010-volume-3-ns-sec--rebased-on-soc2010--user-manual/index.html} (accessed 06/06/2011)
<table>
<thead>
<tr>
<th>Social Grade</th>
<th>Local Authority (%)</th>
<th>Focus Group (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>C1</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>C2</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>D</td>
<td>23</td>
<td>26</td>
</tr>
<tr>
<td>E</td>
<td>21</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 3: Comparative social grades between Middlesbrough Local Authority average and focus groups (Source: Office for National Statistics based on 2001 Census).

5.3.2. Positionality

The sessions were advertised as a two-hour discussion about heating in the home and wellbeing. During the first hour of the session, where the emphasis was on heating in the home generally and the full range of technical solutions, nuclear energy was not mentioned. Nuclear heat networks were only introduced to the groups at the beginning of the second presentation. This was to prevent the nuclear aspect of the technology from dominating the early parts of the discussion and establish a group dynamic before introducing a potentially divisive issue.

I facilitated the focus groups, introducing myself as a researcher from the University of Manchester researching a novel alternative for heating supply, funded by the EPSRC and ESRC. I did not reference either the Tyndall Centre for Climate Change Research or the SPRInG Nuclear Sustainability project during the sessions to avoid influencing the discussion by not associating myself directly with nuclear power or climate change research. During the sessions I assumed the role of ‘technical expert’, by giving the presentations and answering questions about the technology. I tried to limit my role in the discussions to asking pre-defined questions and keeping the discussion focused in the event of a lengthy digression.

At the end of each session I handed out cards with my name, email address and office postal address stating that I would be happy to correspond with anyone wanting to know more about me or the research.
5.4. **Summary**

Despite the issues with recruitment, requiring the use of a recruitment agency, the focus groups achieved their aim. A diverse range of local residents discussed nuclear heat network technology and made comments that highlighted and explored issues with the technology. The focus groups were recorded and the transcribed. The transcription response were compared and used to inform the analysis in Chapters 6 and 7.
6. Domestic Energy User Interactions with Nuclear Heat Networks

This chapter uses data from three focus groups in the Teesside area of England (described in Chapter 5) to discuss how domestic energy users may respond to a nuclear heat network development in their area. The chapter begins with an overview of how domestic energy users can be influential in determining the development of a nuclear heat network. Subsequently the theoretical perspective used to analyse the focus group outputs is set out, before the analysis is discussed in three themes; cost, functionality and institutional configuration.

6.1. Domestic Energy Users and Nuclear Heat Networks

While it is possible to envisage a future where connection to a heat network is compulsory – a model used in Europe and Russia throughout the twentieth century (Werner and Cutler 2004) – it is equally plausible that the commitment to energy user choice, prevalent in UK political discourse since the late 1980’s will persist. Where domestic energy users have been connected to heat networks in the UK since the 1990’s, such as in Lerwick and Nottingham, both home owners and social tenants have been offered a choice on whether to connect or not (Martin and Spence 2010). While mandatory connection diminishes the energy user role in heat network development, in an optional connection scenario domestic energy user choices become crucial for its viability, not simply in terms of the number of connections, but also in terms of concentration of system users. Heat networks are more economical and efficient if a high proportion of energy users in an area are connected; preferably at same time to reduce installation costs (Zinko, Bohm et al. 2008; Martin and Spence 2010).

Optional connection and the demand density requirement of the technology present challenges for nuclear heat networks. To be viable nuclear heat networks in the UK require constructive interactions between energy users and technology, whereby a large
proportion of energy users in an area are willing to connect to the system. This research
focuses on domestic energy users, who contribute significantly to heating related GHG
emissions. The focus groups offer insight into domestic energy user responses to new
heating system proposals, their criteria for considering replacing their existing system
and their concerns about doing so.

6.2. Theoretical Perspective
The theoretical perspective used to analyse the focus group data comes from the Science
and Technology Studies (STS) tradition and is concerned with the obduracy of existing
technological systems and how this affects emerging technology systems. It was
proposed by Bijker (1993) and developed by Hommels (2012). Initial analysis of the focus
group data suggested experiences of existing heating system exerted influence on how
they interpreted and understood nuclear heat network technology and its social aspects -
particularly in terms of ownership and contractual arrangements. This in turn influenced
opinions about whether or not the technology was acceptable for them as energy users
as well as ownership and contract preferences. Obdurance best conceptualises how
existing socio-technical regimes exert a shaping influence on new technologies and their
socio-technical configurations. Hommels draws on the work of Staudenmaier (2006) and
Bijker (1995) to identify different forms of socio-technical obduracy; durability of the
technology artefact, financial vested interest, and dominant ways of thinking (Hommels
2000).

The concept of ‘technological frames’ is used in this approach to describe how ways of
thinking about an existing socio-technical regime can influence how actors make sense of
a new technology and therefore whether they decide to adopt it (Hommels 2000). Bijker
summarises the role of technological frames in making socio-technical regimes obdurant:

“The relevant social groups have, in building up the technological frame,
invested so much in the artefact that its meaning has become quite fixed – it
cannot be changed easily and it forms part of a hardened network of
practices, theories and social institutions.” (Bijker 1995, p.282; cited in;
Hommels 2000)
Technological frames consist of ‘goals, problems, problem-solving strategies, standards, current theories, design methods, testing procedures, and so on’ (Hommels 2000, p. 656). In the context of this work ‘standards’ are taken to include expectations of reliability, functionality and design of the technology. ‘Hardened network of practices, theories and social institutions’ describe how obdurance applies to the wider socio-technical system a technology is part of, which in this case this includes familiar modes of supply contract and ownership.

While obdurance is seen as a powerful force in locking energy users unto existing systems, it is suggested that its influence can vary depending on the level of inclusion an actor has in the system:

“An actor with a high inclusion in a particular technological frame thinks and interacts very much in terms of the technological frame. For such an actor, it is difficult to think of alternative technology designs outside the frame in which he or she is included: closed-in hardness. The opposite, closed-out hardness, is also possible. This occurs when an actor has a low inclusion in a particular technological frame. For this actor, the technology presents a take-it-or-leave-it choice.” (Hommels 2000, p. 656)

In the focus groups ‘closed-in hardness’ was observed in all three sessions with regard to the reliability, performance and design of heating systems. Many participants however demonstrated ‘closed-out hardness’ when discussing modes of supply contract and organisation, being willing to consider alternatives outside of the technological frame (as discussed in the following sections).

6.3. Analysis
The analysis of the focus group responses, in relation to domestic energy user responses is grouped into three parts; cost, reliability, performance and design, and finally ownership and contract length. Each part explores the underlying assumptions and meanings that focus group participants used to inform their interpretations of nuclear heat networks. This analysis discusses the impact of these interpretations on responses
to nuclear heat networks and considers how this might change over time. This then leads a conclusion section.

### 6.3.1. Cost

The costs incurred by the energy user were a dominant issue throughout the discussions on alternative technologies to existing heating systems. It was clear that if there is a substantial upfront cost and higher per unit prices of energy that energy users cannot afford then there are financial barriers to changing heating systems. ‘We cannot afford it’ was a common statement in all three groups. The issue of what energy users’ pay for heating however goes beyond the ability to afford an alternative technology. The responses from the majority of participants suggested that if nuclear heat networks - or any other alternative - had no installation cost and was the same price per unit of energy as natural gas, it would still not necessarily be considered as an attractive option:

> “That [nuclear heat network] would be ideal but what is it going to cost you? If it’s going to cost you same as gas then it defeats the object.” #9 Social Housing Group

> “If it’s [only saving] £5-6 a month you’re not bothered are you?” #5 Home Owner Group

> “See that wouldn’t be an incentive, 10% [less that the price of gas]. [It] would have to be something 30, 40, 50% to sign up to something like that.” #1 Home Owner Group

Using the typology of Bijker and Hommels it can be suggested that the technological frame being used by the majority of participants in the focus groups situated ‘goals, problems, problem-solving strategies’ (Hommels 2000, p. 656) around reducing the price of energy:

> “A lot of people do make the effort; double glazing loft conversions and everything. But I think most people have done double glazing over the years but it hasn’t made the bills any cheaper.” #1 Home Owner Group

> “When I got mine done, my old boiler died, so I got a new boiler and I got all the insulation done, got it done and then my bills shot up high. I actually
I think the last one [environment] people are not that bothered about and will just go for the cheapest option whatever it is.” #9 Social Housing Group

“So long as I can plug my hairdryer in, or wherever, I don’t give a damn where it comes from, as long as it’s cheap.” #1 Home Owner Group

Two possible explanations for this present themselves in the focus group data. Firstly, in the social housing and private rent groups the price of heating was strongly tied to energy insecurity. The key ‘problem’ framing their discussion of alternative heating systems was the ability to afford thermal comfort:

“It would be interesting to survey families and see how they have been affected over the last two winters. To see what the effect has been on relationships. Because you can’t afford your heating, it’s either heating or shopping.” #3 Private Rent Group

“You can’t cook a hot meal either, because you haven’t got energy for the cooker, or the microwave. You save it to keep warm, or for the bus fare to visit my friend. She’s got a little girl of five and she does get the heating allowance, but it was so expensive and so extreme, the weather, it just kept running out because she is on the meter.” #1 Private Rent Group

“It’s getting to the stage where people can’t afford gas. There has got to be people not heating houses, there’s got to be.” #9 Social Housing Group

“My daughter told me, she ran out of money for the gas so when the kids are out she’ll leave it off, put another jumper on and save it for the next day for the kids.” #5 Social Housing Group

In this context, if nuclear heat network connection does not address this central problem, it is unlikely to enter into contention as an alternative to existing heating systems.

Secondly, even when the price of energy does not relate to a direct problem such as thermal discomfort, cost remains the primary criteria because other competing goals and problems may not accepted by an energy user. In the home owner group the inability to afford thermal comfort was not raised or discussed. Instead concerns about cost related to getting the best deal:
“It would have to be permanently cheaper, so if gas and electric came down cheap by E.ON or whatever, it would always be constantly 10% or 15% cheaper.” #1 Home Owner Group

Although affordability of heating was less of an issue for this group the majority of participants would not consider heating alternatives that did not reduce the price of energy.

One participant in the group was willing to consider nuclear heat network connection at the same price as natural gas if ‘it was better for the environment’ (#10 Home Owner Group). This participant said she was concerned about climate change and interested in alternative heating systems if she can afford it. This contrasted with many other members of the group who did not acknowledge environmental issues such as climate change as a problem:

“But does anyone really bother about the climate change? As far as I’m concerned, turn your heating up you turn it up. Most of us aren’t bothered about whether the turn the heating alters the climate control or whatever. If you want to be warm you want to warm, whether it affects the climate or not.” #1 Home Owner Group

“It’s because there is not a defined end point to it. Nobody has said the climate will – for want of a better word – implode or be destroyed in certain year, for instance 2013, 2015. If it was more imminent and a substantial body of scientists said yes it’s going to happen then and there will be significant consequences then we would be more worried, but it’s something we only relate to abstractly, I don’t think we sort of worry that much about it.” #8 Home Owner Group

“People are concerned when they watch it [climate change] on the telly then they switch over and watch something else.” #7 Home Owner Group

The reference to climate change as ‘abstract’ is particularly interesting. For home owner group energy price becomes a ‘real’ and tangible problem every billing period, whether monthly or quarterly. For the social housing group members with pre-payment meters this direct interaction with ‘the problem’ can be daily. In each case it is not an issue that can be ignored by changing TV channel, as the home owner groups participant suggests is the case with climate change. The participant responses suggest that they are however
able to ignore problems that make the low carbon attributes of a technology a solution to an acknowledged problem.

6.3.2. Reliability, Performance and Design
The second topic that dominated the focus groups discussion was the functionality of the technology in comparison with existing heating systems. Existing heating systems provide a familiar point of reference against which to compare alternatives. The durability of an artefact, such as a combination gas boiler, ‘exerts an ongoing cultural and technical influence simply because it is “there” and because people have come to depend on its being there’ (Staudenmaier 1985; Hommels 2000). Broadly speaking most participants were satisfied with their current heating systems;

![What is your opinion of your current heating system?](image)

Figure 14: Participant responses to question; What is your opinion of your current heating system?

The effect of the technology’s durability was most apparent in the home owner focus group, who also appeared most satisfied with their existing heating system:

“If it ain’t broke you’re not going to fix it are you?” #8 Home Owner Group

“Well mine is the other way around. I’ve got an old gas boiler and I dare not change because it has been reliable for me in case I get a new combi boiler and it packs in because of all the circuit boards.” #3 Home Owner Group
“Generally most people’s heating in houses are very well, mine lasted forty odd years and is just starting to go on the blink now [stop functioning]. So I should imagine everybody else’s has been fine in the past. So the reliability of what people have put in has been fantastic, but you wouldn’t know about something like that (points to presentation slide). What is the lifespan of something like that [ground source heat pump]?” #1 Home Owned Group

The quotes suggest that experience of durability instills confidence in the reliability of existing heating systems. The reliability of existing systems was viewed positively by the majority of participants, and they used this as a point of reference to discuss other heating technologies. In the terminology of Bijker (Bijker) this can be identified as a technological frame because of the way participants conceive of acceptable standards of performance and reliability that appear to be embedded in their understanding of heating systems. The quotes below represent views expresses regarding usage, reliability, comfort and performance;

“[Do] you only have a set amount you can use? When you’ve got your own heating you want to put it on, you can leave it on or turn it off if you want. Have you only got restricted use of it?” #2 Social Housing Group

“Is there a limit to the number of houses that can have their central heating on, say they all put their central heating on at the same time would it still work?” #2 Private Rent Group

“What about reliability, do they have problems with a leak outside, would you lose heating you know, for how long?” #9 Social Housing Group

“Will it be guaranteed to be the same temperature? Sometimes it might be 10°C sometimes 30°C in your house? ‘Cos my boiler heats up when I need it.” #2 Home Owner Group

“Does it work similar to a combi boiler heat wise, so you can get your heat instantaneously?” Social Housing Group

Similarly, ideas about how the parts of the system that integrate with the building should look, their impact on the appearance of the building and how much indoor and outdoor
space they requires were framed by knowledge and experience of existing heating systems:

“I don’t think there is anything there I would like in my house.” #1 Home Owner Group

“So it is not like another big clumsy thing to add to your house? Compared to a combi-boiler?” #5 Homes Owner Group

“I wouldn’t want to have two unsightly things, if I had to have another tank or light or whatever else, you’ve already got a boiler taking up your cupboard so I wouldn’t like to lose any more space for something else.” #6 Home Owner Group

“Will they cover up the hole? Most people now have the pipes outside of the wall, does it actually go into the wall, the cavity in the wall?” #3 Home Owner Group

In general participants were happier with the concept of heat networks when points of familiarity were apparent. For example a hydraulic interface unit (HIU) for a heat network is very similar to a gas combination boiler in appearance and requires roughly the same space inside the home. Being considered as a ‘like-for-like’ replacement for existing heating systems seemed to make the technology a more acceptable alternative. The statements made in the sessions suggest a fairly ‘closed-in hardness’ to the existing technological frame in terms of reliability, performance and design standards particularly expressed in the home owner group:

“I think the vast majority of people will just stick with what they know and unless they are forced.” #9 Home Owner Group

“Another thing is conventional sort of fuel sources, they are ingrained in us now generation through generation. And I think the inertia that that means in terms of what we perceive to be acceptable fuel, that I think is quite immense and is something they need to look at, because I think it is going to take a lot to convince people on mass, or even [inaudible] on mass or something like that to sort of change to these things. I think terms like ‘new fangled’ and ‘luddite’ and all that sort of thing comes into play because people just stick to what they are
comfortable with, we’re just not ready yet. Personally I just don’t think we’re ready to make a massive transition on that sort of nature.” #8 Home Owner Group

These obdurate ways of thinking about heating systems constrain interpretive flexibility to what is already known and experienced. Existing systems have, for most participants, raised expectations of what is meant by high standards of reliability, performance and design. Potential heat network users will test and compare the technology against these standards.

6.3.3. Ownership and Supply Contracts

The ownership of heat networks and user supply contracts were another topic the participants focused the discussion on. Heat networks are usually premised on modes of supply contract and ownership that are in some ways the antithesis of the modes of ownership and supply that domestic energy users in the UK have become familiar with since 1999.40

The background to the discussion on ownership and supply contracts is a political emphasis over the past decade, to promote competition and choice in energy markets.41 The general trend has been to encourage domestic energy users to look for the best deal and ‘switch’ between private energy suppliers to reduce energy bills through increased competition. The participants in the focus groups, like most domestic energy users in the UK, were on short (12-24 months) supply contracts, able to switch between several private sector energy suppliers – although those on pre-payment meters were less aware of their ability to ‘switch’. This is however not compatible with heat networks, where contracts typically involve long (5-20 years) periods, and with no option to switch supplier.42 Many heat networks – including all of those in the UK - involve some form of

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40 This is the year the electricity market monopolies ended and supplier competition emerged and consumers could ‘switch’ to different suppliers. The same thing happened with natural gas in 2000.
42 In large schemes such as Gothenburg in Sweden, supplier competition has been possible, giving users a choice of supplier. See Grohnheit, P. E. and B. O. Gram Mortensen (2003). “Competition in the market for
local authority ownership, often because they are established for environmental and social as opposed to commercial reasons and require public sector support either financially or through planning measures. A previous study on energy user interpretations of heat networks in the UK highlighted the change to longer contracts and greater involvement of local authorities as a potential barrier to acceptance of the technology (Upham and Jones 2012).

The discussions about ownership and supply contracts were entwined and located around issues of trust. Long term contracts would only be considered if the owner of the network could be trusted not to increase prices and profiteer from having energy users locked into the system. Trust in the owners of the network was also an issue in terms of competency and expertise to provide the service reliably.

With regard to existing supply contracts and ownership, the majority of participants made it clear that there was a lack of trust in current private energy companies:

“*If a big company comes to your door, you don’t trust them because they lie.*” 
#2 Social Housing Group

“It’s exactly the same gas. Goes all the way round underneath the sea, to Germany over to Norway then back down into England and we use it at double the price. Because everything has been privatised.” #1 Home Owner Group

“Yeah, I mean if you start using less [energy], they will say, look at our profits. They’ll charge you more for that first chunk, [so] they aren’t losing money.” #1 Social Housing Group

This for many led to a preference for local authorities, community organisations and charities to have some form of inclusion in the ownership structure:

I think a lot the older generation are starting to trust Age UK because they are one of the more active charities looking at people who are freezing to death. That is who put me in touch with the Energy Saving Trust for my dad. But it space heating. District heating as the infrastructure for competition among fuels and technologies.” Energy Policy 31(9): 817-826.

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needs to come through a body like that. Private energy companies they’re in it for what they are in it for. I think it needs to be an independent body. #3 Private Rent Group

“If it was part of the council you would think about it, if the council were involved then it would be more…” #2 Social Housing group
“… You know where you stand.” #5 Social Housing Group

“I think I would be wary of a private company just in case they decided to up and up their prices, because well you’ve got it now you’re stuck with it we can charge you what we want…I would personally feel a little bit more comfortable if it was the council or a community based organisation than a private firm.” #10 Home Owner Group

However while not-for-profit entities such as local authorities, communities and charities were trusted to protect energy users’ interests, some participants doubted the competency and expertise of such organisations to operate a heating supply network system:

“I’m not sure [about community ownership]. Running a farm shop is one thing but district heating with nuclear might be better if someone professional was doing it.” #4 Private Rent Group

“Once they do get involved it’ll go tits-up, you know what the council is like. So private for me.” #1 Home Owner Group

Ultimately in all three groups local authority ownership was preferred by the majority of participants. In the social housing group they suggested the authority could ‘bring in’ expertise, while in the home owner group a private-public partnership was favoured:

“I think I would like the mix then you have somebody with the expertise but then someone on the community front that would have your best interests at heart.” #10 Home Owner Group

While the change in ownership of heating systems was broadly accepted in all three groups, changes in supply contract were a more divisive issue. In the home owner and private rent groups short supply contracts with a choice of suppliers was linked to encouraging competition and driving down price. Switching tariffs was something
members of the private rent group discussed in depth. One participant described his father switching energy tariff:

“He is confused because he keeps getting different bills from different firms. I keep telling him, it’s competition, it’ll help drive down the price. That’s who I trust, the energy switch people, because they are paid a commission for getting you to switch. I don’t think there is anybody championing heating for people who are unemployed and vulnerable.” #3 Private Rent Group

Long term contracts were seen as problematic if the supplier was able to increase the price significantly as had happened recently with the majority of natural gas supplier in the months preceding the sessions:

“That would be a big problem because you can’t trust, if you sign up for it they can turn around and say well actually it’s 10% more, then you are stuffed [in difficulty].” #1 Social Housing Group

It was suggested by the facilitator that nuclear heat networks could offer price stability by not being closely tied to natural gas and oil prices. The proposal of a stable price over a long period was seen as very positive by a number of participants, particularly in the private rent and social housing groups, and this made long term contracts more appealing:

“What they could do is say for the next ten years we are going to set the price at this much and we’ll only ever increase it if such and such happens... I think a perfect contract would be about five years, particularly in town houses. You are there for roughly a few years and then you move on. In the estates they are there for ten years.” #2 Private Rent Group

“It would be ideal, if you know you are going to be tied for ten years at a certain price, I could live with that.” #9 Social Housing Group

“You can say, that’s how much I need to spend this week and for the next ten years, whereas with gas you can use £50 one week and £10 the next.” #5 Social Housing Group

“It’s good for stability, I suppose if it were five years at one level a lot of people would also be prepared just to do that, they know what they are paying next month for the next five years.” #1 Home Owner Group
In the home owner group however there were mixed views about a stable price, in case the price of gas heating dropped. In this group the majority said a long term contract would have to guarantee to be at least 10% cheaper than the corresponding cost of natural gas heating:

“As long as you get the benefits of it being cheaper, I wouldn’t be bothered about being locked in.” #1 Home Owner Group

In the second questionnaire completed by the social housing and home owner groups the participants were given options of different contract lengths and asked to state which they would consider. From the responses (below) it was clear the two groups came to different conclusions about supply contracts.

![Bar chart: What Contract Length Would You Consider?](image)

Figure 15: Participant Responses to question; what contract length would you consider?

Further focus groups or surveys would be needed to determine whether these differences relate to the type of accommodation ownership or intra-group dynamics. It is however interesting to note that while both groups have the same level of inclusion in the socio-technical regime as energy users, they have had different experiences with the existing supply contract and ownership model. In the social housing group the negative impacts of fluctuating natural gas prices on finances and health were very salient issues,
while no member of the home owner group expressed or raised this issue when discussing the price of energy:

“I didn’t think it [lack of heating] would affect sort of physical or mental health problems.” #3 Home Owner Group

In the framework proposed by Hommels this could be an indication of ‘closed-out’ and ‘closed-in’ hardness with the existing technological frame on type of supply contract. One hypothesis to examine through further study is whether, as suggested by these findings, the technological frame is more malleable for participants who cannot afford adequate heating because current supply contracts and ownership structures do not meet their needs. The private rent group were not given the second questionnaire, but in the discussion a similar pattern of inadequate heating and preference for a long term set price was observed for three of the four participants.

The strong support for long term contracts by the social housing group is surprising in light of previous studies into energy responses to contract lengths (Upham and Jones 2012). One possible explanation is the impact of natural gas price fluctuations over the past six years.

![Domestic Natural Gas Bills](chart.png)
The above chart shows changes in the average per unit price of natural gas since fully competitive markets were introduced. Two trends add context to this discussion. Firstly, after a period of stability prices climbed steeply between 2004 and 2009, almost doubling during this period. Secondly, households on pre-payment meters, such as those in the social housing group, pay more per unit of energy than those on direct debit tariffs. Geels in his proposal of socio-technical transitions refers to ‘landscape’ changes that disrupt the existing socio-technical regime and allow innovations to break through (Geels and Schot 2007). In this context, rising natural gas prices appear to have put pressure on the credibility of existing socio-technical regimes to provide adequate heating for less affluent households. It does appear that rising energy prices have undermined trust in private natural gas supply companies for several members of the focus groups. This could explain why concepts of supply contract length and flexibility are not as fixed as other aspects of heating systems, and therefore the willingness to consider long term, inflexible contracts.

6.4. Conclusions

The focus groups aimed to provide a snapshot of how domestic energy users might respond to nuclear heat networks as an alternative heating supply option. The data does provide some interesting insights into how heat network technology and its associated socio-technical components could be interpreted. They show how important cost and functionality are when assessing new energy technologies:

“I think, like people said, if it is proved to be effective and cost effective and people will continue to be happy with it, the nature of the technology doesn’t matter as long as it was delivering what was promised.” #8 Home Owner Group

The data highlights the importance of obdurate ways of thinking in the acceptability of new technologies. While obduracy is used by Hommels to describe barriers to technology change, this is not necessarily the case. Hargadon and Douglas (2004) use the example of how Thomas Edison’s company used this form of obdurance to successfully introduce new electric lighting systems. Familiarity and the existing competencies energy users had from their experience of gas lighting were exploited by Edison to introduce a competing technology (Hargadon and Douglas 2001). Because Edison mimicked the structural and functional aspects of the gas lighting socio-technical regime as much as possible, it can be argued that obduracy was utilised to connect new customers. In the case of nuclear heat networks, the HIU has similar aesthetic and physical dimension qualities as a gas combination boiler. It also offers the same performance in terms of constantly available, instant hot water and thermostatic heating control. Participants became more comfortable with the concept of heat networks once they began to see it as a ‘like-for-like’ replacement of gas and oil boilers. This is an attribute of heat networks, which given the observed influence of existing heating systems on the discussions about alternatives, should not be undervalued.

The long term contracts and lock-in to a supplier necessary for heat networks can be acceptable to domestic energy users in some conditions. The prospect of predictable stable pricing of heating over a long period was appealing for participants in the private rent and social housing groups susceptible to thermal discomfort from sharp rises in natural gas prices. However the supplier would have to be trusted to deliver a promised, stable price, and for many participants this entails some form of local authority, community or charity role in the ownership structure because private companies were not fully trusted in this regard. For the home owner group getting the lowest price was the key issue and therefore a long term contract would have to include measures to keep it competitive with natural gas and electric heating, such as a guarantee to always be 15-20% cheaper. If a nuclear heat network has an ownership structure that engenders trust and confidence, offering stable and relatively low prices, long term inflexible contracts could be acceptable to domestic energy users.
Ultimately the findings are positive for nuclear heat network potential. What is clear however is that cost to the user is currently central to decision making for the focus group participants. Matching the price of gas may not be enough to ensure enough users migrate from natural gas and oil to a nuclear heat network. An economic benefit, whether a price guaranteed to track the natural gas price at lower rate or a guaranteed long term fixed price, would most likely be required. Another potential issue in this regard is the durability of existing systems and money already invested in them. If users were not compensated for ‘scrapping’ a system that hasn’t come to the end of its life-span then a user (if they own the system and paid for its installation) might feel they will lose money by changing to a heat network connection. The potential problem is that existing boilers in a heat network connection area may be different ages meaning not all users would be in the same position to change at the same time. Because it is more cost effective to connect as many users as possible at the same time it may be sensible to offer a ‘buy-out’ from the existing system by paying a scrapage fee.
7. Public Responses to Nuclear Heat Networks

This chapter analyses data from three focus groups held with local residents near the Hartlepool nuclear power plant (NPP) in spring 2011 (see Section 5). The data is used to discuss how public groups might respond to a nuclear heat network development, particularly in terms of opposition and support.

7.1. The Role of Public Opposition

Public opposition to new energy infrastructure has an established record of slowing or preventing developments, particularly at the planning approval stage (Owens 2002). Successive UK Governments have altered the planning approval process to allow ‘vital’ energy infrastructure to bypass some of the formal mechanisms for public opposition, initially through the Infrastructure Planning Commission and latterly the Major Infrastructure Planning Unit. Despite a curtailing of the formal mechanisms for participation in the planning process, members of the public can still form campaign groups to apply pressure on their elected officials in an attempt to delay or reverse planning decisions. While opposition has been observed as active engagement, support for energy infrastructure developments may be more likely to be tacit, in the form of a lack of public opposition to the development (McLachlan 2010).

Public interpretations of the role of nuclear energy in the local area is of particular interest as this is anticipated to be central to different public responses to a nuclear heat network. Public opinion surveys in the UK consistently show that nuclear energy is not a preferred electricity generation technology (Pidgeon, Lorenzoni et al. 2008). Nuclear energy has unique risks associated with it due harmful radiation is released by the fission process. The wide ranging impacts of a failure to contain this radiation was demonstrated when safeguards at the Fukushima Diiachi nuclear facility in Japan were compromised in

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44 Both commissions take planning decisions at a national level, bypassing the role of local authorities. Whereas the IPC was a quasi-autonomous non-governmental organisation, the MIPU will be similar, but with Parliamentary Ministers making decisions.
March 2011 by a tsunami, resulting in a 40km exclusion zone being established. The utilisation of nuclear energy may be expected to take place within a broader debate about nuclear safety.

The analysis uses an interpretive approach from the renewable energy siting controversy literature (discussed in Section 2) to identify different logics of support and opposition that define public engagements with new energy infrastructure developments (McLachlan 2009). Interpretivist approaches to public understandings of risk are used to augment the siting controversy literature by conceptualising the unique public risks associated with nuclear energy. The focus group analysis found three interpretations of nuclear energy that appeared to make concerns of nuclear safety secondary to performance and price criteria. Firstly, nuclear energy is acceptably safe. Secondly, nuclear fission is a necessary technology for the UK’s future energy mix. Thirdly, nuclear energy is a local resource. These interpretations were evident in responses to nuclear energy that framed the technology as uncontroversial and the acknowledged risks as manageable. This was surprising because the nuclear component of the system may been expected to be controversial and invoke opposition, particularly in light of the Fukushima Diiachi nuclear disaster which occurred two days prior to the initial focus group.

Logics of opposition were less apparent in the focus group discussions. Nineteen of the participants completed a questionnaire at the end of their group sessions, of who only one considered nuclear heat networks to be an unacceptable option. The analysis does however discuss how supportive interpretations were constituted and how they may be sensitive to new events and information that could cause a re-evaluation of support.

7.2. Theoretical Framing
The framing of public interaction with new energy infrastructure development in terms of opposition as the result of narrow local self interest and uniformed, irrational perceptions, is generally referred to as NIMBYism (Not in My Back Yard) (Devine-Wright
Walker and Cass suggest opposing is only one of ten roles ‘publics’, as heterogeneous entities not a homogeneous ‘public’, can have in relation to energy infrastructure – ‘captive consumer; active customer; service user; financial investor; local beneficiary; project protestor; project supporter; project participant; technology host; and energy producer’ (Walker and Cass 2007, p.464). They suggest that these roles are highly fluid, leading to a variety of configurations between a public and a local development. The type of interaction between the public and an energy infrastructure development, it is suggested, is the result of the meanings that members of that public attach to the development (Bickerstaff and Walker 2001; Walker and Cass 2007; McLachlan 2010; Parkhill, Pidgeon et al. 2010). Public engagement with nuclear heat networks as service users and captive consumers is discussed in Section 6. The other roles possible with a nuclear heat network, local beneficiary, project protestor and project supporter are considered here.

This research adopts the symbolic interpretivist approach set out by McLachlan (2009; 2010) to study renewable energy siting controversies. Different public interactions with new energy infrastructure are considered to stem from meanings (symbolism) attached to the technology and the locality in which it is situated by local residents (McLachlan 2010). These interpretations are key to the forms of interaction members of the public align themselves to, such as opponent or support (Walker and Cass 2007).

‘Symbolism refers to more abstract meanings that stakeholders associate with the physical developments themselves (McLachlan 2010, p.181)’.

These abstract meanings of the technology and the place it is sited give rise to ‘various symbolic logics of opposition and support’ (McLachlan 2009, p.5344). The interpretations of a technology and its proposed site are considered variables that produce and justify different interactions between people and technology. Divergent interactions with a technology could, for example be based on different interpretations of whether the technology ‘fits’ with the local area, or what the benefits are (McLachlan 2009).
The interactions with new energy infrastructure defined by Walker and Cass depend on the type and scale of energy development (Walker and Cass 2007). In the case of nuclear heat networks in the UK there are two factors that make it distinct from other types of low carbon technology explored by interpretivist approaches to new energy infrastructure. Firstly, the initial phases of new nuclear development in the UK are likely to be at existing nuclear sites. No changes to the public amenity of an area are necessarily required in terms of visual impact and modification of public spaces. The distribution infrastructure for heat network would be below ground and the new nuclear reactor would be adjacent to an existing reactor building. An exception to this however could be the location of back-up boilers and whether the continued use of the existing reactor location for nuclear energy is considered acceptable. Secondly, heat networks are themselves local supply infrastructure. This makes local benefits in terms of energy supply easier to demonstrate, something which can be problematic for national grid connected developments (see (McLachlan 2010)).

While nuclear heat networks may not change the public amenity of the local area as significantly as some renewable energy technologies, technology and place symbolism remains significant. Section 4 discusses the possible effects of opposition to the thermal input technology of a heat network. It gives the example how opponents of waste incineration technology can lead to rejecting the offer of heat network connection because the thermal supply is a contentious local health issue. In this case the particular safety risks from nuclear energy are of interest. The expectation in the case of nuclear heat networks is that a favourable response to the development of a nuclear heat network is likely to depend upon local interpretations of nuclear energy, particularly with regard to risk.

Research using an interpretivist lens to explore public knowledge and understanding of nuclear risk suggests that the proximity of risk shapes local resident interpretations of the technology (Bickerstaff and Walker 2001; Zonabend 2007; Bickerstaff and Simmons 2009; Parkhill, Pidgeon et al. 2010). The presence of a nuclear facility may make nuclear risks seem normal and familiar, skewing how local residents interact with the technology and making risks appear acceptable (Bickerstaff and Walker 2001; Zonabend 2007;
This approach suggests that concepts of risk are socially constructed, maintained and altered in relation to local experiences (Bickerstaff and Walker 2001; Zonabend 2007; Bickerstaff and Simmons 2009; Parkhill, Pidgeon et al. 2010).

7.3. Analysis
The focus group analysis uses both the symbolic interactionism and the interpretation of risk literature to identify and explore participant interpretations of nuclear heat networks. Three interpretations were identified that underpinned a generally positive reaction to nuclear heat network technology; that it is acceptably safe, that it is a necessary technology for the UK, and that it is a local resource to exploit. The literature warns that such interpretations are not static and open to re-evaluation and change. The following analysis therefore explores ways in which these interpretations may be sensitive to change. While the participants appear supportive of nuclear heat networks, their responses also suggest how positions of opposition might form, which is discussed in the conclusion.

7.3.1. Acceptably Safe
The risks attributed to nuclear energy are assumed here to be essential in determining the acceptability of nuclear heat networks for local residents and framing their interactions with the system as publics. This section analyses the implicit and explicit interpretations of nuclear energy as a potential health risk observed in the focus groups. Theoretical approaches from the interpretation of risk literature are used to analyse participant responses, the majority of which consider nuclear energy to be acceptably safe.

Research into interpretations of local industrial hazards suggests that responses to risks associated with a hazard, such as a nuclear reactor, are based on socially constructed understanding and knowledge of potential risks:

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‘while many environmental threats (e.g. air pollution, ionising radiation, climate change) hold very real consequences for both people and ecosystems, our knowledge and understanding of them can only ever be viewed as socially constructed...In turn community understandings of risk themselves shape practices and behaviour, giving rise to secondary (real) consequences for people and institutions. (Parkhill, Pidgeon et al. 2010, p.40) ’ (emphasis in original text).

The primary risks of nuclear energy relate to failures in containment on the nuclear ‘island’ and the release of harmful radiation into the local environment and beyond leading to long term radioactive contamination. As the quantifiable human health risks from failures in nuclear containment remain unclear however (Moysich, McCarthy et al.), there is scope for a wide range of interpretations, even within the observed scientific data, that can be used to justify different positions of support and opposition. The health impacts of the Chernobyl nuclear disaster in 1986 for example, which resulted in the release of harmful radiation across large parts of the former Soviet Union and Europe, are still contested; most notably between the Chernobyl Forum (representing eight UN agencies and the governments of Belarus, Ukraine and Russia, led by the International Atomic Energy Agency) and Greenpeace. Consequently there are, in principle, ‘expert’ opinions to sustain opposing interpretations of nuclear safety.

Within the focus groups three categories of response to nuclear risks were observed:

1. Nuclear energy risks are a concern and nuclear heat networks are unacceptable
2. Nuclear energy risks are a concern/unsure about nuclear risks but nuclear heat networks are acceptable
3. Nuclear energy risks are not a concern and a nuclear heat network is acceptable

In two of these categories nuclear energy is acceptably safe, in that even if concern about nuclear safety is acknowledged participants will still consider nuclear heat network connection. The first response was least frequent, with the third response most frequent. Participants in the social housing and home owner groups (see Section 5) were given a

questionnaire before leaving that asked for their opinions of nuclear energy and whether they would consider connection to a nuclear heat network. In the responses only one of the nineteen participants in the two groups stated they would not consider nuclear heat network connection, highlighting concern over nuclear waste as a reason. Several respondents expressed concern about nuclear risks but stated they would consider connection. The majority however expressed confidence in nuclear safety and were unconcerned by the risks. Overall the questionnaires showed unexpectedly low levels of concern by residents about risks associated with nuclear:

![Opinions of Nuclear Safety (2nd Questionnaire)](image)

This was a trend reflected in the group sessions where there was very little discussion about nuclear risks even in response to prompt questions from the facilitator on radiation. The nuclear component of the system, which had been expected to be controversial, was marginal in the group discussions. Questions relating to the nuclear heat network presentation given half way through the session focused on the heat network component of the scheme, particularly price of energy and performance (see Section 6). In the home owner group there was no significant engagement with the issue, nuclear energy was ‘fine’ as a heat source and the discussion quickly changed to price of energy and functionality of a heat network. There was more debate in the social housing

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46 One respondent in the Home Owner Group did not answer the questions on nuclear energy.
group, but again the issue was not as contentious as expected. The private rent group engaged most with the issue, however there was no indication of significant concern about nuclear safety, as the following discussion in response to a facilitator question on radiation risks illustrates:

“Cosmic radiation is passing through us right now.” #2 Private Rent Group

“Look at all the WiFi. There is a big build up of background radiation.” #1 Private Rent Group

“The biggest dose of radiation you will ever get is on an aeroplane.” #4 Private Rent Group

“I don’t know about that.” #1 Private Rent Group

“It is like a thousand times worse than standing next to a nuclear power station.” #4 Private Rent Group

These results appear counterintuitive, particularly given the serious nuclear disaster that occurred at the time of the group sessions. The interpretation of risk literature however suggests these findings are not necessarily unusual given the presence of a nuclear facility in the local area. This literature describes processes through which local residents with industrial hazards can discount risk or internalise underlying anxiety and suggests ways acceptance of risk is constructed, maintained and challenged.

Studies show that knowledge and understanding of risk can be heavily influenced by local conditions, specifically the presence or not of an industrial hazard such as a nuclear power station (Zonabend 2007; Bickerstaff and Simmons 2009). Local context is identified in interpretive studies of industrial hazards as ‘inextricably tied’ to how individuals interpret risk (Bickerstaff and Walker 2001).

In the focus groups participant interpretations of nuclear safety often referenced the nearby Hartlepool nuclear site. The impact of the local physical environment is noted in two ways. Firstly the presence of the industrial hazard can illicit support from locals against negative ‘outsider’ comments about the hazard, which might be taken as stigmatising the area – referred to as the ‘halo effect’ (Bickerstaff and Walker 2001).
Studies of industrial areas and areas with industrial pasts suggest risks can be mediated by positive associations with the perceived social and economic benefits of industrialisation, particularly in providing employment (Bickerstaff and Simmons 2009). Secondly, and conversely, the industrial nature of an area may lead to a lack of empowerment or lack of care about changes to the local environment (Bickerstaff and Walker 2001). These themes were inferred by comments made in the private rent focus group when discussing whether the risks of nuclear energy were acceptable:

“With us being in an industrial area I don’t think we object as much, it’s not like down south ‘not in my back yard’. That is where you would get the opposition. I don’t think you would get that in areas like Teesside. I think we accept everything, cooling towers, petrochemical plants, whatever.” #3 Private Rent Group

“We got rid of those American warships and I think there was something about nuclear bombs we are dismantling, we’re already glowing... Why don’t we take out of this what no one else will and turn it into something good?” #1 Private Rent Group

The inference here is that risks associated with nuclear hazards have are an excepted part of living in the area. The meaning of place in this instance makes industrial hazards common place. Teesside is the most industrial of the existing sites in the UK and it would be interesting to investigate whether this response to risk is fundamentally different in areas with nuclear facilities but no other experience with industrialisation.

The lack of discussion about nuclear safety could also be linked to the normalisation and familiarisation of risk from living with a hazard on daily basis (Parkhill, Pidgeon et al. 2010). Studies of how local populations deal with and interpret risk suggest that people can silence or ‘absence’ risk by not thinking about or discussing the potential danger (Bickerstaff and Walker 2001; Zonabend 2007; Bickerstaff and Simmons 2009; Parkhill, Pidgeon et al. 2010). The inference here is that although the participants seemed largely disinterested and dismissive when talking about nuclear safety, there could be underlying concern and anxiety. Such a concern was alluded to by one participant in the social housing group discussion:
You tend not to worry about it, you just hope to god nothing happens with it. #9

Social Housing Group

The theme was more pronounced however in the questionnaire responses to the questionnaire that participants in the social housing and home owner groups were given at the end of the session:

‘It is something we all had to get used to. Am glad I live close to Hartlepool Power Station because if anything serious goes wrong then I should die quicker. Sorry to be defeatist :)’ #3 Home Owner Group

‘I don’t know enough about it, it has always frightened me. I don’t want to live too near, there used to be stories of birth defects?’ #6 Social Housing Group

Normalisation of risk and underlying anxiety are important to note because even subtle changes may bring the exceptionality of the nuclear hazard to the forefront of people’s mind, reshaping nuclear energy as unacceptable risk (Bickerstaff and Simmons 2009; Parkhill, Pidgeon et al. 2010).

While local context is deemed to be formative in constructing risk, Bickerstaff and Simmons highlight the concept of folding space and time, so that events that occur far away geographically or in the past can be salient in a local, present context (Bickerstaff and Simmons 2009). This changes the idea the idea of proximity and risk, so things which happen outside of the local context can ‘impinge’ on the interpretive practices of a population with an industrial hazard (Bickerstaff and Simmons 2009). In the studies cited by Bickerstaff and Simmons the Chernobyl nuclear disaster was sometimes referenced by participants discussing a local hazard (Bickerstaff and Simmons 2009). A similar ‘folding’ was observed in the focus groups when participants discussed the Fukushima Daiichi nuclear disaster. The incident happened a day before the private rent focus group and continued to feature heavily in the media at the time of the social housing and home owner groups. At Fukushima a tsunami overwhelmed the safeguards (back-up generators for reactor cooling systems) of six reactors on the site leading to a prolonged release of radioactive compounds that contaminated the seawater, air and ground in the area.47

Applying the frameworks already discussed, it would be expected that Fukushima would

disrupt absenting and normalisation interpretive practices by highlighting the exceptional nature of the nuclear hazard.

The events at Fukushima were referenced by the participants in two of the focus groups in their discussions about whether they thought nuclear energy was safe or not:

“What’s concerned me now is this earthquake thing in Japan, and we’ve started to have tremors over the last couple of years haven’t we?” (#1 Private Rent Group)

“What about Japan?” (#1 Social Housing Group)

In both cases however other members of the group countered that they did not necessarily interpret the events in Japan as making nuclear energy unsafe in the UK:

“Yes, but the UK is pretty much in the middle of a plate, we won’t get bad earthquakes, only tremors.” (#2 Private Rent Group)

“It’s different there [Japan], it’s probably the most volatile part of the planet. Whereas here they [nuclear reactors] are a lot safer.” (#1 Social Housing Group)

Fukushima was also referenced in the second questionnaire completed by the social housing and home owner groups (see figure 1). Again different ways of interpreting the risk in a local context are expressed. For example, one response infers a ‘halo effect’

‘Fine as it’s the way to go and we have no risk like Japan etc... I am more for nuclear [now] than in the past’ #1 Social Housing Group.

The response to Fukushima is surprising and it suggests that interpretations of nuclear safety can be more fixed and durable than expected. It may be however that an event highlighting nuclear safety risks closer to the local context – for example in Europe or the UK – could have greater impact on changing interpretations. The participants seemed able to distance the events at Fukushima from ‘their’ reactor site.

The apparent acceptance of the nuclear risk posed by the Hartlepool nuclear power plant appears to show a capacity to accommodate existing safety risks when considering nuclear heat network development. It should be noted however that two participants (a social housing tenant and a home owner) stated they would be unwilling to accept a
nuclear site ‘any nearer’ to where they live. This suggests that changing the reactor site could change the basis for acceptance.

7.3.2. A Necessary Technology

Another interpretation that appeared to underpin participant acceptance of nuclear heat networks was that nuclear fission is necessary for the future energy mix in the UK. Case studies of how renewable energy technologies are interpreted by the public suggest that whether a technology deployed in an area is seen as necessary or not is contested and used in narratives that support and oppose a development (McLachlan 2010). The focus group discussions reveal the underlying assumptions on which the interpretations of nuclear energy as necessary were constructed. They suggest that interpretations may not be static and that changes in the energy supply context may cause a re-evaluation of this view.

The interpretation of nuclear fission as a necessary technology was frequently expressed by participants in the focus groups to suggest that its use is in some way inevitable and there are no other choices. Central to this view were assumptions that fossil fuel and renewable energy alternatives are not viable because of eventual scarcity:

“What are the other options? Go back into the coal mines? It isn’t going to happen. I think a lot more people are more positive about it [nuclear energy].” #3 Private Rent Group.

“I can understand that they need to for our security, for where the oil is coming from and diversity you definitely need different fuels.” #1 Private Rent Group

“Solar and wind just can’t generate enough... There is nothing else, is there? We’ve got no choice. Nuclear is the only viable option when the oil and gas run out.” #1 Social Housing Group.

Concern about the availability of oil and natural gas was pervasive in the groups. The decline of domestic UK North Sea oil and gas reserves was covered in the first presentation in the group sessions, but participants in the private rent and home owner groups drew on other sources to express concern about global decline:
“I’m sure I just read an article about the fact fossil fuels, are they going to run out in twenty or thirty years time or something, I’m sure there is some danger of us not having fossil fuels much longer.” #2 Home Owner Group

“Aren’t the oil reserves drying up as well? They estimate 50 to 70 years or so, there’ll be no more?” #8 Home Owner Group

“It has to be environmental as well, not just money. You’ve got to have some motivation. When the gas runs out it is gone.” #1 Private Rent Group

As well as concern about the absolute global supply of fossil fuels, some participants claimed to be anxious about relying on oil and gas from ‘countries who don’t like us’. Some participants considered nuclear energy to be a way of providing energy security by making the UK less dependent on fuels imported from unfriendly countries – although participants did not comment on where uranium fuel for nuclear reactors may come from.

Renewable heat technologies were described by the facilitator in the first presentation of the group sessions but were not seen as credible alternatives to existing heating system. The participants considered them to be too expensive and untested:

“I saw a TV programme on with the solar thermal maybe a few months back but I can’t remember, but it was a really good introduction to that type of heating and how to get it into your house, but then it ended up saying well it’s too expensive. It gave a lot of information but then it said look the average person is not going to be able to do it.” #10 Home Owner Group

“My friend has just moved into a new house and she’s got that [ground source heat pump], but she can’t tell me if it is any good yet.” #5 Social Housing Group

“Solar thermal will probably be a bit useless with the British weather anyway.” #2 Private Rent Group

“They [renewable heat technologies] are not as effective as they say they are.” #7 Social Housing Group

“With solar, it’s so expensive we can’t afford that, no chance.” #6 Social Housing Group

These assumptions could be attributed to a lack of awareness about renewable heating technologies recorded in the first questionnaire completed by all three groups:
The information they had received about renewable technologies, from television, newspapers and friends did not engender the same confidence that participants had in nuclear technology to provide reliable affordable energy. The negative views of fossil fuels and renewables led many participants to see nuclear energy as inevitable, although not necessarily preferable. In the group discussions and the second questionnaire responses, nuclear heat networks were considered a sensible approach to making use of a development needed anyway for electricity production.

The generally held view of nuclear energy as necessary may however be sensitive to re-evaluations of both fossil fuel and renewable alternatives in addition to a more critical understanding of long term nuclear costs and availability. Greater exposure to debates on the life-cycle costs of nuclear energy and uranium availability, for example, could alter interpretations of nuclear energy’s viability. Similarly, if renewable technologies are seen to produce energy at low prices and demonstrate robust track records (if this information is effectively communicated to domestic energy users such as the participants in the focus groups) the participants may re-evaluate whether nuclear energy is necessary.
7.3.3. A Local Resource

The understanding of nuclear energy as necessary, and therefore the continued use of the Hartlepool nuclear facility as in some way inevitable, led some participants to interpret nuclear energy as a long term local resource. In this sense nuclear heat networks can be seen as means for obtaining local benefits from a technology some participants seemed to consider almost indelible in the landscape.

Whether an energy development symbolises a local benefit is another contested issue highlighted by the renewable energy siting literature (Devine-Wright 2005; McLachlan 2009; McLachlan 2010). In a case study of the siting of a biomass power station McLachlan notes that public support for the development, that was originally promoted as boosting the local rural economy, decreased when the feed stock for power station changed to biomass from outside the local area (McLachlan 2010). In the same example it was also noted that because the electricity was exported to the national grid the development was not seen as providing ‘green’ energy for the local community, rather the benefits were seen to be distributed nationally (McLachlan 2010). It is suggested that if there are perceived local detriments, such as visual impact, from a development but the benefits – such as low carbon energy – are national this can result in logics for opposition (McLachlan 2010).

For many participants in the focus groups nuclear energy was seen as part of the local area, something that would ‘be there anyway’. With this symbolic interpretation of place – as somewhere nuclear energy ‘fits’ – heat networks were seen as providing a local benefit by some participants:

“*If you are going to have a nuclear power station on your doorstep anyway, might as well be a benefit.*” #3 Rented Accommodation Group.

“*You might as well get the benefit, it’s going to be there anyway isn’t it?*” #9 Social Housing Group.

“*Why don’t we take out of this what no one else will and turn it into something good?*” #1 Private Rent Group
Participants in the focus groups suggest that the Hartlepool nuclear facility, when seen as part of the local landscape, justifies a heat network being developed in order to make use of a local resource.

7.4. Conclusions
The analysis of the focus group data suggests that public responses to a nuclear heat network development could be positive, or at least lead to the tacit support identified by McLachlan (2010). Although risks associated with nuclear energy were acknowledged, this did not necessarily translate into opposition towards the technology. The supportive interpretations of nuclear energy appeared however to be heavily contingent upon understandings of energy supply that frame nuclear energy as necessary and their experience of the local nuclear facility at Hartlepool. The development of a new reactor at the Hartlepool was discussed as a foregone conclusion on the basis of nuclear energy’s necessity for future power supplies, characterising the reactor’s thermal output as a resource for the local community to obtain benefit from. The presence of the risk at the Hartlepool nuclear power plant was accepted, enabling participants to see the heat from the reactor as a potential local resource. This suggests that the existing nuclear site (and a new reactor building on that site as discussed in the group presentations) is part of the public understanding of the local area held by focus group participants and therefore acceptable within this context. Participants in all three groups seemed able to manage concerns about nuclear risk that related to the Hartlepool site so that such anxieties were secondary to price and performance criteria discussed on Section 6.

The strong influence of the local nuclear facility on interpretations of nuclear heat network development suggests that if the focus groups were held in an area without a nearby nuclear facility different interpretations would be observed. On two occasions it was explicitly stated by participants that discussions about use of the existing site, as proposed in the presentation, would be different to a discussion about a new site. A participant in the social housing group and a participant in the home owner group both stated they would not want a nuclear facility any closer to where they currently live, although they would consider using heat from the existing Hartlepool site. Furthermore,
unlike other nuclear sites in the UK, Teesside is heavily industrialised making nuclear energy one of several industrial hazards. Cessation of nuclear developments at the Hartlepool site would not of itself return the local area to a non-industrial state. At nuclear sites such as Hinckley and Sizewell non-renewal of the site through new reactors would de-industrialise the area. This distinction should be considered if the focus group analysis is applied to other parts of the UK with nuclear sites that are viable candidates for nuclear heat networks such as Heysham and Oldbury.

As the Beznau nuclear heat network, discussed in Section 3, also highlights nuclear heat networks are not an impossible proposition for all publics. The focus groups show that there is potential for greater utilisation of nuclear energy on the basis of local resident responses.
8. Scenario Development

This chapter and Section 9 answer the research question identified in the scoping exercise (Section 2) relating to the suitability of potential new build nuclear sites in the UK for heat networks. This chapter describes the process of developing scenarios that explore the suitability of potential new build nuclear sites in the UK for heat networks using a case study. It explains why the Hartlepool nuclear site was chosen as this case study and describes how baseline data, such as a heating demand density map was produced. The process of using heating demand, network geographic coverage and user connection rate variables to produce twenty seven different technology development outcomes is outlined. The chapter concludes by discussing how attributes such as the number of connected users, annual heating demand and network heat loss were derived in relation to the scenario variables. This provides quantitative outputs that were used to assess the suitability of the Hartlepool nuclear power plant for heat network development, presented in Chapter 9.

8.1. Scenario Method

The suitability of a nuclear reactor site for a heat network depends on the spatial distribution of heating services demand relative to the reactor site. The performance of a heat network in terms of its financial viability (costs against revenue) and efficiency (heat lost in distribution as a proportion of heat delivered to users) is principally determined by how far a network extends the connection rates of users in the areas that are covered and the annual heating demand of users. These factors are variable, particularly as new build reactors are not expected before 2020 (DECC 2011), meaning social and economic contexts have the potential to deviate significantly from current conditions (Berkhout, Hertin et al. 2002). Heating services demand may be changed by government policy to incentivise insulation in buildings, or as a result of shifts in user heating practices. The coverage extents of heat networks and the connection rates of users are sensitive to factors such as energy prices, the alignment of different actors (such as Local Authorities, housing associations, private companies and community groups) user interpretation of a
technology and local or national government incentives for a technology (such as a boiler scrapage scheme to increase the uptake of A-rated natural gas boilers in the UK) (see Section 6).

The foresight scenario approach that is used in this research theme has been defined as a ‘learning machines’ for providing possible ‘futures’ that that encapsulate different outcomes, which could then be compared and analysed (Berkhout, Hertin et al. 2002). This approach involves producing a range of possible future nuclear heat networks through which variations in average heating demand, networks area coverage and connection rate can be considered. By providing different versions of future that can be compared, the effect of different outcomes on the potential to utilise nuclear energy through heat networks can be assessed. Furthermore, as discussed in Section 9, the scenarios can be used to suggest pathways to enabling the effective utilisation of nuclear energy for heating services.

The development of the future scenarios had three stages (see figure below). The stages of the scenario development process are described to provide a guide to how the underlying assumptions and modified secondary data used to create the scenarios:

- Collect Baseline Data: The first stage of the process was to obtain data for the fixed and varied parameters in the scenarios. The fixed parameters, unchanged in the scenarios include the thermal energy available from a new build nuclear reactor site and the performance factors for heat network pipes, particularly thermal transfer capacity by diameter. The varied parameters include current (using 2009 data) total statistics for, the number of energy users and annual heating services demand within the local authority areas adjacent to the nuclear reactor site as well estimates of current average peak user

demand for heating services (i.e. the capacity requirement of existing domestic and non
domestic heating systems). This provided reference data on which to base the scenarios.

- Differentiate Data Using Variables: While the available thermal output from the reactor
site and the performance factors for heat network pipes were held constant in all
scenarios, the areas covered by a heat network, the number of users connected within
these areas, their annual energy consumption and peak requirements are different in
each scenario. Baseline data, such as annual and peak heating demand and the number
of users, was selected and modified according to the variations of heating services
demand, network coverage and connection rate in a scenario. This produced twenty
seven distinct data spreadsheets that provided scenario specific information about the
number of users, where users are located and their annual and peak demand, that are
connected to a heat network in this ‘future’.

- Assign Attributes to Heat Networks in the Scenarios: The datasets in stage two were used
to determine the attributes of a heat network needed to connect the users in each
scenario. Each combination of average heating services demand, network coverage and
connection rate implies a different heat network. Several assumptions and numerical
values were used to assign attributes such as the type and length of heat network pipe
required, back-up boiler capacity and heat loss in distribution. These assumptions and
values acted as ‘rules’ for developing distinct heat networks shaped by a range of
different possible outcomes that they could be compared and analysed.
The figure above illustrates the three stages that are described in this chapter. The outcomes of this process were twenty seven scenarios, each with several comparable attributes describing distinct heat networks that reflect different social and economic conditions. The attributes of these scenario heat networks indicate how much nuclear energy would be utilised, the efficiency and illustrative costs in each alternative future.

**8.2. Selecting a Case Study**

The foresight scenario process, outlined above, entails in-depth, geographically specific analysis (particularly heating services demand density maps, see Section 2.2), which meant only one existing nuclear site could be studied as part of this research. Selecting the case study had to be properly considered as geographic context is important when assessing heat network potential. For example, in Dolman, Abu-Abid et al. (2012) a high-level assessment of potential nuclear heat network opportunities, used Torness and Hunterston nuclear sites as test cases. Both sites however are unsuitable candidates
(selected because of data availability (Dolman, Abu-Abid et al. 2012)) because neither site is on the prospective new build list\(^{49}\) and they are two of the most remote – relative to urban areas - nuclear sites stations in the UK.

The Hartlepool nuclear site was picked as a case study after an assessment of the eight potential nuclear new build sites; Bradwell, Hartlepool, Heysham, Hinkley Point, Oldbury, Sellafield, Sizewell and Wylfa (DECC 2011). Of the eight sites assessed, three were found to have potential demand centres, such as towns, cities and industrial parks near enough to the reactor site to warrant further investigation; Hartlepool, Heysham and Oldbury:

\(^{49}\) Scotland has a no nuclear policy, prohibiting new nuclear reactor construction.

The figures above show the high level analysis undertaken, using the geographic information system (GIS) software (ArcGIS), to identify areas with high domestic and non-domestic building density near the three potential nuclear sites. The map data was used to identify areas with compact housing (particularly terrace rows and high rise flats) as well as large retail and industrial estates. A 20km radius was used define the furthest limit a heat network. Transporting heat further than this distance is likely to require non-conventional thermal transfer technology, as described in Pierres, Lao et al (2009), to avoid massive heat loss in distribution, although other studies, Macadam, Davies et al.
Hartlepool was selected as the case study because the potential demand centres identified were larger than in the Heysham case and in closer proximity to the reactor site than the Oldbury case. The findings from the Hartlepool case study do however enable a more informed discussion of the potential for heat networks at the Heysham and Oldbury sites (see Section 10).

8.3. Producing Baseline Data.
Before the scenarios were developed, four pieces of analysis were undertaken to provide baseline data. Firstly the available thermal output from a new build nuclear facility at the Hartlepool nuclear site was assessed. Secondly a heating services demand map was produced to analyse the distribution of heating services demand near the Hartlepool nuclear site. Thirdly research was carried out to determine the maximum heating services demand of domestic and non-domestic users in the scenarios. Fourthly, the operating parameters of heat network pipes were assessed to determine constraints for thermal transfer between the reactor site and potential energy users.

8.3.1. Thermal Output of New Build Nuclear Reactors:
The potential thermal energy output from new build nuclear reactors on the Hartlepool site was required to provide an indication of the size of heat network that nuclear energy could support in the scenarios. It entailed determining reactor type, the proportion of reactor energy output available for a heat network and the number of reactors to be located at the site.

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50 This study has a stronger emphasis on commercial rather than technical viability.
8.3.2. Reactor Type

There are numerous types of nuclear fission reactor (see Section 3), both in operation and in development. For heat network applications the specifics of a reactor’s design, such as fuel cycle and operating temperature, are not essentially relevant, as all reactors provide thermal energy to generate steam with temperatures in excess of 120°C.\textsuperscript{51} The most significant attribute of a reactor in this context is its thermal energy output capacity.

Two reactor designs were considered for the scenarios; the Westinghouse AP-1000 and the Areva Evolutionary Pressurised Reactor (EPR). They are the two nuclear reactor designs that are at an advanced stage of the Generic Design Assessment (GDA) process in the UK. Reactor designs must complete the GDA - an in-depth technical review by the Office for Nuclear Regulations (part of the Health and Safety Executive) and the Environment Agency - before they can be granted UK site licenses. Other reactor designs may be submitted for GDA, however the current process takes four years, meaning the AP-1000 and EPR are most likely to be constructed at existing nuclear sites in England and Wales. Of the three developers planning to build new nuclear capacity, the EPR is the reactor design choice of EDF, while Horizon Nuclear Power (a partnership between E.ON and RWE Npower) and NuGen (a partnership between GDF Suez and Iberdrola) are considering both reactor designs.\textsuperscript{52}

8.3.3. Thermal Output

Both the AP-1000 and the EPR have evolved from pressurised light water cooled reactor (PWR) designs in a similar way. They both have design fundamentals (water moderator, water moderator, \textsuperscript{51} A steam based heat network may require higher reactor temperatures, but water based heat networks, which are the focus of this study, will most likely operate at below 120°C. See, Skagestad, B. and P. Mildenstein (2011). District Heating and Cooling Connection Handbook. Paris, International Energy Agency . \textsuperscript{52} EDF and Areva are closely linked having developed the EPR in close cooperation, Areva & EDF (2012), UK EPR Generic Design Assessment, Available at: http://www.epr-reactor.co.uk/scripts/ssmod/publigen/content/templates/show.asp?P=183&L=EN (Accessed 12 February 2012). Horizon Nuclear Power and NuGen are considering both the EPR and AP-1000, Jeremy Gordon, (2010), UK Waits for Market Reform, Available at: http://www.world-nuclear-news.org/NN_UK_nuclear_waits_for_market_reform_0212101.html (Accessed 12 February 2012). As of 17\textsuperscript{th} February 2012 Horizon Nuclear Power and NuGen had not made a decision on reactor design.
water cooled, pressure vessel, twin loop) that are similar to the Westinghouse PWR reactors that supply the Beznau heat network (Handl 1998) indicating their suitability for CHP operation.

As of 2012 the first EPR and AP-1000 reactors are not expected to begin operation until 2013, and therefore design specifications were used to estimate reactor outputs. In terms of thermal output both reactors are designed to operate at typical light water cooled reactor temperatures (~325°C). The EPR is designed for greater maximum thermal output, 4,500MWt (Framatome ANP 2005), than the AP-1000, which has an anticipated maximum output of 3,400MWt (Sutharshan, Mutyala et al. 2010).

8.3.4. Heat Extraction

Both the EPR and the AP-1000 use condensing steam cycles to generate electricity. Condenser steam cycles used with light water pressurised reactors generate steam from the reactor core’s primary cooling loop (see the figure below). The steam is passed through turbines to generate electricity. Around a third of the thermal energy in the steam can be converted to electrical energy. The rest of the thermal energy has been removed from the cycle to condense it to water at a low enough temperature to re-enter the steam boiler and transfer more thermal energy from the reactor core (Tester, Drake et al. 2005). This entire thermal energy, in any non CHP thermal power station is known as the cooling load. If a nuclear energy facility is operated for CHP, then steam is

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extracted (bled) from the steam cycle at different points and passed through heat exchangers that transfer thermal energy to a district heating network (or directly for process use). This reduces the cooling load and more thermal energy is recovered for energy use (see Section 3 for an overview).

Figure 23: Simplified diagram of nuclear CHP. Adapted from Handl (1998)

Thermodynamic and system constraints limit the amount of thermal energy that can be extracted from the steam cycle at temperatures usually required for district heating networks. An accurate assessment of the thermal energy recoverable from the steam cycles of the EPR and AP-1000 would require in-depth analysis of the thermodynamic characteristics of the steam cycle and the extraction heat exchangers. It was not in the scope of this thesis to undertake this work, however Diamant and Kut (1981) provide a

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56 District heating networks typically require the flow temperature of water to be between 80°C and 120°C, this means extracting steam at sufficient temperature. In the final stages of the condenser steam cycle the temperature of the working medium (water/steam) is at too low a temperature to be valuable for district heating, as it may be cooler than the district heating network return temperature. Harvey, L. D. D. (2006). A Handbook on Low-energy Buildings and District-energy Systems: Fundamentals, techniques and examples. London, UK, Earthscan.
simplified method of calculating potential thermal energy extraction from a condenser steam cycle:\(^{57}\)

\[
\frac{X - (\eta_{Th}X)}{2} = Y
\]

Where \(Y\) is the available thermal energy for district heating, \(X\) is reactor thermal output and \(\eta_{Th}\) is the thermal efficiency of the nuclear facility. Therefore for an EPR nuclear facility operating at designed 37\% thermal efficiency with full reactor output:

\[
\frac{4500 - (0.37 \times 4500)}{2} = 1,417\text{MWth}
\]

For an AP-1000 nuclear facility at designed 35\% thermal efficiency with full reactor output:

\[
\frac{3400 - (0.35 \times 3400)}{2} = 1,105\text{MWth}
\]

This acts a heuristic, ‘rule of thumb’ when estimating the extraction of useable energy from a condensing steam cycle.

### 8.3.4.1. Number of Reactors at Nuclear Site

To determine the total thermal energy resource available from the nuclear site in the scenarios, the next step was to decide the number of reactors to be situated at the site.

The co-location of several nuclear reactors is common. There is an economic case for constructing and operating more than one reactor on the same site, relating to economies of scale (Mott MacDonald 2010). The UK Government has demonstrated a preference for locating 16GW of new nuclear capacity at existing nuclear locations,

having dropped new locations from their approved site list. Both factors suggested that it would be reasonable to assume that two new reactors would operate at the Hartlepool site in the scenarios. This was an assumption supported by an EDF proposal to construct two EPRs at Hinkley Point.

Based on the assumptions made about available thermal energy for district heating from the two reactor types, the total thermal energy output capacity in the scenarios was determined for both reactor types. Two EPRs operating at full output with maximum heat extraction could provide 2,834MWth thermal energy capacity for a heat network. Under the same assumptions, two AP-1000 reactors could provide 2,210MWth thermal capacity.

### 8.3.4.2. Availability

Reactor availability typically refers the disparity between the energy a reactor could produce without interruption and its actual output (load factor). In the context of supplying thermal energy to heat network however it is more relevant to know the availability of the reactor(s) during high demand months (the heating season). The figure below illustrates the difference between power (electricity) and heating services (using natural gas as a proxy) demand:

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There are strong economic\textsuperscript{60} and engineering factors\textsuperscript{61} that mean nuclear operators aim to constantly maximise thermal output throughout the year and achieve consistently high availability during operational life of a reactor. Consequently the EPR and AP-1000 are designed to operate at >90% capacity factor availability, through optimised refuelling and simplification of design to reduce maintenance requirements (Framatome ANP 2005; Sutharshan, Mutyala et al. 2010).\textsuperscript{62} However as the figure above demonstrates, seasonal

\textit{Figure 24: Daily Natural Gas and Electricity Supply to UK end users in 2004. Adapted from National Grid Operational Data. See http://www.nationalgrid.com/uk/Electricity/Data/Demand+Data/ (Accessed 2 April 2012) and http://www.nationalgrid.com/uk/Gas/Data/ (Accessed 2 April 2012)}

\textsuperscript{60}The operational costs of nuclear energy are relatively low due to proportionately low fuel costs in comparison with other thermal power station types, while construction and decommissioning costs are greater Mott MacDonald. (2010). "UK Electricity Generation Costs Update." Retrieved 20 January 2012, from http://www.decc.gov.uk/assets/decc/statistics/projections/71-uk-electricity-generation-costs-update-.pdf. There is therefore an incentive for an operator to maximise energy output even when the market price for electricity is low (as opposed to natural gas power stations with proportionately higher fuel costs but with lower construction and decommissioning costs where there is an economic incentive to vary output based on electricity price) Mott MacDonald. (2010). "UK Electricity Generation Costs Update." Retrieved 20 January 2012, from http://www.decc.gov.uk/assets/decc/statistics/projections/71-uk-electricity-generation-costs-update-.pdf, Denholm, P., J. C. King, et al. (2012) "Decarbonizing the electric sector: Combining renewable and nuclear energy using thermal storage." Energy Policy Volume, DOI: http://dx.doi.org/10.1016/j.enpol.2012.01.055.

\textsuperscript{61}There are aspects of reactor physics and thermal inertia in large steam turbines that limit the flexibility of nuclear reactors to decrease or increase output Denholm, P., J. C. King, et al. (2012) "Decarbonizing the electric sector: Combining renewable and nuclear energy using thermal storage." Energy Policy Volume, DOI: http://dx.doi.org/10.1016/j.enpol.2012.01.055.

\textsuperscript{62}Historically only one quarter of reactors would-wide operate at above 90% capacity, and there is significant variation by type and age of reactor from (~50%-91%).\textsuperscript{62} However, assuming the reactors do not
availability is a more significant factor than annual availability for heating services. At a twin reactor site, as in the scenarios, reactor availability sufficient to meet heat network demand can be achieved throughout the year. Scheduled maintenance and refuelling can be planned so that it does not overlap the heating season. Installing heat extraction at both reactors at the nuclear site, as in the case of the Beznau nuclear heat network, means the network is not affected if one reactor is unavailable due to refuelling or maintenance during summer months (as network demand is low enough to be met by a single reactor’s output) (Handl 1998). This means that while unplanned shut downs need to be accounted for with back-up boilers, when the reactors are in normal operation availability should not an issue for a heat network operator.

This assessment of the potential thermal output from the reactor site in the scenarios indicates that a substantial thermal resource would be available for heat networks. For comparison, the Metropolitan Copenhagen Heating Transmission Company (CTR), which supplies 5,108GWh of heating services annually to the Greater Copenhagen area of Denmark, has 1,931MWth of thermal energy generating capacity available (CTR 2009). This indicates the potential for a large heat network based supplied entirely by the Hartlepool nuclear site. The next stage the scenario development was to locate heating services demand near the reactor site to utilise this capacity.

8.3.5. Heating Services Demand Map
Having assessed the potential thermal energy capacity available from the nuclear site in the scenarios, the next step was to produce a map showing the distribution of heating services demand near the Hartlepool nuclear site. The distribution of this demand, whether concentrated or dispersed, is necessary for determining the energy efficiency and economic viability of heat networks. The heating services demand map highlights areas with sufficient demand density – based on thresholds set out in district heating literature (Woods, Riley et al. 2005; Zinko, Bohm et al. 2008). This analysis also provided

have persistent technical problems, it is reasonable to anticipate that reactor output would be consistently very high.
baseline heating services demand and user data that could be varied in the different scenarios.

Three datasets were used to produce the heating services demand map; annual natural gas consumption data, geographic boundary data and Ordnance Survey (OS) map data. This section explains how the datasets were modified and integrated to produce the heating services demand map. The figure below outlines the approach taken (LLOSA refers to lower level super output areas and MLSOA refers to middle level super output areas; geographic data classifications used by the Office for National Statistics):

![Heating Services Map Development Diagram](image)

**Figure 25: Heating Services Map Development Diagram.**

### 8.3.5.1. Selecting the Method Used

Ensuring a detailed understanding of actual heating services demand near the Hartlepool reactor was important as the spatial relationship between the reactor site and energy users is fixed. This is because only existing nuclear sites will be available for new reactor
facilities\textsuperscript{63} and existing buildings are connected to the heat networks in the scenarios (as opposed to a study where there is flexibility in where a CHP unit is located or the network will primarily connect new builds).

Approaches that use illustrative examples based on generic representations (i.e. typical UK city layouts and building types) to represent different heating load distribution configurations, as in Fragaki et al (2008), Macadam et al (2008) and Woods et al (2005), were therefore considered to be inappropriate. Similarly a ‘building physics stock model’, such as the Building Research Establishment’s Housing Model for Energy Studies (BREHOMES) or the UK Carbon Domestic Model (UKDCM), approach was also rejected. Building physics stock models use data such as floor space, building fabric, occupancy and solar gains to estimate energy consumption in existing residential building stock (Kavgic, Mavrogianni et al. 2010). However, small sample studies of actual heating services use have shown weaker than expected correlations between building physics and space heating demand (Wright 2008). This may be the a result of social and economic impacts on energy use that are not accounted for in the models or flaws in technical assumptions (Oreszczyn, Hong et al. 2006; Wright 2008; Kavgic, Mavrogianni et al. 2010).\textsuperscript{64} It was decided that the underlying limitations of this modelling approach would make it inappropriate for this research.

Another approach to identifying areas suitable for heat network development is the use of energy bills for each building in a potential heat network coverage area (Skagestad and Mildenstein 2011). This is a method of accurately determining energy use for both domestic and non-domestic buildings that would implicitly include building performance and user practices that affect energy usage. It would also specify individual users in a way that would make the analysis of demand distribution very precise (i.e. identifying key large users who can act as ‘anchor’ demand centres). However, the large scale of the district heating network variations envisaged in the scenarios (with potentially more than 30,000 buildings connected) and the potential problems in accessing individual energy

\textsuperscript{63} Until all eight recommended existing nuclear sites are developed to capacity.

\textsuperscript{64} For example, heat loss through party walls in terrace properties is significantly greater than previously assumed. See Lowe, R. J., J. Wingfield, et al. (2007). "Evidence for heat losses via party wall cavities in masonry construction." \textit{Building Services Engineering Research and Technology} \textbf{28}(2): 161-181.
use data on this scale within the timescale of the thesis meant this was not an available option.

The method that was selected uses records of natural gas consumption available for geographic census areas in England and Wales to approximate actual heating services demand distributions. This is data compiled and published annually by DECC. It provides gas consumption data within lower level super output area (LLSOA) for gas meter points with <73,200kWh annual consumption, and data on natural gas consumption within middle level super output area (MLOSA) for gas meter points with >73,200kWh annual consumption. LLSOA datasets are disaggregated down to 400-1,500 domestic users per zone, the greatest level of precision possible without contravening National Statistic guidelines on data disclosure. MLSOA datasets disaggregate domestic and non-domestic (commercial and industrial) down to groups of 2,000–5,000 domestic users and 6-400 non-domestic users. This means that domestic demand can be attributed to small geographic areas, using LLSOA data, although non-domestic demand data is less geographically precise.

In addition to providing details on the total annual gas consumption of each LLSOA and MLOSA, the DECC natural gas consumption data also records the number of domestic and non-domestic (at MLOSA) users within each area. This is a useful proxy for the number of potential heat network users within each area.

Natural gas consumption data was considered to be a robust proxy for heating services demand because of the high prevalence (94% of households) of natural gas central heating in domestic buildings within the local authorities (Hartlepool, Stockton-on-Tees, Redcar and Cleveland, and Middlesbrough) adjacent to the nuclear site (Office for National Statistics 2004). Data on fuel use for heating services for non-domestic users was not available, however there are two major natural gas terminals in the area (PX and BP on Teesside), suggesting a mature gas network with potentially high levels of

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connection by all energy users in the area.\textsuperscript{66} This data was particularly useful because it can be linked with digital map data that can show the geographic extent of each LLSOA and MLSOA.

The gas consumption data does however have limitations. It is split into ‘domestic’ and ‘non-domestic’ users on the basis of a user’s annual consumption, not by actual user type. This means that potentially small commercial and industrial users may be misclassified as domestic users and exceptionally large domestic users may be misclassified as non-domestic. While the classification of domestic users is useful for analysis, the non-domestic classification for larger, commercial and industrial users is not helpful as it conflates a diverse range of user types. Furthermore, non-domestic data is not available at LLSOA due to data disclosure issues. This means domestic consumption can be more accurately attributed than non-domestic which is only available at MLSOA.

Historic gas consumption data has also been used by DECC to develop their heat demand map.\textsuperscript{67} This is an online tool made available in 2012 that shows heat demand density by user type overlaid onto a Google map. This map is a useful tool for high level analysis and shows very similar outputs as the heat demand map used in the scenarios. It is however not detailed enough for the street-level network planning used in the scenarios and cannot be modified to show changes in user heating demand.

\textbf{8.3.6. Developing the Heat Map from Datasets}

To produce a map showing the distribution of heating services demand in relation to the reactor site at Hartlepool, two datasets – natural gas consumption data and geographic boundary data – had to be modified and combined. The natural gas consumption data had to be modified to more accurately reflect heating services demand while geographic


\textsuperscript{67} The DECC heat map also uses a ‘weighted disaggregation’ model to differentiate user types. See DECC, (2012), \textit{About the National Heat Map}, Available at: \url{http://ceo.decc.gov.uk/en/ceol/cms/heatmap/about_map/about_map.aspx} (Accessed 12 June 2012).
boundary data had to be amended to omit non-energy demand related geographic features, such as lakes, forests, cemeteries and beaches.

8.3.6.1.1. Modifying Natural Gas Consumption Data
The natural gas consumption data was adjusted in two stages to more closely approximate heating services demand. The first adjustment was to omit natural gas consumption not used for heating services. The second adjustment was to account for inefficiencies when combusting natural gas for heating services.

Heat networks are currently unable to provide cooking services for users, and the scenarios do not include steam pipelines required for high temperature processes. Therefore to more accurately represent the heating services that can be replaced by heat networks, cooking and high temperature process use had to be removed from the natural gas consumption data. The data did not offer a disaggregation of gas consumption by end use for either LLSOA or MLSOA. Therefore a general assumption had to be made about the proportion of gas consumption to be removed from the data to represent cooking and high temperature process. As an alternative, average energy consumption by end use statistics, also published by DECC (2009), were used. This provided useful data on typical residential uses for gas and a breakdown of how different types of commercial and industrial user consume gas. For domestic user data this was easily achieved by applying residential sector average end use profiles to the LLSOA gas consumption data. A 3.5% reduction was applied to the annual gas consumption totals for domestic users in each LLSOA, based on DECC average end use data for the residential sector (2009). For non-domestic users in the MLSOA gas consumption data, the process was more complicated because of the range of different end use demand profiles provided in the average end use data, and the conflation of all non-domestic users – both industrial and commercial – in the MLSOA gas consumption data:

68 High temperature processes require a heat value of >120°C
Figure 26: Industrial Sector Natural Gas Consumption by End Use (DECC 2009)

Figure 27: Service Sector Natural Gas Consumption by End Use (DECC 2009).
Based on analysis of the different average end use profiles shown in the figure above, a 5% reduction was assumed to broadly represent non-domestic processes to be omitted from the natural gas demand statistics.

The second adjustment made to the natural gas consumption data was to account for the inefficiencies of boiler systems combusting natural gas for heating services, by applying assumed boiler efficiency to the data. Data on boiler efficiencies of buildings, or the proportion of boiler types in the local authorities adjacent to the reactor site was not available. A representative annual boiler efficiency was assumed using a database of gas boiler types rated by the Seasonal Efficiency of Domestic Boilers in the UK (SEDBUK) methodology.69 The boilers rated (including some obsolete models) had an annual efficiency range of 80% - 90.3%, of which the majority of boiler types were either band A or band B an annual efficiency of >85.5%.70 The database however does not cover all older boiler types, and it has been reported that there could be ~3.5million G-rated (<70% efficient) boilers still in use in the UK (Energy Saving Trust 2010). Consequently 85.5% annual boiler efficiency was assumed and applied to gas consumption data adjusted to remove cooking and high temperature processes.

A new Excel spreadsheet consisting of the approximate heating services demand of users within each LLSOA and MLSOA was created after the adjustments were made. The data fields in the spreadsheet were given a code that could be linked to corresponding geographic boundary data to produce the heating services demand map.

8.3.6.1.2. Modifying Geographic Boundary Data

Geographic boundary data was downloaded from Edina, an online source of geographic map data hosted by the University of Edinburgh. This data visually represents the geographic extent of LLSOAs and MLSOAs as polygon ‘features’ that accurately overlay onto OS digital maps. The polygon features can be measured to accurately provide the area of each LLSOA and MLSOA. This can then be used to derive the density of heating services demand by dividing an LLSOA or MLSOA’s annual demand by its area. In order to do this however, the LLSOA and MLSOA boundary features had to be modified.

Modification of the geographic boundary data was necessary because their boundaries are not uniform and vary in area and composition of geographic features. Heating services demand density should reflect the spatial relationship between energy users in a given area (whether they are dispersed or concentrated). However if LLSOA and MLSOA boundaries include geographic features that do not relate to the relationship between energy users within the boundary, then the boundary data may obscure demand density. For example, this figure shows three LLSOA boundaries, labelled A, B and C:

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From the OS 1:250000 map that the LLSOA boundary features overlay in the figure above, it is possible to identify buildings (energy users) within each boundary feature. With the exception of the school buildings in ‘B’, the buildings in all three boundary areas have a similar distribution pattern, in terms of how they are clustered together. However, while ‘C’ only includes only building features, ‘A’ and ‘B’ include geographic features that are unrelated to energy demand density (i.e. a park and fields). Therefore if the heating services energy consumption of each LLSOA was averaged across the area of
the LLSOA the distribution of energy users in LLSOA ‘A’ would appear to be significantly
ersparser than in ‘C’.

This issue was more acute for MLSOA boundaries. Because the data boundaries cover
larger geographic areas, energy user groupings are more dispersed, making the process
of attributing their energy consumption to relevant portions of the boundary area more
difficult:

Figure 29: Example of MLSOA Boundary Polygons (250K Raster [TIFF geospatial data],
Scale 1:250000, Tile(s): nz42, Updated: September 2011, Ordnance Survey (GB), Using:
EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded:
September 2011)
Incompatible datasets are a common problem when integrating geographically specific data with census boundary data, that can be overcome through dasymetric mapping (Chen, McAneney et al. 2004). Dasymetric mapping involves manually redrawing boundaries in ArcGIS so that they relate more accurately to other datasets.

Dasymetric mapping was used to modify the data to more closely reflect the areas of demand use. The figure below is an example of how the boundaries of the LLSOA boundary features in above figure were redrawn so that their boundaries more closely adhered to the distribution of energy users:
By redrawing the boundaries new features were created (‘D’, ‘E’ and ‘F’ in the above figure). The park land and fields that were within the LLSOA boundary ‘A’ are now in a new data boundary, ‘D’. The new data boundaries were assigned reference codes and
added to the heating services demand spreadsheet as new data fields with a nominal figure to represent that no heating services users are attributed to these areas.\footnote{A value above zero had to assigned for the new boundary areas because ArcGIS cannot ‘read’ them from the spreadsheet data if they are.}

The same process was undertaken for the MLSOA data boundaries:

\textbf{Figure 31:} Example of Modified MLSOA Polygons (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz42, Updated: September 2011, Ordnance Survey (GB), Using:}
The figure shows newly created data boundaries that relate the MLSOA consumption data areas more precisely to buildings and reduce the inclusion of non-building areas, such as the beach, from the skewing heating demand density.

**8.3.6.2. Integrating Datasets to Produce a Heating Services Demand Map**

Having modified the datasets the next step was to combine them to produce a heating services demand map able to show areas suitable for heat networks based on demand density, and provide the annual heating services load of these areas.

Heating services demand maps were created for LLSOA and MLSOA datasets. In both cases demand density was calculated by using ArcGIS to measure the area of each modified boundary feature. By dividing the annual heating services demand of each LLSOA of MLSOA by its area a demand density (kWh/m$^2$) was derived. For the MLSOA map, total heating demand, including domestic and non-domestic users, was used (whereas only domestic data is available for LLSOA datasets).

ArcGIS was then used to ‘join’ the heating demand spreadsheet data to the boundary data by corresponding codes. For example, the demand density of an LLSOA in the spreadsheet became an attribute of the LLSOA data boundary feature in the map. With the datasets joined it was then possible to classify each boundary feature by its demand density. The colour grading in the map legends classifies areas as high density (over 50kWh/m$^2$), medium density (30-50kWh/m$^2$), low density (10-30kWh/m$^2$) and unviable (below 10kWh/m$^2$). This grading was based on a review of Woods et al (2005) and Zinko et al (2008) and used to visually show areas with best potential for heat networks.
Figure 32: LLSOA Heating Demand Density Map (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz41 nz42 nz43 nz51 nz52 nz53, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011)
Both the LLSOA and the MLSOA versions of the demand density map correlate well with the DECC national heating demand density map for this area.\textsuperscript{73} The LLSOA map provides a more geographically specific representation of the data, however it only includes


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\textbf{Figure 33: Domestic and Non-domestic Demand Density at MLSOA (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz41 nz42 nz43 nz51 nz52 nz53, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011)
domestic demand. The MLSOA map, although more geographically vague, includes both domestic and non-domestic heating demand data and highlights industrial and retail parks which do not feature on the LLSOA map. Together the maps can be used to identify clusters of high heating demand suitable for heat networks. The maps were used to select areas covered by heat networks in the scenarios and define the physical attributes of the networks.

8.3.7. Domestic and Non-domestic Peak User Demand
The third piece of analysis undertaken to develop the scenarios was to estimate the peak requirement of users connected to the heat network in the scenarios. This was done by assigning an average heating capacity to domestic and non-domestic user types. The averages derived in this analysis were used to inform the physical attributes of the heat network, the size of user interface and the peak demand from the reactor site in each scenario.

8.3.7.1. Approach to Estimating Peak User Demand
A typical method for establishing the capacity of heating system required by heat network users is to use the capacity of each building’s pre existing heating system as a guide – accounting for potential oversizing (Skagestad and Mildenstein 2011). Alternatively heating requirements can be assessed by determining building usage, thermal conductivity of the building fabric as well as solar and internal (lighting and computers etc) gain (Maidment and Tozer 2002; Yao and Steemers 2005). Both methods are useful when applied to heat networks with a small number of connected buildings, however unsuitable for studies were over 30,000 buildings are being considered. Consequently average domestic and non-domestic heating system capacities were assumed using to approach discussed below.
8.3.7.2. Estimating Domestic Peak User Demand
To determine typical heating loads for domestic users the Building Research Establishment methodology for correctly sizing natural gas combination boilers (Whole House Boiler Sizing Method) was used to understand the factors that determine heating system capacities. Domestic combination boilers, commercially available in the UK, range from 11kW to 48kW\(^7\) and their size depends on a range of factors such as building size, quality of insulation and number of bathrooms (which proportionately increase additional capacity allowance for heating water). It is suggested however that individual gas boilers are often oversized, and that the existing boiler system in a property does not accurately reflect its space and water heating requirements (Skagestad and Mildenstein 2011).

The following table shows the heating system capacity requirements recommended by the Whole House Boiler Sizing Method\(^7\) for domestic dwellings with different internal dimensions and levels of insulation. For each calculation Northern/Midland Britain was the location parameter and water heating allowance was set at 2kW. Water heating allowance in the Whole House Boiler Sizing Method is used to account for addition capacity needed when space and water heating is required simultaneously. 2kW is the recommended allowance for a property with a single bathroom; to estimate for properties with additional bathrooms the allowance may be increased – for example 4kW allowance for a property with two bathrooms.

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\(^7\) See [http://www.sedbuk.com/]\(\) list of available gas boiler (accessed 12 November 2011).

\(^7\) Two online ‘Whole House Boiler Sizing Method’ calculators were used (both with the same inputs to test reliability) Institute of Domestic Heating and Environmental Engineers, (2011), *Boiler Size*, Available at: [http://www.idhee.org.uk/calculator.html]\(\), (Accessed 20 October 2011) and Gastec, (2011), *Whole House Boiler Sizing Method*, Available at: [http://www.sedbuk.com/]\(\), (Accessed 20 October 2011)
<table>
<thead>
<tr>
<th>Dwelling Type</th>
<th>Internal Dimensions</th>
<th>Insulation</th>
<th>Boiler Size (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Back to Front (m)</td>
<td>Side to Side (m)</td>
<td>No. Floors</td>
</tr>
<tr>
<td>Mid-level Flat</td>
<td>10</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Mid-level Flat</td>
<td>10</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Mid-level Flat</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Mid-level Flat</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Mid-level Flat</td>
<td>14</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Mid-level Flat</td>
<td>14</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>14</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>14</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Semi/End terrace</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Semi/End terrace</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Semi/End terrace</td>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Semi/End terrace</td>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Semi/End terrace</td>
<td>14</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Semi/End terrace</td>
<td>14</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Detached</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Detached</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Detached</td>
<td>12</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>
### Table 4: Boiler size estimates for domestic dwellings. Based on Building Research Establishment Whole House Boiler Sizing Method

<table>
<thead>
<tr>
<th></th>
<th>Detached</th>
<th>Detached</th>
<th>Detached</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>12</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Type</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Insulation</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Filled Cavity</td>
<td>Double</td>
<td>Double</td>
<td>Double</td>
</tr>
<tr>
<td>Thickness</td>
<td>75mm</td>
<td>75mm</td>
<td>75mm</td>
</tr>
<tr>
<td>Capacity</td>
<td>9</td>
<td>25</td>
<td>11</td>
</tr>
</tbody>
</table>

This analysis suggests a significant difference in potential heating requirement depending on property size, type and level of insulation ranging from at least 4kW to 25kW (or 27kW for large, poorly insulated detached households with two bathrooms).

To decide upon a suitable average value for domestic user heating capacity in the scenarios further research was undertaken on housing type and insulation level in the Hartlepool area (data on typical property sizes was not available). Figure below shows data on property types for the four local authorities adjacent to the Hartlepool nuclear site, taken from the 2001 Census:

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Figure 34: Household Spaces and Accommodation Type (KS16) by Local Authorities Area. Adapted from Office of National Statistics (2011)\(^6\)

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The following figures show data for northern England taken from the English House Condition Survey 2007 Annual Report (2009), which illustrates levels of insulation that might be typical in the Hartlepool area:

**Figure 35: Wall Insulation in Northern England. Adapted from the English House Condition Survey 2007 Annual Report (2009)**

**Loft Insulation**

The data showed that terraced and semi-detached households were most common in the area being assessed. Furthermore, while levels of wall insulation appeared evenly weighted between high, medium and low levels of insulation, this data suggested high levels of loft insulation (>75mm being the highest loft insulation band in the Whole House Boiler Sizing Method) and high incidence of double glazing in the area. This meant that detached, poorly insulated properties were likely to account for only a small proportion of domestic households in the four local authority areas. Using this analysis the heating requirement for an ‘average’ two storey, three bedroom, semi-detached house with >70mm, unfilled cavity walls and double glazing was calculated using the Whole House Boiler Sizing Method. This produced a required boiler capacity of 15kW, which was used as the baseline average domestic capacity requirement in the scenarios.

8.3.8. Estimating non-Domestic Peak Load

The process for providing a baseline average heating capacity for non domestic users was different to the domestic approach because of the wider range of building types and the lack of a methodology similar to the whole house boiler sizing method. The capacities of...
heat network user interfaces (hydraulic interface units) for non-domestic users range from 50kW to 20MW, reflecting the varied building types within this category, including “apartment buildings, industrial properties, schools, sports facilities, health facilities, hotels, and barracks.” To narrow this range, examples of non-domestic user capacities from existing UK heat networks were compared:

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Heating Capacity (kW)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office Building</td>
<td>300</td>
<td>Sheffield City Council, (2011)(^{78})</td>
</tr>
<tr>
<td>Supermarket</td>
<td>507</td>
<td>Maidment and Tozer (2002)</td>
</tr>
<tr>
<td>Cinema</td>
<td>1,000</td>
<td>Sheffield City Council, (2011)(^{79})</td>
</tr>
<tr>
<td>Civic Centre</td>
<td>2,000</td>
<td>IEA (2011)(^{80})</td>
</tr>
<tr>
<td>Hospital</td>
<td>2,000</td>
<td>Sheffield City Council, (2011)(^{81})</td>
</tr>
<tr>
<td>Large Leisure Centre</td>
<td>3,500</td>
<td>Sheffield City Council, (2011)(^{82})</td>
</tr>
</tbody>
</table>

Table 5: Heating Capacities of Non-domestic Users Connected to Heat Networks in the UK

The table shows considerable variation between non-domestic user types. Data on the proportion of non-domestic energy user types within local authority areas adjacent to the reactor site was not available to enable establishing an ‘average’ non-domestic user for area. For the purposes of the scenarios a 1,000kW heating capacity was assigned to non-domestic users. This reflected an assumption that large users, such as hospitals and

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\(^{79}\) Ibid  
\(^{82}\) Ibid
large leisure centres were likely to be less frequent than smaller users in the denser urban areas most suitable for heat networks.

8.3.9. Physical Constraints of Heat Network Pipes
The fourth piece of background analysis conducted for the scenarios assessed the capacity of heat network pipes to transfer thermal energy between the reactor site and energy users.

The operating thresholds of heat network pipes, determine the maximum rate of thermal energy a heat network can distribute. These thresholds are determined by the internal diameter of the pipe, the maximum water flow rate (where water is used as the transfer medium) they can safely accommodate and the temperature difference between the user’s flow and return parameters. The operating thresholds are used when selecting the diameters of pipes used in the scenarios and for determining the maximum capacity of users that can be connected to a heat network.

The operating thresholds of heat network pipes were obtained through a personal communication with pipeline supplier Durotan, who provided the design specifications of German Pipe heat network pipes they supply:

<table>
<thead>
<tr>
<th>Internal Pipe Diameter (mm)</th>
<th>Maximum Water Velocity (m/s)</th>
<th>Maximum Transferable Heat Capacity by Flow - Return Temperature Difference (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>30°C</td>
</tr>
<tr>
<td>500</td>
<td>3.5</td>
<td>84,600</td>
</tr>
<tr>
<td>600</td>
<td>3.6</td>
<td>125,900</td>
</tr>
<tr>
<td>700</td>
<td>3.7</td>
<td>176,100</td>
</tr>
<tr>
<td>800</td>
<td>3.8</td>
<td>236,900</td>
</tr>
<tr>
<td>900</td>
<td>3.9</td>
<td>307,200</td>
</tr>
<tr>
<td>1000</td>
<td>4</td>
<td>389,500</td>
</tr>
<tr>
<td>1100</td>
<td>4</td>
<td>562,000</td>
</tr>
</tbody>
</table>
The temperature difference of the heat networks in the scenarios is 40°C. This was based on the standard return temperature expected from standard UK central heating systems and the highest optimal flow temperature currently recommended. Although return temperatures as low as 50°C may be possible for district heating schemes connecting existing buildings in the UK (Martin and Spence 2010), the standard design return temperature of central heating systems in the UK is 70°C (Skagestad and Mildenstein 2011). Water based heat networks can accommodate flow temperatures of up to 130°C, however at temperatures of 120°C or higher the expected operational lifetime of the network declines to half (i.e. 40 years at 110°C to 20 years at 130°C) (Skagestad and Mildenstein 2011). A flow temperature of 110°C is high enough to obtain an effective temperature difference in the network without adversely impacting pipeline durability (Skagestad and Mildenstein 2011).

A 40°C temperature difference in the network allows a maximum transferable heat capacity of 749,300kW, if the largest pipe diameter were to be selected. This means each major branch of a heat network in a scenario cannot connect user capacity over this threshold. It also means that even with three large transmissions pipelines in a heat network, the maximum thermal energy demand that could be required from the reactor site (up to 2,247,900kW) could be met by reactor output (2,834,000kW for EPR and 2,210,000kW for AP-1000 design). Although no scenario reaches a connected capacity close to this (Scenario 7 has the highest connected user capacity, 1,844,000kW), it means that network capacity would not be a significant constraint on using all available reactor capacity.

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83 This is temperature difference during the heating season. As discussed in Section 4.5 the flow temperature outside of the heating season (May to October) is 90°C, meaning a temperature difference of 20°C in the network during summer months with lower heating demand.
8.4. Scenario Variables

The scenarios were developed to answer questions about whether heat networks can utilise nuclear energy for heating services. As discussed in Section 3 the performance and viability of heat networks depend upon the spatial distribution of user demand in relation to the thermal energy source. The distribution of demand is not necessarily fixed as social and economic factors may alter user demand, affect the areas near a thermal source that are covered by a network and the users who opt to connect. The scenarios therefore explore the impact of three variable factors on a heat network based at the Hartlepool nuclear site:

- Changes in user demand as a result of energy efficiency measures and/or user behaviour change: Changes in annual and peak user heating demand impact on heat networks in two ways. Firstly heat demand density reduces when the annual demand in an area reduces. Secondly, pipelines can have a narrower diameter if peak loads are lower. Both issues would be expected to influence the efficiency and economic viability of heat networks. With UK Government environmental policy and economic considerations driving targets to lower per user energy use, this is a significant variable to explore.

- The impact of extending the heat network further from the reactor site: Heat networks have different performance features if they cover large areas as opposed to small contained local schemes (Woods, Riley et al. 2005). As networks extend further to include more users their cost and efficiency attributes may change. In the Hartlepool example the geographic coverage can be varied by expanding the network from connecting a demand centre 5km away to covering three demand centres within a 15km radius of the reactor site.

- The influence of user connection rate on the viability and performance of a heat network at the Hartlepool nuclear site: The proportion of users who connect to a heat network within an area has a very significant on the economic and energy efficiency performance of the network. If more users are connected per metre of pipeline then the infrastructure costs are spread across more users and energy lost in distribution will be a smaller proportion of delivered services. Connection rates can however vary significantly owing to social and economic factors, meaning a range of possibilities need to be considered.
To develop scenario that represent different variations of these factors, the baseline data described in Section 8.2 relating to heating services demand distribution was differentiated to create scenario specific data on energy demand, geographic extent of heat network and users available for connection. The table below lists the twenty seven scenarios and describes their defining variables:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>User heating demand remains the same. The network covers a demand centre within 5km of the nuclear site. The connection rate is high.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>2</td>
<td>User heating demand remains the same. The network covers a demand centre within 5km of the nuclear site. The connection rate is moderate.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>3</td>
<td>User heating demand remains the same. The network a demand centre within 5km of the nuclear site. The connection rate is low.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>4</td>
<td>User heating demand remains the same. The network extends to cover two demand areas within 10km of the nuclear site. Connection rate is high.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>5</td>
<td>User heating demand remains the same. The network extends to cover two demand areas within 10km of the nuclear site. Connection rate is moderate.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>6</td>
<td>User heating demand remains the same. The network extends to cover two demand areas within 10km of the nuclear site. Connection rate is low.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>7</td>
<td>User heating demand remains the same. The network extends to three demand areas within 15km of the nuclear site. Connection rate is high.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>8</td>
<td>User heating demand remains the same. The network extends to three demand areas within 15km of the nuclear site. Connection rate is moderate.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td>9</td>
<td>User heating demand remains the same. The network extends to three demand areas within 15km of the nuclear site. Connection rate is low.</td>
<td>![Symbol]</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Connection Rate</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>10</td>
<td>User demand is reduced. The network covers a demand centre within 5km of the nuclear site. Connection rate is high.</td>
<td>High</td>
</tr>
<tr>
<td>11</td>
<td>User demand is reduced. The network covers a demand centre within 5km of the nuclear site. Connection rate is moderate.</td>
<td>Moderate</td>
</tr>
<tr>
<td>12</td>
<td>User demand is reduced. The network covers a demand centre within 5km of the nuclear site. Connection rate is low.</td>
<td>Low</td>
</tr>
<tr>
<td>13</td>
<td>User demand is reduced. The network extends to two demand centres within 10km of the nuclear site. Connection rate is high.</td>
<td>High</td>
</tr>
<tr>
<td>14</td>
<td>User demand is reduced. The network extends to two demand centres within 10km of the nuclear site. Connection rate is moderate.</td>
<td>Moderate</td>
</tr>
<tr>
<td>15</td>
<td>User demand is reduced. The network extends to two demand centres within 10km of the nuclear site. Connection rate is low.</td>
<td>Low</td>
</tr>
<tr>
<td>16</td>
<td>User demand is reduced. The network extends to three demand centres within 15km of the nuclear site. Connection rate is high.</td>
<td>High</td>
</tr>
<tr>
<td>17</td>
<td>User demand is reduced. The network extends to three demand centres within 15km of the nuclear site. Connection rate is moderate.</td>
<td>Moderate</td>
</tr>
<tr>
<td>18</td>
<td>User demand is reduced. The network extends to three demand centres within 15km of the nuclear site. Connection rate is low.</td>
<td>Low</td>
</tr>
<tr>
<td>19</td>
<td>User Demand is greatly reduced. The network covers a demand centre within 5km of the nuclear site. Connection rate is high.</td>
<td>High</td>
</tr>
<tr>
<td>20</td>
<td>User Demand is greatly reduced. The network covers a demand centre within 5km of the nuclear site. Connection rate is moderate.</td>
<td>Moderate</td>
</tr>
<tr>
<td>21</td>
<td>User Demand is greatly reduced. The network covers a demand centre within 5km of the nuclear site. Connection rate is low.</td>
<td>Low</td>
</tr>
<tr>
<td>22</td>
<td>User Demand is greatly reduced. The network extends to two demand centres within 10km of the nuclear site. Connection rate is high.</td>
<td>High</td>
</tr>
<tr>
<td>23</td>
<td>User Demand is greatly reduced. The network extends to two demand centres within 10km of the nuclear site. Connection rate is moderate.</td>
<td>Moderate</td>
</tr>
<tr>
<td>24</td>
<td>User Demand is greatly reduced. The network extends to two demand centres within 10km of the nuclear site. Connection rate is low.</td>
<td>Low</td>
</tr>
<tr>
<td>25</td>
<td>User Demand is greatly reduced. The network extends to three demand centres within 15km of the nuclear site. Connection rate is high.</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>User Demand is greatly reduced. The network extends to three demand centres within 15km of the nuclear site. Connection rate is moderate.</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>User Demand is greatly reduced. The network extends to three demand centres within 15km of the nuclear site. Connection rate is low.</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Hartlepool Nuclear Heat Network Scenarios.

The figure below describes how by applying variations to each of the three variables, distinct combination of energy use, geographic coverage and connection rate were produced:
By varying the influential factors, distinct ‘futures’ are represented in each scenario’s data outputs. This differentiated data can be used to produce comparable futures for foresight analysis. This section explains the values and assumptions used to vary data for the scenarios.

### 8.4.1. Average Energy Demand for Heating Services
Average heating services demand was varied in the scenarios to explore whether a nuclear heat network at the Hartlepool site would still be viable if heating demand is reduced. It is assumed in the research that actions by building owners, energy companies
and governance institutions, driven by climate change policy and energy prices, will aim to reduce average heating services demand for existing buildings (Committee on Climate Change 2008; DECC 2009). The variations represent a range of different future outcomes:

- **Variation 1:** Annual and peak energy demand for heating services is unchanged for both domestic and non domestic users in relation to baseline data.
- **Variation 2:** Annual and peak heating services consumption decreased by 20% for domestic users and by 10% for non-domestic users in relation to the baseline data.
- **Variation 3:** Annual and peak heating services consumption decreased by 40% for domestic users and by 20% for non-domestic users in relation to the baseline data.

The variations were based on assumptions about the extent to which heating services demand in existing buildings can be reduced and the relationship between domestic and non-domestic reductions.

The high reduction variation for domestic users was based on assumptions from the 40% House scenarios developed by the University of Oxford Environmental Change Institute. This study suggests that a 38% decrease in average household space heating requirements (16,600kWh to 9,000kWh) and a 32% decrease in average water heating requirements (5,000kWh to 3,400kWh) could be possible by 2050 for pre-1996 housing stock through building fabric improvement and behaviour change (Boardman, Darby et al. 2005). With a standard 75/25 split between space and water heating requirements for domestic buildings (Skagestad and Mildenstein 2011) this would mean a 36.5% reduction in average heating services demand for pre-1996 housing stock should be possible. The 40% reduction for domestic users in Variation 3 assumes further reductions can be realised and therefore sets an even more challenging context for heat networks.

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84 Post 1996 housing stock is considered to have better thermal performance and therefore less scope for space heating demand reduction through energy efficiency measures, see Boardman, B., S. Darby, et al. (2005). 40% House. Oxford, Environmental Change Institute.
While domestic buildings in the scenarios are analogous with residential buildings in studies such as the 40% House, the non-domestic user classification does not fit well with building classifications in other studies. This issue stems from the classification of energy users in the gas consumption data from which the baseline data was derived (see Section 2.2), which conflates several distinct user types, including schools, hospitals, shopping centres and factories, into one group. Different user types are known to have different reduction potentials. This made attributing an average reduction that could be applied to all non-domestic users in the scenarios problematic. Work by the Committee on Climate Change (CCC) suggests there is greater demand reduction potential in the domestic sector, relative to the current baseline, than for average non domestic buildings (Committee on Climate Change 2008). This is in part attributed to non-domestic buildings having organisational systems in place to reduce demand (and improve efficiency) before the baseline comparison year and because of the types of building fabric used (Committee on Climate Change 2008). As such, while the CCC emphasises energy efficiency for reducing domestic sector heating emissions, supply side options are emphasised for non-domestic emissions reduction.

<table>
<thead>
<tr>
<th>Carbon Saving (MtCO2)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Efficiency</td>
<td>0 - 0.5</td>
</tr>
<tr>
<td>Energy Management</td>
<td>4</td>
</tr>
<tr>
<td>Energy Efficiency (inc. insulation)</td>
<td>3</td>
</tr>
<tr>
<td>Lights and Appliances</td>
<td>1</td>
</tr>
<tr>
<td>Renewable Heat &amp; Microgeneration</td>
<td>8-10</td>
</tr>
</tbody>
</table>

**Figure 39: Technical CO₂ Reduction Potential for Non-Residential Buildings by 2020.**
Source: Committee on Climate Change (2008)

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A reduction of 20% in non-domestic buildings was assumed for the high reduction variant. This captures the distinction between domestic and non-domestic buildings demand reduction in the scenarios.

The second and third variations regress from the high demand reduction variation with lower or no reductions for domestic and non domestic users. They represent future contexts where policies and actions to reduce heating demand are less successful. This may be the result of a weak levels of uptake for energy efficiency measures such as the Green Deal, or because insulation measures prove less effective than anticipated, or because user practices subvert efficiency improvements (reflecting work by Shipworth (2011), Chappells and Shove (2004), Wright (2008) and Scott (2004)).

A key assumption in all three variations is that annual and peak demand correlate directly, so that a 20% reduction in annual demand means a 20% reduction in peak user demand. This is because the measures to reduce annual demand such as improved building insulation are expected to also reduce the heating capacity requirement of the building’s heating system. The figure below shows typical annual heating demand curves for buildings with different levels of thermal performance:

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In the example given above, buildings with better insulation have lower annual and peak demand. Where peak demand reduces by 35%, between the existing building and the better insulated new building, annual demand reduces by 32%. Similarly a 54% reduction in peak demand between the existing building standard and the low energy building means a 50% reduction in annual demand. This may be a simplification of the relationship between peak and annual demand, particularly as changes in user behaviour may impact on annual demand more than peak demand (i.e. if insulation lowers peak requirement but makes it more economically viable to have space heating for more hours in a year). It was not however possible within this thesis to investigate this dynamic, and therefore the established direct relationship was used.

The different average demand characteristics in the variations were used to produce new spreadsheet datasets for domestic and non domestic annual and peak demand based on the 2009 demand estimates described in Section 2 and altered according to the variations.

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87 Peak demands are shown as the highest values on the ‘x’ axis and annual demand is the area beneath the chart lines.
This process of varying the baseline data produced three distinct sets of data on annual demand, peak demand and demand density. The table above shows peak user demand for each variation. The demand in each LLSOA and MLSOA in baseline data was modified in line with the variants to produce new annual demand density attributes for each geographic data boundary. The maps below show the heat demand density maps produced from each of the datasets, reflecting the change in attributed values for energy demand:

<table>
<thead>
<tr>
<th>Variant</th>
<th>Domestic (kW)</th>
<th>Non-Domestic (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant 1</td>
<td>15</td>
<td>1,000</td>
</tr>
<tr>
<td>Variant 2</td>
<td>12</td>
<td>900</td>
</tr>
<tr>
<td>Variant 3</td>
<td>9</td>
<td>800</td>
</tr>
</tbody>
</table>

**Table 8: Variations in peak user demand.**
Figure 41: Variation 1 Domestic Heating Services Density Map. (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz41 nz42 nz43 nz51 nz52 nz53, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011)
Figure 42: Variation 2 Domestic Heating Services Demand Density. (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz41 nz42 nz43 nz51 nz52 nz53, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011)
8.4.2. Geographic Coverage Areas

The second variable used in scenario development specifies the area covered by a heat network. The geographic coverage areas were used to select the heating demand and user data included in a scenario. Only data in LLSOA and MLSOA data fields that fell
within the geographic coverage area boundary, or boundaries, specified in a scenario were included in its spreadsheet data.

The coverage area variations were created by selecting three clusters of suitable heating services demand that each represent a further extension of the network into the surrounding area. The three coverage areas were produced by using demand density map information to identify clusters of demand that would be most suitable for heat networks. This determination was based on three considerations:

- **Demand Density:** Heat networks are more cost effective and heat lost in distribution is lower in areas of high demand density. Heating services demand density maps were used to highlight areas of high domestic demand co-located with significant non-domestic demand.

- **Network Constraints:** Each heat network main transmission pipeline (primary pipe) is constrained by the maximum thermal energy it can transfer. In keeping with the practice of other studies, such as Woods et al (2005), Parsons Brinckerhoff (2009) and McNaught et al (2011), only one main transmission pipeline is assumed per coverage area. This constraint limited the size of geographic coverage areas to avoid too more users being included in the coverage area than the network could accommodate.

An exact overlap of all data boundaries was necessary to wholly incorporate each geographic boundary’s data into the scenario. The figures below show how the coverage areas relate to domestic demand at LLSOA and non-domestic demand at MLSOA:
Figure 44: Variation 1 Domestic Heating Services Demand Distribution Map with Geographic Coverage Areas. (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz41 nz42 nz43 nz51 nz52 nz53, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011)
The variation in coverage area increases the geographic extent of the network from a 5-10km radius to a 15km radius:

- **Variation 1**: Network extends to nearest area with high demand density (Hartlepool).
- **Variation 2**: Network extends to the two nearest areas with high demand density (Hartlepool and Middlesbrough).
• **Variation 3:** Network extends to the two nearest areas with high demand density (Hartlepool and Middlesbrough) and also includes a town farther away with lower demand density (Stockton-on-Tees).

### 8.4.3. Connection Rate
The third variable used to differentiate scenario data was the proportion of users within each geographic coverage area connected to a heat network. This variable was applied each scenario spreadsheet to modify the number of users and the annual demand attributed to each LLSOA and MLSOA.

Connection rates for heat networks vary, as does the balance between domestic and non-domestic users. In the case of the Greater Copenhagen area in Denmark, ~90% of all buildings are connected to interconnected heat networks, with high proportions of domestic and non-domestic user connection.\(^{88}\) UK heat networks such as Nottingham\(^{89}\) and Sheffield\(^{90}\) are characterised by high connection rates in a small proportion of the urban area; with non-domestic users dominating connected demand. The Lerwick heat network in Shetland is an example of a medium connection rate, with around half of the town covered by the network (Martin and Spence 2010). In terms of connection rate, extensions to the Lerwick scheme are considered if an >15% of domestic users on a street agree to connect, with a current per-street connection rate of between 35% and 100% (Martin and Spence 2010). Three variations were selected to express different connection rates possibilities for heat networks in the scenarios:

• **Variation 1:** High connection rate. Extensive connection of both domestic and non-domestic users means 90% of all users within each geographic coverage area are connected.

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• **Variation 2:** Medium connection rate. An average of 45% of domestic users and 75% of non-domestic users are connected. The connection rate per area remains high (at 90% of users on each street served by a network branch) as in Variation 1, but only 50% of each coverage area is served by the heat network. This reflects a high proportion of non-domestic users, but lower interest in domestic connection meaning only half of coverage areas have sufficient demand for a network branch.

• **Variation 3:** Low connection rate. An average of 25% of domestic users and 50% of non-domestic users are connected. As in Variation 2 only 50% of the streets in each geographic coverage area have sufficient demand for a network branch, however user connection per branch is also lower. Only half of users on a street are connected and there are fewer non-domestic users interested in signing up.

### 8.5. Scenario Attributes

The final stage of scenario development was to assign attributes to the heat networks in each scenario based on the different data sets discussed in the previous section. These attributes include the number of users, their heating demand, the physical infrastructure that would be required to connect users, the thermal energy lost in distribution and network costs. In this section the process for assigning the attributes based on scenarios is described. Throughout this section Scenario 10 is used as a reference example to demonstrate how the variables for differentiating scenario data influence attribute section.
8.5.1. Number of Users

The number of users connected to the heat network in a scenario is determined by the geographic coverage area and connection rate variations in the scenario. The geographic coverage area dictates the LLSOA and MLSOA data fields applicable to the scenario. They detail the total number of domestic and non-domestic users within each geographic data boundary. The scenario’s connection rate is then applied to determine how many of these users are connected to the heat network. For example, in Scenario 10 data for the LLSOAs and MLSOAs applicable to geographic coverage area variation 1 was used to
provide the total number of possible connections. This total number was reduced by 10% because 90% of domestic and non-domestic users (connection rate variation 1) are connected to the heat network in this scenario.

### 8.5.2. Peak User Demand

Peak user demand refers to the combined total capacity of heating systems connected to the heat network. This attribute was used to approximate the peak capacity requirement for the heat network and the peak heat extraction from the nuclear site in a scenario. It is, in essence, the potential peak user demand, and not necessarily the same as the peak demand the network is expected to provide in operation. This is because it is unlikely that all users will operate their heating systems at full capacity simultaneously, and as the number of users increases, the likelihood of simultaneous peak use may decrease (Parsons Brinckerhoff 2009). Similarly if different user types with different demand profiles, such as hospitals, schools and houses, are connected to a network, simultaneous peak use for all users is even more unlikely (Skagestad and Mildenstein 2011). It is therefore possible that network peak demand may only by up to 80% of potential peak user demand (Diamant and Kut 1981). There was however not enough detail about user types and their different demand profiles to make a robust assumption about what proportion of potential peak user demand would represent ‘actual’ peak demand for the network. Using ‘potential’ peak user demand as an attribute constitutes a more challenging criteria for heat networks in the scenario, than if it was proportionally reduced for demand differentiation. In some cases pipe diameters may be greater as a result, increasing heat loss and capital cost. However this was preferred to potential for underestimating network requirements.

Peak user demand was determined for each scenario by multiplying the number of domestic and non-domestic users connected to the heat network by their average peak demand as stipulated in the scenario. Connected users are defined as described in Section 4.1 and the average peak demand of users in a scenario is informed by the heating demand variation being applied. For example in Scenario 10 average heating system capacities for domestic and non-domestic users were based on heating demand
variation 2 (see Section 8.4.1); 12kW and 900kW respectively. They were then multiplied by the number of domestic (14,700) and non-domestic (201) users connected to the heat network in the scenario (see Section 8.5.1) to calculate peak user demand (358,000kW).

8.5.3. Annual Heating Services Demand
Each scenario datasheet contains annual demand for domestic and non-domestic users, adjusted energy demand variations, for the LLSOAs and MLSOAs covered by the network in the scenario. Annual demand was made relative to user connection rate variations by averaging the annual demand in LLSOAs or MLSOAs by the number of users attributed to them. This meant that in a scenario with a high connection rate where 90% of users in an area are connected, 90% of the area’s annual heating demand (adjusted by the relevant energy demand variation) was attributed to the heat network.

8.5.4. Network Specifications
The diameter and length of heat distribution pipes are important factors for determining the efficiency and costs of a heat network. These attributes are specific to the capacity requirements and the spatial distribution of users; both of which are shaped by energy demand, geographic coverage and connection rate variables. This section explains the ‘rules’ used to ensure consistency when assigning pipeline specifications in the scenarios.

As is common practice for large heat networks, the distribution networks in the scenarios were split into three categories; primary (transmission) pipeline(s), secondary pipelines and tertiary pipelines:
For each scenario primary, secondary and tertiary pipeline diameters and lengths were assigned using pipeline specification data (as described in Section 2.4), peak user demand attributes (see Section 4.2) and distance measurement tools in ArcGIS.

As discussed in Section 2.4, a pipeline’s capacity to transfer energy depends on the temperature difference between flow and return water, the flow rate of water in the pipes and the physical space within the pipes (their internal diameter). Selecting the appropriate pipeline specifications involved selecting an internal diameter able to meet capacity requirements at each stage of the network (the other parameters are fixed in the scenarios). While it was important to ensure the pipeline widths would make the required energy transfer possible, it was equally important to avoid unnecessarily oversize the pipes in the scenarios. While pipes with greater diameters can transfer more energy, they are more expensive to buy and install (as they require a wider installation trench) and the greater surface area of wider diameter pipes also increases heat loss. The specifications of heat network pipelines obtained from Durotan (see Section 2.4) were
used to select diameters appropriate for the assumed capacity requirement of the network at each stage.

Pipeline lengths were based on measurements made using ArcGIS and assumptions about likely pipeline routes. In each case routes that had minor roads with ‘soft’ verges were preferred because of their potential cost saving advantages (Macadam, Davies et al. 2008). A tool in ArcGIS was then used to measure the length of the line relative to the geographic features on the digital OS map to provide an estimate of distance covered in metres.

**8.5.4.1. Primary Pipeline**

The primary pipeline is the main transmission conduit that transfers thermal energy from the heat generation source to areas of demand. In the scenarios one primary pipeline is assumed for each geographic coverage area. The diameter of a primary pipe is dependent upon the peak user demand within a geographic coverage area.

For example, in Scenario 10, the peak user demand estimate for the coverage area in the scenario (357,599kW) was used as the criteria for the pipe diameter (this scenario has geographic coverage area variation 1, whereby the network only extends to the nearest demand cluster). Based on the pipe transfer capacity data (shown in Section 2.4) a 900mm pipe diameter, able to transfer up to 409,600kW of thermal energy, was selected.⁹¹

To calculate the length of primary pipeline in a scenario potential pipeline routes between the reactor site and geographic coverage areas were drawn onto the demand density map:

---

⁹¹The next pipe diameter down in size, 800mm, can only transfer up to 315,900kW making it too narrow for this application.
The pipeline in the figure above follows minor roads and is within 2km of all users. This estimate of a primary pipeline route is consistent with the approach used in Woods et al (2005) and McNaught et al (2011). The pipeline in the example was measured as 8,399m using the ArcGIS feature measuring tool.

**8.5.4.2. Secondary Pipelines**

Secondary pipelines are intermediaries that connect primary pipelines to tertiary local pipes in large heat networks. They were drawn at regular intervals within each geographic coverage area. They were positioned to bisect each LSSOA within the
coverage area. As with the primary pipelines the lengths of secondary pipes for each geographic coverage area were estimated using ArcGIS and the demand density map:

Figure 49: Example of Secondary Pipeline Routes. (250K Raster [TIFF geospatial data], Scale 1:250000, Tile(s): nz41 nz42 nz43 nz51 nz52 nz53, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011)

The above figure shows the secondary pipeline measurements for one of the geographic coverage areas. The secondary distribution pipelines in this example have a combined length of 11.9km.
To derive the diameters of secondary pipes, the total capacity of the primary pipeline in the geographic coverage area was divided by the number of secondary pipes branching from it. For example in the geographic coverage area shown in the figure above there are fifteen branch points. In a scenario with baseline heating demand and high connection rate the thermal capacity of the primary pipeline is required to be 421,911kW, therefore the capacity of each secondary branch is estimated to be 28,127kW. In this case a 300mm diameter pipe was selected for primary pipes in this coverage area. Secondary pipe diameters in the scenarios range from 200mm to 350mm depending upon the heating services variation being used, the number of users within each geographic coverage area and the connection rate.

8.5.4.3. Tertiary Pipelines

Tertiary pipelines distribute thermal energy at the local level; they are network branches linking secondary pipelines to individual users. They are laid close to user buildings so that the connecting pipes that are part of the user’s heating system only cover a short distance (this distance will typically vary based on the proximity of the connected building to the street or other public space in which the tertiary pipe is laid).

The tertiary pipeline category has the greatest potential for variation in pipe diameter owing to the different capacity requirements of users on each branch of the network. In each scenario a generic value for the diameter of all tertiary pipes within the scenario was used. The pipe diameters in the scenarios were chosen to reflect the energy demand and connection rate variations being applied to the scenario. Reduced per user heating capacity and fewer users connected per pipeline mean pipes with smaller diameters can be used. Three pipe diameters were used for tertiary pipes in the scenarios:

- A 100mm diameter pipe would constitute a tertiary network with an average thermal transfer capacity of 3,010kW per branch. This was suitable for scenarios with baseline peak user demand (1,000kW for non-domestic users and 15kW for domestic users) and a connection rate where the majority of properties on a street are connected (connection rate variations 1 and 2). In a scenario like this a 100mm
A diameter pipe can connect 200 domestic users or three non-domestic users or a combination of one non-domestic user and 134 domestic users per branch.

- An 80mm diameter pipe, which can transfer up to 1,699kW of thermal energy, was suitable for scenarios with the moderate demand reduction variation of peak user demand (900kW for non-domestic users and 12kW for domestic users) and either connection rate variation 1 or 2. In a scenario with these variables an 80mm diameter pipe could connect either 141 domestic users, or one non-domestic user and 67 domestic users, or two non-domestic users per branch based on their assumed peak demand and the thermal transfer capacity of the pipe.

- A 65mm diameter pipe, which can transfer up to 1,169kW of thermal energy, would be suitable for a scenario with the high demand reduction variation of peak user demand (800kW for non-domestic users and 9kW for domestic users) and low connection rate per street (connection rate variation 3). In a scenario like this a 65mm pipe can connect either 130 domestic users, or one non-domestic user and 41 domestic users per branch.

A judgement was made about most appropriate pipe diameter based on the user connection and peak demand attributes in each scenario.\(^{92}\)

Total length of tertiary pipeline was estimated by mapping out a network of pipes connecting the buildings within a sample of LLSOAs in the local authority areas adjacent to the Hartlepool nuclear site. A sample method was adopted due to the time requirement for mapping out all streets covered by heat networks in the scenarios. Seventeen sample LLSOAs were chosen that represented the range in area and building density in the 232 LLSOA boundary segments of the heating demand density map. A series of lines were drawn using tools in ArcGIS to show the route of a distribution pipeline network connecting all buildings in the sample LLSOA:

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\(^{92}\) I am grateful to Poul Weiss of COWI consultancy for verifying these assumptions. Personal communication, Poul Wiess, Head of Section for Energy Planning and District Heating, COWI (3\(^{rd}\) March 2011).
Figure 50: Measuring Pipe Length Requirement for Small Area LLSOA with High Demand Density. 250K Raster [TIFF geospatial data], Scale 1:2500000, Tile(s): nz43, Updated: September 2011, Ordnance Survey (GB), Using: EDINA Digimap Ordnance Survey Service, <http://edina.ac.uk/digimap>, Downloaded: September 2011
ArcGIS was then used to measure the network lines, relative to the underlying digital OS map, to estimate the pipe length in each sample case. In connection rate variations 2 and 3 (see Section 3.3) only 50% of each geographic coverage area is served by tertiary network, reflecting users connection outcomes. Consequently in scenarios with these connection rate variations, the assumed length of tertiary pipe was reduced by half.
<table>
<thead>
<tr>
<th></th>
<th>LLSOA Code</th>
<th>Area (m²)</th>
<th>Demand Density - Baseline (kWh/m²)</th>
<th>Distribution Pipe Length High Connection Rate (m)</th>
<th>Distribution Pipe Length Medium and Low Connection Rates (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E01012038</td>
<td>87,059</td>
<td>85.7</td>
<td>2,263</td>
<td>1,132</td>
</tr>
<tr>
<td>2</td>
<td>E01011965</td>
<td>127,748</td>
<td>104.1</td>
<td>4,797</td>
<td>2,399</td>
</tr>
<tr>
<td>3</td>
<td>E01011986</td>
<td>192,580</td>
<td>42.5</td>
<td>2,896</td>
<td>1,448</td>
</tr>
<tr>
<td>4</td>
<td>E01012025</td>
<td>194,129</td>
<td>36.1</td>
<td>2,489</td>
<td>1,245</td>
</tr>
<tr>
<td>5</td>
<td>E01012079</td>
<td>221,955</td>
<td>45.2</td>
<td>4,016</td>
<td>2,008</td>
</tr>
<tr>
<td>6</td>
<td>E01012026</td>
<td>248,679</td>
<td>37.4</td>
<td>4,427</td>
<td>2,214</td>
</tr>
<tr>
<td>7</td>
<td>E01011979</td>
<td>273,196</td>
<td>26.7</td>
<td>4,395</td>
<td>2,198</td>
</tr>
<tr>
<td>8</td>
<td>E01012045</td>
<td>288,696</td>
<td>19.7</td>
<td>3,351</td>
<td>1,676</td>
</tr>
<tr>
<td>9</td>
<td>E01012057</td>
<td>305,656</td>
<td>36.1</td>
<td>4,503</td>
<td>2,252</td>
</tr>
<tr>
<td>10</td>
<td>E01011949</td>
<td>329,282</td>
<td>28.1</td>
<td>4,995</td>
<td>2,498</td>
</tr>
<tr>
<td>11</td>
<td>E01012075</td>
<td>382,354</td>
<td>17.4</td>
<td>4,936</td>
<td>2,468</td>
</tr>
<tr>
<td>12</td>
<td>E01012071</td>
<td>425,926</td>
<td>27.5</td>
<td>6,105</td>
<td>3,053</td>
</tr>
<tr>
<td>13</td>
<td>E01012249</td>
<td>482,642</td>
<td>17.1</td>
<td>6,545</td>
<td>3,273</td>
</tr>
<tr>
<td>14</td>
<td>E01011972</td>
<td>509,551</td>
<td>24.6</td>
<td>7,542</td>
<td>3,771</td>
</tr>
<tr>
<td>15</td>
<td>E01012087</td>
<td>572,769</td>
<td>17.8</td>
<td>6,361</td>
<td>3,181</td>
</tr>
<tr>
<td>16</td>
<td>E01012065</td>
<td>602,155</td>
<td>20.3</td>
<td>7,721</td>
<td>3,861</td>
</tr>
<tr>
<td>17</td>
<td>E01012207</td>
<td>684,333</td>
<td>17.7</td>
<td>8,115</td>
<td>4,058</td>
</tr>
</tbody>
</table>

Table 9: Tertiary pipeline lengths in example LLSOAs by Scenario

The sample measurements were matched to LLSOAs within the geographic coverage areas on the basis of area and demand density (used to approximate user density). To determine the length of tertiary pipe in Scenario 10 for example, data on the area and
demand density of the LLSOAs in the scenario was used to match the LLSOAs to an appropriate sample LLSOA. High connection rate estimates were applied to all the LLSOAs within the variation 1 geographic coverage area stipulated by the scenario’s variables. This estimated the tertiary pipe requirement for the scenario to be 110,292 metres.

8.5.5. Estimating Heat Loss
The heat loss attributes of a heat network indicate its efficiency and cost effectiveness. Peak heat loss form a network is included with peak user demand to estimate the full thermal energy generation capacity required from the nuclear reactor site. If heat loss adds significantly to peak demand, then pipeline diameters have to be resized to accommodate this.

To calculate the heat loss attributes for networks in the scenarios, the heat loss characteristics of each pipe diameter used in the scenarios were estimated using a software programme developed by heat network pipeline manufacturer Logstor (StaTech 2.3.2). StaTech allows users to make calculations about the heat loss of different types of heat network pipe in different environmental and operational conditions. The heat loss factors derived from the software were used in conjunction with other scenario attributes, such as pipeline length, to estimate the total heat loss for each heat network.

To make calculations on the heat loss of each pipe the StaTech programme required the input of several operating parameters:

- Soil cover for buried pipelines
- Soil temperature
- Level of pipe insulation
- Pipe material
- Pipeline configuration
- Flow and return pipe temperatures
8.5.5.1. Soil Cover

The depth at which a heat network pipeline is buried influences heat loss as greater soil cover increases insulation for pipes. In addition there are planning and safety factors that determine a minimum depth for pipelines. The typical UK soil cover for pipelines of different diameters was informed by a private communication with the Danish heat network consultancy COWI. A 1000mm covering of soil is considered to be a typical for large primary pipes, and 400mm of soil coverage is recommended for pipes with smaller diameters.

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93 Based on private telephone conversation with Poul Wiess, Head of Section for Energy Planning and District Heating, COWI (3rd March 2011).
diameters, such as secondary and tertiary pipes. This standard practice soil coverage was used because it correlates with cost assumptions used in Section 4.6 (which are based on industry standard practice (Parsons Brinckerhoff 2009)).

8.5.5.2. Soil Temperature
Soil temperature refers to the ambient temperature in which a heat network pipe operates. A greater temperature difference between water in a pipeline and the ambient temperature of surrounding soil increases heat loss. Soil temperature at a depth of around 400-1,000mm has only slight fluctuations throughout the year in comparison with air temperature (Garcia Gonzalez, Verhoef et al. 2012). It also lags behind seasonal changes in air temperature due to the mass and thermal properties of the soil (Garcia Gonzalez, Verhoef et al. 2012). Different soil depths, types (e.g. variations in sand or clay content) and coverage (e.g. vegetation or tarmac) influence the average below-ground temperature (Garcia Gonzalez, Verhoef et al. 2012). A soil temperature of 10°C was chosen because this is the annual average ambient temperature for the soil around 400-1000mm deep with an average UK soil type (Garcia Gonzalez, Verhoef et al. 2012).

8.5.5.3. Pipe Material
The StaTech programme allows for either steel or plastic to be used as pipe material. Plastic pipes have cost advantages over steel pipes in that they can be installed to follow curves instead of straight lines, reducing the need for junctions and to work in straight lines (this makes subsurface obstructions easier to avoid) (Skagestad and Mildenstein 2011). Steel pipes however can be used with higher flow rates, with temperatures of up to 110°C possible without reducing their lifespan (Skagestad and Mildenstein 2011). Plastic pipes have a maximum temperature tolerance of 95°C, which means either the whole system must operate at <95°C, or, if only tertiary pipelines use plastic, flow temperatures can be lowered at branch points or pump stations connecting secondary and tertiary pipelines. While plastic pipes for the tertiary stages of the heat networks in the scenarios could have potentially lowered costs, full cost and thermal capacity data
was only available for standard steel pipelines. For these reasons steel pipes were chosen for the whole system.

8.5.5.4. Level of Pipe Insulation
There are four options for internal pipe insulation (including a no insulation option) available in the heat loss calculator. Higher levels of insulation slightly increase pipe costs and the width of trench needed for pipe installation as the overall width of the pipe is increased. Increased insulation however has cost saving implications by reducing distribution heat loss, which is particularly important for schemes covering large areas. In all the scenarios the highest level of insulation for each pipe diameter was chosen (pipelines over 900mm internal diameter have only the basic level of insulation available).

8.5.5.5. Pipe Configuration
Two pipe configurations are available; double pipes – where flow and return pipes are laid side-by-side – and twin pipes – where flow and return pipes are encased within a larger pre-insulated pipe. Twin pipes offer cost and efficiency savings as they have lower heat loss per meter and trench size can be reduced. They are however only available for pipelines with up to 150mm internal diameter. Twin pipe configuration was assumed for tertiary pipes in the scenario networks, with double pipe configurations selected for secondary and primary pipes.

8.5.5.6. Flow and Return Temperature
The temperature difference between the water in heat network pipes and the ambient temperature is an important variable for heat loss. Higher flow temperature leads to increased heat loss, while operating networks at lower flow temperatures can provide significant efficiency improvements.
Two flow temperatures were used in the scenario, adopting the practice of lowering network flow temperature in response to significantly lower heating demand in warmer months of the year (Skagestad and Mildenstein 2011). During cold months of the year (heating season), a high thermal energy transfer capacity in the network is required. With the standard UK return temperature of 70°C being assumed, a flow temperature of 110°C was used to achieve sufficient thermal transfer in the scenarios for the heating season. Outside of the heating season however, the demand for space heating will be significantly lower, therefore the system can operate with a lower flow temperature to reduce heat loss without compromising network capability. Following the example of the Beznau nuclear heat network a flow temperature of 90°C was selected for summer months in the scenarios (Handl 1998). Heat loss calculations with both flow temperatures were included in the scenarios.

8.5.6. Calculating Heat Loss for Pipes

The parameters for pipe diameter were imputed into the Logstor StaTech programme to provide the energy loss per metre at the two flow temperature in the scenarios:

<table>
<thead>
<tr>
<th>Pipe Diameter (mm)</th>
<th>Heat Loss (watts/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110°C</td>
</tr>
<tr>
<td>1000</td>
<td>142</td>
</tr>
<tr>
<td>900</td>
<td>90</td>
</tr>
<tr>
<td>800</td>
<td>64</td>
</tr>
<tr>
<td>700</td>
<td>57</td>
</tr>
<tr>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>500</td>
<td>43</td>
</tr>
<tr>
<td>350</td>
<td>43</td>
</tr>
<tr>
<td>300</td>
<td>44</td>
</tr>
<tr>
<td>250</td>
<td>41</td>
</tr>
<tr>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>150</td>
<td>36</td>
</tr>
<tr>
<td>100</td>
<td>30.9</td>
</tr>
<tr>
<td>80</td>
<td>30.6</td>
</tr>
<tr>
<td>65</td>
<td>26.7</td>
</tr>
</tbody>
</table>

Table 10: Heat loss by pipe diameter. Outputs from Logstor StaTech software programme.
With the heat loss per metre known for each pipe diameter, the length and diameter attributes for primary, secondary and tertiary pipes in the scenarios could be used to calculate the total heat loss for the network. This was achieved by multiplying the heat loss per meter by the estimated length of pipe of the same diameter in the scenario. To ascertain annual heat loss in a scenario, heating season (winter) and non-heating season (summer) durations within a year were determined. The heating season in the scenarios was assumed to be 58% of the year (May to October). This was based on work in Skagestad and Mildenstein (2011) suggesting that lower flow temperatures should be used when average air temperatures are above 10°C. Using average air temperature data, 1st May to 31st September was defined as a low demand ‘summer’ period in the scenarios:

![Daily UK Average Air Temperature 2009](http://www.nationalgrid.com/uk/Gas/Data/misc/)

*Figure 53: Adapted from National Grid, (2011), Historic Actual NTS Demands, Actual CWV and SNT, Available at [http://www.nationalgrid.com/uk/Gas/Data/misc/](http://www.nationalgrid.com/uk/Gas/Data/misc/), (Accessed 12 December 2011).*
The heating season therefore accounted for 5,081 hours of the year and summer for 3,679 hours. Winter and summer heat losses for each pipe diameter in a scenario were calculated and combined to give an annual heat loss attribute. The table below gives an example of the heat loss outputs for Scenario 10 based on these calculations:

<table>
<thead>
<tr>
<th>Pipe Diameter (mm)</th>
<th>Pipeline Length (m)</th>
<th>Winter</th>
<th>Summer</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Loss rate (kW/m)</td>
<td>Peak loss (kW)</td>
<td>Seasonal Loss (MWh)</td>
</tr>
<tr>
<td>900 (Primary)</td>
<td>8,339</td>
<td>0.09</td>
<td>751</td>
<td>3,813</td>
</tr>
<tr>
<td>200 (Secondary)</td>
<td>13,124</td>
<td>0.042</td>
<td>551</td>
<td>2,800</td>
</tr>
<tr>
<td>80 (Tertiary)</td>
<td>110,292</td>
<td>0.0306</td>
<td>3,375</td>
<td>17,148</td>
</tr>
<tr>
<td>Total</td>
<td>131,755</td>
<td>N/A</td>
<td>4,677</td>
<td>23,762</td>
</tr>
</tbody>
</table>

Table 11: Scenario 10 network heat loss attributes.

Winter peak loss was used as the networks peak heat loss and as an attribute to determine peak heat extraction from the nuclear site and thermal energy transfer requirement of the network.

8.5.7. Economic Attributes

The main capital costs for the heat networks in each scenario were estimated to provide economic attributes for comparison. They inform the discussion on the potential financial viability of a large nuclear heat network at the Hartlepool nuclear site, and show how costs are affected by scenario variables.

The capital cost attributes discussed in this section do not include the building, operation (including fuel costs) and decommissioning of the nuclear site (including the two nuclear reactors and their steam turbine plants). New nuclear sites are expected to be built and operated primarily for electricity generation, with heat extraction to provide thermal energy for a heat network as an addition. The nuclear site is effectively treated as a separate economic consideration; with the heat extraction points in the steam turbine plant rooms acting as an interface for exporting thermal energy from the nuclear site.

94 Based on an 8,760 hour year used in energy scenarios and statistical publications, such as the Digest of UK Energy Statistics.
This reflects the arrangement in the Beznau nuclear heat network, discussed in Section 3. In the Beznau example the nuclear power station operator Axpo are responsible for all of the costs associated with the nuclear reactor and the adjoining steam turbine plant. Refuna, the heat network developer and operator are responsible for the heat extraction exchangers in the turbine plant and the costs of building and operating the heat network. The heat network operator pays the nuclear operator for electricity revenue lost as result of heat extraction from the steam cycle and the nuclear operator’s business model remains essentially unchanged. The capital costs that are included in the scenarios are:

- Cost of buying and installing pipes (including civil engineering costs).
- Cost of user hydraulic interface units (HIUs) and heat meters.
- Cost of connecting users to heat network.
- Cost of back-up generating capacity.
- Cost of adding heat extraction to the nuclear reactor site.

Other upfront costs associated with heat networks include pump equipment, planning and legal fees, supervisory control and data acquisition (SCADA) systems for monitoring and control. They were not incorporated due to the unavailability of appropriate data, however they are considered to have minimal impact on overall costs in relation to the costs that are included.\(^{95}\)

The cost data used to provide economic attributes for the scenarios was taken from reports by McNaught, Williams et al. (2004) and by Parsons Brinkerhoff (2009). Both were commissioned by the Scottish Government to support the development of heat networks in Scotland. They include the most up-to-date estimates for UK heat network costs. This data was used in conjunction with the physical characteristics of each scenario, such as pipe length and diameter, to provide comparable economic attributes.

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\(^{95}\) These costs are minimal in relation to pipe installation, user connection and heat extraction, Personal communication, P. Weiss, Cowi District Heating consultancy, 13 October 2010.
8.5.7.1. Heat Network Pipes and Installation

Parsons Brinkerhoff (2009) produced an assessment method for heat network designers that updates, and puts into a UK context, previous work by the International Energy Agency’s District Heating and Cooling Project (Woods, Riley et al. 2005). The report includes the costs of heat network pipes of different diameters including associated installation costs such as excavating trenches:

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Construction Cost (£/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>450</td>
</tr>
<tr>
<td>80</td>
<td>500</td>
</tr>
<tr>
<td>100</td>
<td>500</td>
</tr>
<tr>
<td>150</td>
<td>500</td>
</tr>
<tr>
<td>200</td>
<td>600</td>
</tr>
<tr>
<td>250</td>
<td>800</td>
</tr>
<tr>
<td>500</td>
<td>1,400</td>
</tr>
<tr>
<td>600</td>
<td>1,700</td>
</tr>
<tr>
<td>700</td>
<td>1,950</td>
</tr>
<tr>
<td>800</td>
<td>2,150</td>
</tr>
<tr>
<td>900</td>
<td>2,300</td>
</tr>
<tr>
<td>1,000</td>
<td>2,711</td>
</tr>
</tbody>
</table>

Table 12: Heat Network Pipe Costs, adapted from Parsons Brinkerhoff (2009)

These cost estimates were the most relevant, in terms of date and national context, available. They are however only approximations as actual costs can vary depending on where pipelines are being installed. For example if hard rock or contaminated soil has to be excavated installation costs could be twice that of an installation into normal soil.  

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96 N. A. Martin, personal communication, 18 October 2010.
The costs described in the above table were used to estimate pipeline costs based on their pipe diameter and length attributes, as shown in this example from Scenario 10:

<table>
<thead>
<tr>
<th></th>
<th>Diameter (mm)</th>
<th>Length (m)</th>
<th>£/m</th>
<th>Total Cost (£)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>900</td>
<td>8,339</td>
<td>2,300</td>
<td>19,179,700</td>
</tr>
<tr>
<td>Secondary</td>
<td>200</td>
<td>13,124</td>
<td>600</td>
<td>7,874,400</td>
</tr>
<tr>
<td>Tertiary</td>
<td>80</td>
<td>110,292</td>
<td>500</td>
<td>55,146,000</td>
</tr>
</tbody>
</table>

|          |               |            |     | 82,200,100     |

Table 13: Cost Estimates for Scenario 10 Heat Network

8.5.7.2. Hydraulic Interface Units and Heat Metering
Hydraulic interface units (HIUs) and heat meters are not essential components of heat networks (Skagestad and Mildenstein 2011). They do however have features that are likely to improve connection rates, including individual control over energy usage and separate billing. That these features may improve connection rates is informed by the preferences expressed by focus group participants (Section 6) that heat networks emulate natural gas boilers wherever possible.

8.5.7.3. Hydraulic Interface Units
HIUs transfer heat from the heat network to the user’s hot water and heating system, so that the user is indirectly connected to the network. It is also possible to connect users directly to heat networks, so that the flow water itself circulates through the user’s space heating system, thereby avoiding the cost of a HIU (Skagestad and Mildenstein 2011). The inclusion of HIUs however has three benefits for heat networks that warrant their inclusion:
As discussed in Section 6, focus group participants ranked functionality and performance highly as conditions for considering connecting to a nuclear heat network. The HIU user interface is very similar to that of a gas boiler and do not require additional competencies or changes in user practices to work efficiently. HIUs offer the same controllability and responsiveness as a combination gas boiler, including very rapid hot water provision, and have similar aesthetic properties in terms of their external appearance and space requirement within a building. These features were seen as attractive by focus group participants, suggesting they could be used to obtain high user connection rates.

HIUs mean that user heating systems can operate at a different pressure to the heat network. Where existing 'wet' central heating systems already exist, there is no need to replace them with heating system that conform to the pressure specification of the network (Skagestad and Mildenstein 2011). Compatibility with existing heating systems means a developer can take advantage of the high penetration of water based central heating systems in the UK (91% of domestic buildings) (Utley and Shorrock 2008). The cost of not installing a central heating, estimated as around £2,500 for domestic users offsets the cost of an HIU (Skagestad and Mildenstein 2011; BioRegional 2012). Eschewing the need to modify user heating systems also reduces disruption during installation. Evidence from studies such as Armstrong and Winder et al (2006) and the focus groups in Section 6 suggest avoiding internal disruption may improve domestic connection rates by removing a potential barrier.

Although it was not emphasised in the focus groups (see Section 6), there may be an advantage in terms of user acceptability if there is an additional stage of separation between the nuclear reactor steam cycle and the user heating system.

The cost of a HIU is dependent upon the output capacity required. For domestic users the cost of the smallest capacity HIU considered by Parsons Brinkerhoff, a 37kW unit, estimated at £1,300, was included in the scenarios. A 1MW capacity HIU costing £21,795 was estimated for non-domestic users in the baseline and medium
energy demand reduction scenarios, and a 800kW HIU costing £11,370 for the high demand reduction scenario (Parsons Brinckerhoff 2009).

8.5.7.4. Heat Meters
Heat meters record how much thermal energy a user is transferred from a heat network to the user’s system. They can also be optional and there are several examples of schemes that were or still are unmetered (such as Aberdeen). Meters are now considered to be important for successful heat networks (Martin and Spence 2010).

Unlike in heat network schemes with no metering, where users pay a fixed fee regardless of how much energy they use, metered schemes enable individual billing. Retrofitting established heat networks with meters can also be problematic if connected users feel individualised bills will increase their heating costs, therefore meters may be best fitted when connecting users. An additional reason for including heat meters was identified in the focus groups, where the ability to exercise some control over heating payments was raised as an important feature (see Section 6). By only paying for what they use, network users can choose to use less energy to reduce their bills quickly if needed; an option unmetered schemes do not allow. Heat meters in the scenarios were included at £230 per user, taken from a study of UK heat meters by the Building Research Establishment (Routledge and Williams 2012).

8.5.7.5. User Connections.
To connect users to a heat network, flow and return pipes linking the nearest tertiary network pipe to the user HIU have to be installed. The cost of doing this primarily depends upon the distance between the user and the heat network pipe. There may also

97 While the variation in capacity requirement for average domestic users from 15kW to 9kWh does not require a different HIU – because the smallest available with cost is oversized – it is appropriate to change the size of non-domestic HIUs in line with the change in average capacity from 1,000kW to 800kW in the scenarios (there is not a 900kW option in the cost data).
98 There are several examples of unmetered heat networks including the Aberdeen scheme.
be additional costs if the level of difficulty in putting the customer connection pipe through the wall of the user’s building (for example, the building may have solid stone walls as opposed to brick) is greater than ordinarily expected. In the case of the Lerwick heat network, the cost of connection varied between £600 and £3,000 due to similar factors.100

In the Parsons Brinkerhoff study a figure of £2,514 is used for semidetached and terrace properties (Parsons Brinckerhoff 2009), which assumes a 6 metre average distance been the heat network and the user. Daysemtric analysis of the map data shows this is likely to be a greater distance than would actually be encountered (many terrace housing rows in Hartlepool and Middlesbrough have no front area between the building and the public path), therefore this maybe an overestimate of domestic user connection costs:

100 N. Martin, Personal communication

The cost of connecting a non-domestic user in the scenarios was taken also taken from the Parsons Brinkerhoff report. It was based on the cost estimate for connecting a building 10metres from tertiary network pipes (£4,250 per user). The additional cost for
non-domestic users in relation to domestic users is drawn from the consideration that non-domestic users such as schools, hospitals, swimming pools and supermarkets may be situated further from a road where a heat pipe is installed (they may for example have a parking area between the road and the front entrance).

8.5.7.6. Heat Extraction at the Reactor Site
The costs of the nuclear reactors and their steam generators are not considered in the scenarios. The economics of the nuclear site are assumed to be based on electricity generation, with the heat network operator paying the value of any electricity generating capacity lost as a result of steam extraction. However the costs of modifying the steam plants at the nuclear site to function as a combined heat and power (CHP) plant are included and are based on the McNaught, Williams et al. (2011) study of the costs of converting large thermal power stations to CHP.

McNaught, Williams et al. (2011) use a cost of £11million for the fitting of steam extraction to the condensing steam cycle of large thermal power stations. Double stage steam extraction, as used at the Beznau nuclear CHP plant is envisaged for the scenarios. This approach improves the Z-factor\(^{101}\) of the CHP process from 6.3 to 8.3, which decreases the proportion of electricity lost during heat extraction from 16% to 12% of the thermal energy recovered for a heat network (Handl 1998). The improved Z-factor reduces operational costs for the heat network by reducing the thermal energy from steam cycle to 12% of the market value of electricity, but increases capital costs at the reactor site. Double stage steam extraction was assumed to cost twice that of single stage extraction, making the cost of heat extraction from a reactor steam turbine plant in the scenarios £22million.

\(^{101}\) The Z-factor describes how many units of thermal energy are recovered from a steam cycle for every unit of electrical energy not generated as a result of steam extraction.
The scenarios also follow the example of the Beznau nuclear CHP plant by assuming heat extraction in both steam turbine plants at the reactor site (as discussed in Section 2.1, a twin reactor site is envisaged in the scenarios). Fitting double stage extraction to both steam plant rooms doubles the total cost of converting the reactor site to CHP, but the overall resilience of the scheme is improved. Even in the scenario with the greatest peak demand (Scenario 7) a single reactor steam plant has sufficient thermal capacity, however by sharing the load between two reactors the network can be unaffected if one reactor is shut down for refuelling or maintenance.

8.5.7.7. Back-up Capacity
The final major cost considered in the scenarios relates to several large gas boilers installed to provide thermal output if both nuclear reactors at the Hartlepool site are not in operation. Back-up capacity improves the resilience of a heat network, reduces risk arising from a heat network operator’s liability if heat is not provided to users and provides confidence for potential users when considering connection.

The combined capacity of the gas boilers in each scenario depends on the required back up for the heat network in the scenario. Required back-up was estimated by assuming 80% of installed user capacity would have to be met by auxiliary thermal output if required, based on work by Diamant and Kut (1981). Peak heat loss (discussed in Section 4.5.7) was also added to assess the full network requirement. The cost of installing several large boilers to meet this requirement was then estimated using data provided by the Parsons Brinkerhoff report (£17,000/MW installed boiler capacity) (2009). For example 286MW of back up capacity was estimated for Scenario 10, equalling a £4.9million capital expenditure.
8.5.8. Total Capital Cost
The costs for the major elements of the heat networks in each scenario were combined to provide illustrative capital costs. The table below shows the estimated capital cost for Scenario 10:

<table>
<thead>
<tr>
<th>Economic Attributes (£’s)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Network</td>
<td>82,200,100</td>
</tr>
<tr>
<td>Hydraulic Interface Units</td>
<td>23,339,614</td>
</tr>
<tr>
<td>Heat Meters</td>
<td>3,438,063</td>
</tr>
<tr>
<td>User Connections</td>
<td>37,868,949</td>
</tr>
<tr>
<td>Adaption of thermal power station to CHP</td>
<td>44,000,000</td>
</tr>
<tr>
<td>Back up Capacity</td>
<td>6,079,180</td>
</tr>
<tr>
<td><strong>Total Capital Cost</strong></td>
<td><strong>196,925,905</strong></td>
</tr>
</tbody>
</table>

Table 14: Scenario 10 Economic Attributes

The combined capital costs for each scenario illustrate the potential costs of heat networks in each context. By analysing this attribute in line with the number of users and the low carbon heating services supplied in a scenario the economic implications of nuclear heat networks can be discussed.

8.5.9. Scenario Attribute Table

The analysis discussed earlier in this section was used to produce twenty seven nuclear heat network scenarios for the Hartlepool site. Table 15 presents the outputs from this process for nine key heat network attributes:

**Users**: Table 15 shows the total number of heat network users attributed to each scenario. As discussed in Section 8.5.1 this is determined by the geographic area covered by the network and
whether the connection rate to the network is low, medium or high. The range from 2,160 to 69,200 users reflects the variation heat network configuration across the scenarios.

**Annual Demand:** The heating services met by the heat networks in the scenarios annually is a key indicator of the potential to utilise nuclear energy for heating services in a variety of contexts. This output is significant for estimating the potential of heat networks in the scenarios to decarbonise heating services in the area around the reactor site (see Section 9.2) and the amount of energy sold.

**Peak Demand Capacity:** The peak demand capacity in the scenario attribute table shows the accumulated heat load of connected users (see Section 8.5.2) and peak heat loss from the network pipes calculated, based on StaTech software calculations and the system attributes of the scenario (pipeline length, width and environmental factors) discussed in Section 8.5.6. Although in practice there is unlikely to have such a high simultaneous heating load given diverse user load profiles, this figure is an indicator of the thermal transfer capacity required by the network and the scale of thermal output required form the nuclear site.

**Total Pipeline Length:** The total pipeline length given in the attribute table is the combined length of primary, secondary and tertiary pipeline in the scenario (see Section 8.5.4).

**Capital Cost:** This attribute represents the total capital cost estimated for the heat network scheme in each scenario. As discussed in Section 8.5.7 this figure is based on cost estimates from a range of sources from 2009 to 2012, and does not account for future price fluctuations. It is primarily a means of comparison between the scenarios to assess the impact of changing variables on total capital cost.

**Average User Costs:** The average user costs for domestic and non-domestic users show how costs would be distributed if allocated evenly. These costs include the costs of installing heat extraction and the heat network averaged across all users. Specific costs for domestic and non-domestic heat meters and heat exchangers for individual users are then added. This does not necessarily represent the assumed upfront costs for users, as this would be determined by financial arrangements such as how much of user connection costs is incorporated into the unit price of energy or borne by the network operator.
**Network Heat Loss:** The scenario attribute table gives a comparison of percentage heat loss per year for each scenario. This is based on the annual heat loss calculated for the network (see Section 8.5.5) relative to the total annual energy supplied to users in the scenarios. It shows how efficient the network is in supplying energy.

**Line Heat Density:** Line heat density is another indicator of network efficiency. It reflects the number of users per metre of heat network pipeline and the demand of users (see Section 3.3.1 for a full description). This figure is also an indicator of economic viability as high demand per metre of pipeline suggests a good ratio of revenue from energy sales to capital expenditure in network infrastructure.
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Users</th>
<th>Annual Demand (GWh)</th>
<th>Peak Demand Capacity (MW)</th>
<th>Total Pipeline Length (m)</th>
<th>Capital Cost (Thousand £s)</th>
<th>Average Domestic User Cost (£s)</th>
<th>Average Non-Domestic User Cost (£s)</th>
<th>Heat Loss</th>
<th>Line Heat Density (MWh/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseline DR/ Low GC/ High CR</td>
<td>15,000</td>
<td>260</td>
<td>422</td>
<td>132,000</td>
<td>201,000</td>
<td>13,000</td>
<td>35,000</td>
<td>14%</td>
<td>1.98</td>
</tr>
<tr>
<td>2</td>
<td>Baseline DR/ Low GC/ Medium CR</td>
<td>7,000</td>
<td>155</td>
<td>278</td>
<td>70,000</td>
<td>129,000</td>
<td>17,000</td>
<td>39,000</td>
<td>11%</td>
<td>2.22</td>
</tr>
<tr>
<td>3</td>
<td>Baseline DR/ Low GC/ Low CR</td>
<td>2,000</td>
<td>67</td>
<td>142</td>
<td>39,000</td>
<td>88,000</td>
<td>40,000</td>
<td>62,000</td>
<td>15%</td>
<td>1.72</td>
</tr>
<tr>
<td>4</td>
<td>Baseline DR/ Medium GC/ High CR</td>
<td>42,000</td>
<td>811</td>
<td>1,272</td>
<td>391,000</td>
<td>516,000</td>
<td>12,000</td>
<td>34,000</td>
<td>14%</td>
<td>2.07</td>
</tr>
<tr>
<td>5</td>
<td>Baseline DR/ Medium GC/ Medium CR</td>
<td>21,000</td>
<td>500</td>
<td>422</td>
<td>209,000</td>
<td>315,000</td>
<td>14,000</td>
<td>36,000</td>
<td>13%</td>
<td>2.39</td>
</tr>
<tr>
<td>6</td>
<td>Baseline DR/ Medium GC/ Low CR</td>
<td>6,000</td>
<td>231</td>
<td>446</td>
<td>118,000</td>
<td>186,000</td>
<td>29,000</td>
<td>51,000</td>
<td>18%</td>
<td>1.96</td>
</tr>
<tr>
<td>7</td>
<td>Baseline DR/ High GC/ High CR</td>
<td>69,000</td>
<td>1,236</td>
<td>1,844</td>
<td>391,000</td>
<td>810,000</td>
<td>11,000</td>
<td>34,000</td>
<td>16%</td>
<td>3.16</td>
</tr>
<tr>
<td>8</td>
<td>Baseline DR/ High GC/ Medium CR</td>
<td>35,000</td>
<td>738</td>
<td>1,194</td>
<td>209,000</td>
<td>478,000</td>
<td>13,000</td>
<td>35,000</td>
<td>15%</td>
<td>3.53</td>
</tr>
<tr>
<td>9</td>
<td>Baseline DR/ High GC/ Low CR</td>
<td>10,000</td>
<td>321</td>
<td>597</td>
<td>118,000</td>
<td>278,000</td>
<td>27,000</td>
<td>49,000</td>
<td>19%</td>
<td>2.73</td>
</tr>
<tr>
<td>10</td>
<td>Medium DR/ Low GC/ High CR</td>
<td>15,000</td>
<td>216</td>
<td>358</td>
<td>132,000</td>
<td>197,000</td>
<td>13,000</td>
<td>35,000</td>
<td>15%</td>
<td>1.64</td>
</tr>
<tr>
<td>11</td>
<td>Medium DR/ Low GC/ Medium CR</td>
<td>7,000</td>
<td>130</td>
<td>239</td>
<td>70,000</td>
<td>128,000</td>
<td>16,000</td>
<td>39,000</td>
<td>13%</td>
<td>1.86</td>
</tr>
<tr>
<td>12</td>
<td>Medium DR/ Low GC/ Low CR</td>
<td>2,000</td>
<td>58</td>
<td>175</td>
<td>39,000</td>
<td>89,000</td>
<td>40,000</td>
<td>62,000</td>
<td>17%</td>
<td>1.48</td>
</tr>
<tr>
<td>13</td>
<td>Medium DR/ Medium GC/ High CR</td>
<td>42,000</td>
<td>677</td>
<td>1,082</td>
<td>391,000</td>
<td>509,000</td>
<td>12,000</td>
<td>34,000</td>
<td>16%</td>
<td>1.73</td>
</tr>
<tr>
<td>14</td>
<td>Medium DR/ Medium GC/ Medium CR</td>
<td>21,000</td>
<td>423</td>
<td>735</td>
<td>209,000</td>
<td>313,000</td>
<td>14,000</td>
<td>36,000</td>
<td>15%</td>
<td>2.03</td>
</tr>
<tr>
<td>15</td>
<td>Medium DR/ Medium GC/ Low CR</td>
<td>6,000</td>
<td>200</td>
<td>392</td>
<td>118,000</td>
<td>182,000</td>
<td>28,000</td>
<td>50,000</td>
<td>18%</td>
<td>1.70</td>
</tr>
<tr>
<td>16</td>
<td>Medium DR/ High GC/ High CR</td>
<td>69,000</td>
<td>1,025</td>
<td>1,557</td>
<td>391,000</td>
<td>794,000</td>
<td>11,000</td>
<td>33,000</td>
<td>17%</td>
<td>2.62</td>
</tr>
<tr>
<td>17</td>
<td>Medium DR/ High GC/ Medium CR</td>
<td>35,000</td>
<td>620</td>
<td>1,023</td>
<td>209,000</td>
<td>466,000</td>
<td>13,000</td>
<td>35,000</td>
<td>15%</td>
<td>2.97</td>
</tr>
<tr>
<td>18</td>
<td>Medium DR/ High GC/ Low CR</td>
<td>10,000</td>
<td>277</td>
<td>523</td>
<td>118,000</td>
<td>256,000</td>
<td>25,000</td>
<td>47,000</td>
<td>19%</td>
<td>2.35</td>
</tr>
<tr>
<td>19</td>
<td>High DR/ Low GC/ High CR</td>
<td>15,000</td>
<td>171</td>
<td>293</td>
<td>132,000</td>
<td>188,000</td>
<td>12,000</td>
<td>34,000</td>
<td>16%</td>
<td>1.30</td>
</tr>
<tr>
<td>20</td>
<td>High DR/ Medium GC/ Medium CR</td>
<td>7,000</td>
<td>105</td>
<td>200</td>
<td>70,000</td>
<td>126,000</td>
<td>16,000</td>
<td>38,000</td>
<td>15%</td>
<td>1.51</td>
</tr>
</tbody>
</table>
In the next section of this chapter the comparable features of the scenarios are discussed and analysed. The impact of different variables on the potential viability for utilising nuclear energy is assessed. This analysis is used to consider the social and economic conditions necessary to foster a heat network that makes best use of nuclear energy in the Hartlepool example. It is also used to explore the potential for heat networks at other UK nuclear sites.

<table>
<thead>
<tr>
<th></th>
<th>High DR/ Low GC/ Low CR</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>High DR/ Medium GC/ High CR</td>
<td>42,000</td>
<td>543</td>
<td>892</td>
<td>391,000</td>
<td>499,000</td>
<td>12,000</td>
</tr>
<tr>
<td>22</td>
<td>High DR/ Medium GC/ Medium CR</td>
<td>21,000</td>
<td>347</td>
<td>618</td>
<td>209,000</td>
<td>305,000</td>
<td>14,000</td>
</tr>
<tr>
<td>23</td>
<td>High DR/ Medium GC/ Low CR</td>
<td>6,000</td>
<td>170</td>
<td>339</td>
<td>118,000</td>
<td>169,000</td>
<td>27,000</td>
</tr>
<tr>
<td>24</td>
<td>High DR/ High GC/ High CR</td>
<td>69,000</td>
<td>813</td>
<td>1,270</td>
<td>391,000</td>
<td>773,000</td>
<td>11,000</td>
</tr>
<tr>
<td>25</td>
<td>High DR/ High GC/ Medium CR</td>
<td>35,000</td>
<td>502</td>
<td>853</td>
<td>209,000</td>
<td>451,000</td>
<td>13,000</td>
</tr>
<tr>
<td>26</td>
<td>High DR/ High GC/ Low CR</td>
<td>10,000</td>
<td>232</td>
<td>449</td>
<td>118,000</td>
<td>239,000</td>
<td>23,000</td>
</tr>
</tbody>
</table>

**Table 15: Main Scenario Attributes**
9. Scenario Analysis

This chapter discusses the scenario outputs described in Section 8 in relation to the suitability for the Hartlepool Nuclear site for heat networks. It begins with a guide to understanding the scenario outputs (charts). It then assesses the suitability of the Hartlepool site, firstly in terms of the overall nuclear energy that is utilised in the scenarios and the energy efficiency and financial indicators of heat network performance in each scenario context. It concludes with a discussion of the potential to utilise nuclear energy through heat networks at the Hartlepool site based on the scenario outputs.

9.1. Guide to Scenario Outputs

In the analysis of the scenario heat networks presented in this chapter, scatter charts are used to compare scenario outputs. The following section is guide to how the scenarios are represented.

The following figure shows how the scenarios can be seen as three ‘bands’ on the scatter charts according to the heating services demand variable being applied in the scenario. Scenarios 1-9 all have baseline heating demand, scenarios 10-18 all have moderate heating demand reduction and scenarios 19-27 all have high heating demand reduction:
Figure 55: Line Heat Density. Figure shows which scenarios have baseline, moderate reduction and high reduction heating demand variations.

Within each heating demand ‘banding’ there are three groupings for geographic coverage area. The first three scenarios in a band have low geographic coverage, the second group of three have medium geographic coverage and the third group of three have high geographic coverage:
Within each geographic area grouping there are three variations in connection rate. The first has a high connection rate, the second has a medium connection rate and the third one has low connection rate. This shown in the following figure as a change in symbol:

**Figure 56: Line Heat Density. Figure shows geographic coverage groupings.**
9.2. Utilisation of Nuclear Energy

The scenario outputs show a considerable range of nuclear energy utilised for heating services as a result of energy demand, geographic coverage and connection rate variables. The outputs meet expectations for the scale of heat networks under different scenario conditions.

The outputs show that the change between medium and low connection rates is not as great as between high and medium connection rates. This is as a result of non-domestic users being held constant in medium and low connection rate variations while domestic use is varied. The role of non-domestic demand in offsetting the lower domestic user connection rate shows the importance of non-domestic users in heat networks.
Figure 58: Annual User Demand

The range in annual user demand outputs illustrate the significance of geographic coverage and connection rate variables on network demand.

The range of demand outputs show that comparatively large heat networks can be developed in the vicinity of the Hartlepool reactor site. Data on existing heat networks is scarce and often comparable data is not available for the same attribute (such as user number). The table below compares the scenarios with the highest and lowest annual user demand with four other heat network examples using available attributes:

<table>
<thead>
<tr>
<th>Name</th>
<th>Annual Heat Demand (MWh)</th>
<th>Number of Users</th>
<th>Network Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copenhagen (City)</td>
<td>4,000,000</td>
<td>30,000</td>
<td>3,900</td>
</tr>
<tr>
<td>Scenario 7</td>
<td>1,237,000</td>
<td>69,200</td>
<td>1,500</td>
</tr>
<tr>
<td>Beznau</td>
<td>141,000</td>
<td>2,160</td>
<td>70</td>
</tr>
<tr>
<td>Sheffield</td>
<td>120,000</td>
<td>3,000</td>
<td>60</td>
</tr>
<tr>
<td>Scenario 21</td>
<td>64,300</td>
<td>4,210</td>
<td>101</td>
</tr>
<tr>
<td>Lerwick</td>
<td>35,000</td>
<td>1,000</td>
<td>20</td>
</tr>
</tbody>
</table>
Heat networks in scenarios with high geographic coverage and connection rates would be considerably larger than existing UK heat networks such as Sheffield. The smallest network in scenarios, in terms of annual demand, would also be considered comparatively large in the present UK context.

While the scenarios suggest relatively large heat networks can be supported by the thermal output of a new build nuclear site at Hartlepool, only a small proportion of potential reactor output is utilised in the scenarios.

![EPR Annual Thermal Efficiency](image)

**Figure 59: Effect of CHP on EPR Thermal Efficiency Change by Scenario**

The figure above shows how converting a nuclear site with two EPR reactors to CHP in each of the scenarios changes the thermal efficiency of the steam cycles (at the steam

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turbine, not including system losses in distributing thermal and electrical energy outputs). The reactor output is based on an illustrative 85% load factor per reactor and it is assumed that only one reactor is offline at a time (therefore thermal output to the heat network is not affected by the annual load factor). In principle, if the reactor were utilised constantly at its full potential CHP could improve the thermal efficiency of the reactor site from ~36% to 63.7% (Diamant and Kut 1981). However in the scenarios the increase in thermal efficiency from CHP conversion ranges from 0.1% in the low demand scenarios to 1.6% in the high demand scenarios.

The low overall utilisation is related to the nature of reactor thermal output and where it is sited. The thermal output from a nuclear site is not expected to vary throughout the year (with the exception of planned and unplanned shutdowns), meaning during summer months when heating demand is low, reactor output remains high and under-utilised.

The concentration of nuclear capacity on a single site is also influential in limiting the overall efficiency improvements from CHP operation. The estimated peak demand for the scenarios with the greatest peak demand, only reaches around 50% of available output from the twin reactor site (depending upon whether an EPR or an AP-1000 is assumed). This means that connected heating demand could be significantly higher in relation to available reactor output. However, because the thermal output is concentrated at a single site it is difficult to fully exploit. Full utilisation of the reactors peak output would imply a heat network closer to scale of the Copenhagen network. Copenhagen has however several, diverse thermal sources as opposed to a single large generator. Large heat networks such as this tend to be designed to have several distributed thermal sources because this provides security of supply advantages by avoiding over reliance and a large designated back-up capacity (Woods, Riley et al. 2005). Furthermore, the extent to which a large single heat source can be exploited is constrained by the thermal transfer capacity of heat network pipe (see Chapter 8 discussion of heat network pipe thermal transfer constraints). The research therefore finds that the ‘bottle neck’ effect of concentrated thermal output is a key limiting the scale of a nuclear heat network at the Hartlepool site.
**9.2.1. Increasing Utilisation**

This section considers how the utilisation of reactor thermal outputs through heat networks could be increased. The nuclear thermal resource not used in the scenarios does mean that there could be further utilisation of reactor outputs if network design and demand usage assumptions are altered.

**9.2.1.1. Lower return temperatures.**

The thermal transfer capacity of heat network pipes is constrained by maximum pipe diameters and the temperature difference between flow and return pipes. The scenarios use the UK standard return temperature of 70 °C to integrate with existing heating systems, and flow temperature of 110°C to ensure a long operational life for pipes. This means a network temperature difference of 40°C, enabling a peak transfer capacity of 749MW per primary network pipeline, which link the reactor to demand centres (discussed in further detail in Chapter 8). If a lower return temperature of 50°C can be achieved it would enable a network temperature difference could of 60°C. This would increase the maximum thermal transfer capacity of primary network pipes by 50% to 1,124MW (see Table 6). Lowering the return temperature would involve altering user heating systems (for example increasing the thermal transfer area of radiators) to operate at similar specifications to Danish heating systems and incur additional costs for developing a heat network (Martin and Spence 2010; Skagestad and Mildenstein 2011). Doing so however would mean more annual demand could be connected to the network than is possible with a 70°C return temperature.

**9.2.1.2. Nuclear Energy as Part of a Larger Network**

The scenarios consider nuclear energy as the only input into the scenario heat networks. This would mean large installed back-up capacity if the networks expanded further. If
thermal inputs into the system are diversified however less back up capacity may be required and the network can be more resilient.

The thermal energy from the nuclear could function as base load for a larger, more extensive heat network drawing surplus heat from other sources. In the Hartlepool example there are several industrial processes, including chemical and petroleum works that could also supply a heat network. Diversifying inputs could also introduce competition to the heat network and provide a function for maintaining lower costs by being less sensitive to changes in a single fuel type or process (for further reading on increasing competition in heat networks see Grohnheit and Gram Mortensen (2003)).

9.2.1.3. Low Density Distribution Approaches and Increasing Summer Heating Loads.

In Denmark and Sweden, heat networks have a substantial share of the heating services supply market. This has led to networks which expand into areas with low demand density and connect new, highly energy efficient buildings that were formally considered unsuitable for heat networks (Zinko, Bohm et al. 2008; Dalla Rosa and Christensen 2011). New pipe configurations and applications for heat network thermal energy have been developed to continue growth in mature markets (Zinko, Bohm et al. 2008).

Recently developed triple pipe systems, with two narrow flow pipes replacing a single, wider flow pipe, can reduce distribution losses in low density areas (Zinko, Bohm et al. 2008). Only one of the two flow pipes is used during low demand periods to reduce unnecessary distribution losses. Energy efficient buildings, which may only require a flow temperature of 30°C, can be connected to a network’s return pipe (Dalla Rosa and Christensen 2011). This means they are connected without requiring an increase in flow pipe capacity and help to lower the return temperature of the network, and thereby improve the thermal transfer capacity of the network (Dalla Rosa and Christensen 2011).

In addition to this, the proportion of a building’s energy demand supplied by heat networks can be increased through the use of washing machines, dryers and dishwashers
that are adapted to use thermal energy from a heat network (Zinko, Bohm et al. 2008). This would provide additional demand, particularly during summer months of the year when reactor output is far in excess of network demand.

9.3. Efficiency
The scenario outputs were used to assess the efficiency of the heat networks in two ways that can be used to determine the suitability of the Hartlepool site for a heat network. Firstly the efficiency of the network in distributing heating services was assessed through the line heat density and proportional heat loss attributes of the scenario heat networks. Secondly the overall efficiency of the network in transferring thermal energy from the reactor to users was compared with alternative methods of utilising nuclear energy for heating services.

9.3.1. Line Heat Density
Line heat density (also referred to as linear heat density) is the annual thermal energy delivered to users per metre of pipeline in a heat network. It is a useful indicator of the efficiency and financial viability of a heat network often used by the International Energy Agency’s District Heating and Cooling Project to compare the technical performance of schemes (Zinko, Bohm et al. 2008). The line heat densities of UK heat networks were not available at the time of this analysis to serve as a comparison with the scenarios.\textsuperscript{104} There is however greater availability of data for Danish heat networks that can be used as a guide.

In Denmark the average line heat density of heat networks is 1MWh/m per year, with line heat densities of 2.7MWh/m per year considered very high and line heat densities as low as 0.3 MWh/m per year considered economically viable if special practices are adopted (Zinko, Bohm et al. 2008).

\textsuperscript{104} It is not reported with other sets of data for UK heat networks. Interviews with the operators of the Aberdeen, Lerwick, Nottingham and Southampton heat network suggested this information is not collected in the UK yet.
The figure above shows the line heat density outputs for the scenario heat networks. This data shows that the majority of scenarios compare favourably with Danish examples. The outputs display the expected effect of lower average heating demand and low connection rates on network efficiency, with line heat density decreasing accordingly. This can be seen by comparing the line heat density of Scenario 21 (high demand reduction, low geographic coverage and low connection rate variables) with Scenario 7 (baseline energy demand, high geographic coverage and high connection rate). The outputs also reveal that line heat density is between 10% and 19% higher for scenarios with medium geographic coverage (circled in the figure) than for lower and higher coverage variations. This result suggests that the greater demand density in the Middlesbrough area (not included in the low geographic coverage area variable) is influential in increasing the overall line density of the network. This would also mean that extending the network to the Stockton-on-Tees area (only included in the high geographic coverage variable) adds lower demand density that offsets improvements from incorporating the Middlesbrough area. This means that, on this analysis, the
medium geographic coverage area variation is optimal for a heat network at the Hartlepool nuclear site.

### 9.3.2. Heat Loss
The distribution efficiency of the networks was assessed on the basis of proportional heat loss. This output describes the efficiency of a network in distributing thermal energy from the reactor site to users.

![Distribution Losses](image)

**Figure 61: Proportion of Thermal Energy Lost in Heat Network Distribution. Scenarios with low connection rates are circled.**

The outputs from the scenarios show that reduced heating services demand contributes to greater heat loss in distribution. For example, Scenario 1 has the same geographic coverage and connection rate as Scenario 10 and Scenario 19, but has lower proportional heat loss because it has baseline heating demand in contrast with moderate reduction and high reduction respectively in scenarios 10 and 19. These outputs also reveal a slight increase in proportional heat loss as network geographic coverage extends further from the reactor site. In addition, the distribution loss outputs highlight scenarios with a low connection rate, showing that they have significantly greater heat loss than comparable scenarios with medium and high connection rates. This reflects the lower usage of the
network per metre of pipeline because in the low connection rate variations only 50% of domestic users per street are connected.

While the outputs shown in the distribution loss figure present the expected patterns in the scenario data, the trends are slightly distorted. This is most pronounced when comparing medium and high connection rate scenarios where there is inconsistency in their relationship with each other. In some instances, such as the variation between Scenarios 1 and 2, medium connection rate results in lower heat loss than the comparable high connection rate scenario. However the variation between Scenarios 19 and 20, which would be expected to have the same relationship, despite lower heating services demand, is the opposite. This is a result of the pipeline diameter selection method used in the scenario development process. As the table below shows a range of capacity requirements can be assigned to the same pipe diameter:

<table>
<thead>
<tr>
<th>Internal Pipe Diameter (mm)</th>
<th>Max. Water Velocity (m/s)</th>
<th>Maximum Transferable Heat Capacity at Flow -Return Temperature Difference (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20°C</td>
</tr>
<tr>
<td>500</td>
<td>3.5</td>
<td>58,400</td>
</tr>
<tr>
<td>600</td>
<td>3.6</td>
<td>83,900</td>
</tr>
<tr>
<td>700</td>
<td>3.7</td>
<td>117,400</td>
</tr>
<tr>
<td>800</td>
<td>3.8</td>
<td>157,900</td>
</tr>
<tr>
<td>900</td>
<td>3.9</td>
<td>204,800</td>
</tr>
<tr>
<td>1000</td>
<td>4</td>
<td>259,600</td>
</tr>
</tbody>
</table>

*Table 17: Heat Network Transferable Heat Capacity. Source: GERMAN PIPE Industrie- und Fernwärmetechnik GmbH.*

As a consequence of this allocation process, a reduction in required heat transfer capacity may be enough in one scenario to qualify for a narrower pipe diameter but not in another. This would explain the distortions in the output trends.
Overall the outputs suggest that the Hartlepool nuclear site would be suitable for a heat network in all of the scenario contexts on the basis of their heat distribution efficiency. Skagestad and Mildenstein (2011) suggest annual heat losses of between 5% and 20% are normal for heat networks, and there are examples of Danish schemes with losses as high as 80% (Zinko, Bohm et al. 2008). In comparison only seven of the scenarios are outside of the normally expected range of heat loss for heat networks proposed by Skagestad and Mildenstein (2011). Furthermore, and all of the scenarios compare favourably with the range of annual heat losses reported for Danish heat networks.

9.3.3. Comparison with Alternative Uses of Nuclear Energy
This section compares the utilisation of nuclear energy through heat networks to electricity driven heating alternatives. This was used as a way to assess the relative efficiency of heat networks as a means of utilising nuclear energy. The thermal energy extracted from the reactor site in the scenarios would otherwise have been used to generate electricity, therefore the use of thermal energy through the scenario heat networks was compared with other comparable uses of the same thermal energy. This analysis involved establishing how much electrical energy is ‘used’ by the heat networks in the scenarios - through heat extraction (which decreases electricity output) and electric pumps that circulate hot water through the network– for the heating services that are delivered to users. This was then compared to the electrical energy input required to deliver heating services through electrified low carbon technologies; resistance electric heaters and heat pumps.

The heat networks in the scenarios divert thermal energy from the steam turbines at the nuclear site. This increases the overall energy output of the nuclear site by utilising heat as well as electricity as an energy output, but leads to a proportionate decrease in electricity output. The proportional loss of electricity to thermal energy recovered is the Z-factor. The networks also consume electrical energy to drive pump equipment that circulates water through the pipes and losses thermal energy in distribution. The parameters for determining heating services supplied per unit of electricity were:
• Heat extracted from reactor steam cycles and supplied to heat network. Determined by scenario attributes
• Electrical units lost. A 12% loss in electricity output per unit of thermal energy extracted was used. This was determined by using the Z-factor for double stage heat extraction (8.3) in the scenarios (Handl 1998).
• Electrical energy to pump water throughout network. The annual energy requirement for pumping water through a heat network was assumed to be 2% of energy transferred through the network, based on Skegestad and Mildenstein (2011).
• Heat loss in network. Determined by scenario attributes.
• Heat supplied to users. Determined by scenario attributes.

<table>
<thead>
<tr>
<th></th>
<th>Heat Extraction (MWh)</th>
<th>Lost Electrical Output (MWh)</th>
<th>Network Pumping Demand (MWh)</th>
<th>Total Electricity Input (MWh)</th>
<th>Network Heat Loss (MWh)</th>
<th>Heating Services Supplied (MWh)</th>
<th>Heat Supplied per Electrical Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>303,000</td>
<td>36,000</td>
<td>6,000</td>
<td>42,000</td>
<td>261,000</td>
<td>6.14</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>154,000</td>
<td>18,000</td>
<td>3,000</td>
<td>21,000</td>
<td>135,000</td>
<td>6.25</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>112,000</td>
<td>13,000</td>
<td>2,000</td>
<td>16,000</td>
<td>93,000</td>
<td>5.95</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>939,000</td>
<td>113,000</td>
<td>19,000</td>
<td>131,000</td>
<td>811,000</td>
<td>6.17</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>494,000</td>
<td>59,000</td>
<td>10,000</td>
<td>69,000</td>
<td>421,000</td>
<td>6.09</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>377,000</td>
<td>45,000</td>
<td>7,000</td>
<td>53,000</td>
<td>304,000</td>
<td>5.77</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1,478,000</td>
<td>177,000</td>
<td>30,000</td>
<td>207,000</td>
<td>1,237,000</td>
<td>5.98</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>756,000</td>
<td>91,000</td>
<td>15,000</td>
<td>106,000</td>
<td>638,000</td>
<td>6.03</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>554,000</td>
<td>67,000</td>
<td>11,000</td>
<td>78,000</td>
<td>443,000</td>
<td>5.71</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>255,000</td>
<td>31,000</td>
<td>5,000</td>
<td>36,000</td>
<td>216,000</td>
<td>6.06</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>131,000</td>
<td>16,000</td>
<td>3,000</td>
<td>18,000</td>
<td>112,000</td>
<td>6.09</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>98,000</td>
<td>12,000</td>
<td>2,000</td>
<td>14,000</td>
<td>79,000</td>
<td>5.77</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>803,000</td>
<td>96,000</td>
<td>16,000</td>
<td>112,000</td>
<td>677,000</td>
<td>6.02</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 18: Comparison of Overall Electricity to Heat Efficiency of Scenarios

Table 18 shows the heating services supplied for the electrical losses and other energy inputs in the scenario networks, including heat lost in distribution. These results were then compared to the performance of heat pumps and electric heaters using electricity from the nuclear site through the national grid. Electric resistance heaters directly convert electrical energy into heat even in water storage tanks for water heating or electric radiators for space heating (electric air flow heating is not included here). Heat pumps use electricity to drive vapour compression cycles that take thermal energy from the outside environment (typically the air or the ground in domestic applications) for use in buildings. This process recovers renewable energy (solar energy stored in the air or the ground) from the environment using pump driven expansion and compression to provide more thermal energy output than the electrical energy input required. This means heat
pumps can provide around three units of thermal energy per unit of electrical energy.

The parameters for the electricity based systems were:

- Electrical units supplied to electricity grid. An illustrative 100MWh was used.
- Electrical transmission and distribution losses. A transmission and distribution loss of 7%, based on the 2010 average for the UK national grid, was applied.  \(^{105}\)
- Co-efficient of performance (COP): COP describes how many units of thermal energy are produced per unit of electrical energy consumed at the point of use. A 1:1 COP was assumed for electricity resistance heaters, reflecting a direct conversion of electrical energy to heat. A 1:3.3 COP was used for air source heat pumps and 1:3.6 for ground source heat. This was based on the best performing air source and ground source heat pump examples in Roy, Caird et al. (2010).  \(^{106}\)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Electricity Output (MWh)</th>
<th>Transmission and Distribution Losses (MWh)</th>
<th>Heating Services Supplied (MWh)</th>
<th>Heat Supplied per Electrical Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Heater</td>
<td>100</td>
<td>7</td>
<td>93</td>
<td>0.93</td>
</tr>
<tr>
<td>Air Source Heat Pump</td>
<td>100</td>
<td>7</td>
<td>307</td>
<td>3.07</td>
</tr>
<tr>
<td>Ground Source Heat Pump</td>
<td>100</td>
<td>7</td>
<td>335</td>
<td>3.35</td>
</tr>
</tbody>
</table>

Table 19: Illustrative Comparison of Overall Electricity to Heat Efficiency by Technology.

The comparison between the heat network and the heat pump electricity to heating services ratios show that at a system level (from the reactor to user heating system) the scenario heat networks make more efficient use of nuclear energy outputs than other alternative technologies. It suggests that even scenarios with high network heat loss (20-25%) are more effective at utilising nuclear energy for heating services than heat pumps or electric heaters.


While this analysis is useful for comparing the relative value of electrical and thermal outputs from the nuclear site utilisation it is limited by the system boundaries used. This is because the parameters used for heat pumps and heat networks imply different user heating systems. The heat pump parameters used relate to best practice heat pump examples that imply use with under floor heating or similar retrofitting of user heating system. The lower system temperatures of 30°C to 40°C this provides enables high performance (Roy, Caird et al. 2010). The heat networks in the scenarios however, assume no retrofit of heating services and therefore operate with a return temperature of 70°C. If similar allowances were made for the scenario heat networks then return temperatures as low as 50°C (Martin and Spence 2010; Skagestad and Mildenstein 2011) would be possible. This would mean flow temperatures could be lowered from 110°C to 90°C during the heating season and from 90°C to 70°C through summer months, lowering distribution losses:

<table>
<thead>
<tr>
<th>Pipe Diameter (mm)</th>
<th>Heat Loss (watts/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>110°C</td>
</tr>
<tr>
<td>1000</td>
<td>142</td>
</tr>
<tr>
<td>900</td>
<td>90</td>
</tr>
<tr>
<td>800</td>
<td>64</td>
</tr>
<tr>
<td>700</td>
<td>57</td>
</tr>
<tr>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>500</td>
<td>43</td>
</tr>
<tr>
<td>350</td>
<td>43</td>
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<td>250</td>
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<td>150</td>
<td>36</td>
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<tr>
<td>100</td>
<td>30.9</td>
</tr>
<tr>
<td>80</td>
<td>30.6</td>
</tr>
<tr>
<td>65</td>
<td>26.7</td>
</tr>
</tbody>
</table>

Table 20: Heat Loss per Pipe Diameter, Varied by Operating Temperature. Output from Logstor StaTech

Lower distribution losses would reduce thermal extraction from the reactor site relative to heating services delivered users and improve the electrical energy input to heating
services delivered ratio. However retrofitting would also increase the costs of heat networks and create a potential social barrier to connection (see Chapter 6 discussion of the impact of household disruption on connection rate).

The comparison of electricity units consumed to heat supplied to users at a system level suggests that for the equivalent heating services to be provided through heat pumps in the scenarios, between 204% and 176% more electricity output would be required annually (depending on the heat distribution loss assumption in the scenario). This would offset the lower electricity to heat ratio of the heat pump system. It can be argued that the additional costs of providing electricity generating capacity to account for this difference should factored into a full economic comparison of the supply option.

9.4. Decarbonisation Potential

The potential contribution of each scenario to decarbonising UK energy supply was also considered as a performance indicator. The operational emissions of the heat networks were compared with emissions associated with the pre-existing natural gas heating systems they would replace. This analysis discusses direct emissions and does not include the life cycle greenhouse gas (GHG) emissions of either natural gas or the heat networks.

9.4.1. Associated Direct Emissions

The Department for Environment, Food and Rural Affairs (Defra) and DECC provide direct (scope 1) emissions factors for GHG emissions (this includes the carbon dioxide equivalents of methane and nitrous oxide released in combustion) associated with natural gas combustion (0.2055kgCO$_2$e/kWh). This was used in conjunction with the assumed average boiler efficiency of existing gas boilers in the scenarios to determine the carbon dioxide equivalent (CO$_2$e) emissions from heating services supplied by natural gas.
Defra and DECC do not provide emissions factors relevant for nuclear heat networks. Consequently the reported operational emissions for light water nuclear power stations were used in conjunction with the scenario attributes to provide a comparable emission factor. The operational emissions associated with nuclear reactors range from 0.00074kgCO₂e/kWh to 0.0013kgCO₂e/kWh depending on reactor type and operational performance (Weisser 2007). The high emission factor (0.0013kgCO₂e/kWh) was chosen to represent reactor emissions. The reported emission factors for nuclear energy is based on electricity generation (assuming a standard light water reactor thermal efficiency of ~36%) and not the thermal energy output of the reactor, therefore the electricity lost for providing thermal energy to the heat network was used as the emission multiplier. Because this refers to heat extracted from the steam turbine and not the heat supplied to users in the scenario, it incorporates the heat lost in distribution in the scenario when GHG emissions are compared with heating services in the scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Natural Gas emissions (kgCO₂e)</th>
<th>Heat Network Emissions (kgCO₂e)</th>
<th>Annual Carbon Saving from Heat Network (kgCO₂e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60,000,000</td>
<td>26,900</td>
<td>60,200,000</td>
</tr>
<tr>
<td>2</td>
<td>31,000,000</td>
<td>13,700</td>
<td>31,100,000</td>
</tr>
<tr>
<td>3</td>
<td>21,000,000</td>
<td>9,900</td>
<td>21,800,000</td>
</tr>
<tr>
<td>4</td>
<td>188,000,000</td>
<td>83,300</td>
<td>188,000,000</td>
</tr>
<tr>
<td>5</td>
<td>97,900,000</td>
<td>43,900</td>
<td>97,800,000</td>
</tr>
<tr>
<td>6</td>
<td>71,300,000</td>
<td>33,400</td>
<td>71,200,000</td>
</tr>
<tr>
<td>7</td>
<td>286,000,000</td>
<td>131,267</td>
<td>285,000,000</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emissions factors for natural gas CHP district heating are available in AEA (2012). 2012 Guidelines to Defra / DECC’s GHG Conversion Factors for Company Reporting. Department of Energy and Climate Change and Department for Environment Food and Rural Affairs. London. They are however relative to the direct emissions from natural gas and assume heat distribution losses of 5%. Sensitivity analysis on the heat network emissions estimates show CO₂e savings would be 0.03% greater if the low emission factor had been used.
<table>
<thead>
<tr>
<th></th>
<th>147,600,000</th>
<th>67,100</th>
<th>147,000,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>103,500,000</td>
<td>49,200</td>
<td>103,000,000</td>
</tr>
<tr>
<td>10</td>
<td>50,000,000</td>
<td>22,700</td>
<td>50,000,000</td>
</tr>
<tr>
<td>11</td>
<td>30,400,000</td>
<td>11,600</td>
<td>30,400,000</td>
</tr>
<tr>
<td>12</td>
<td>18,300,000</td>
<td>8,700</td>
<td>18,200,000</td>
</tr>
<tr>
<td>13</td>
<td>157,000,000</td>
<td>71,300</td>
<td>157,000,000</td>
</tr>
<tr>
<td>14</td>
<td>82,100,000</td>
<td>37,800</td>
<td>82,100,000</td>
</tr>
<tr>
<td>15</td>
<td>64,200,000</td>
<td>29,000</td>
<td>64,100,000</td>
</tr>
<tr>
<td>16</td>
<td>220,900,000</td>
<td>109,000</td>
<td>221,000,000</td>
</tr>
<tr>
<td>17</td>
<td>121,000,000</td>
<td>56,900</td>
<td>123,000,000</td>
</tr>
<tr>
<td>18</td>
<td>78,500,000</td>
<td>42,100</td>
<td>78,500,000</td>
</tr>
<tr>
<td>19</td>
<td>39,800,000</td>
<td>18,200</td>
<td>39,800,000</td>
</tr>
<tr>
<td>20</td>
<td>20,700,000</td>
<td>9,580</td>
<td>20,700,000</td>
</tr>
<tr>
<td>21</td>
<td>15,100,000</td>
<td>7,330</td>
<td>15,100,000</td>
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<td>112,000,000</td>
<td>59,300</td>
<td>112,000,000</td>
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<tr>
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<td>63,000,000</td>
<td>32,000</td>
<td>63,000,000</td>
</tr>
<tr>
<td>24</td>
<td>50,000,000</td>
<td>24,400</td>
<td>50,000,000</td>
</tr>
<tr>
<td>25</td>
<td>189,000,000</td>
<td>89,800</td>
<td>189,000,000</td>
</tr>
<tr>
<td>26</td>
<td>98,200,000</td>
<td>47,100</td>
<td>98,200,000</td>
</tr>
<tr>
<td>27</td>
<td>71,700,000</td>
<td>35,800</td>
<td>71,700,000</td>
</tr>
</tbody>
</table>

Table 21: Comparative Direct Emissions for Natural Gas and Heat Network Heating Services Provision in Scenarios

The data suggests that a large heat network, with high geographic coverage and connection rate replacing existing natural gas heating systems could save between
285,524tCO$_2$e and 188,672tCO$_2$e annually (depending upon average heating demand) in the Hartlepool area.

**9.5. Capital Cost and Financial Viability**

This section assesses the suitability of the Hartlepool nuclear site for heat network development based on cost and financial viability criteria. It analyses overall capital costs attributed to each scenario relative to the number of users connected. It then discusses the influence of heating demand, geographic coverage area and connection rate on cost. It also compares per user costs with other low carbon heating technologies. It uses illustrative examples of operating costs and revenue to consider the potential impacts of the scenario variables on financial viability. The section concludes with an assessment of what would be necessary for heat networks in the scenarios to be financially viable.

**9.5.1. Capital Cost**

The outputs from the scenarios were used to compile illustrative capital costs for each of the heat networks that were developed (the process of estimating illustrative costs is explained in Chapter 8). As expected this shows a significant difference in costs as a result of geographic coverage and connection rate as the number of users connected increases overall capital costs:
The outputs from the scenarios also show a slight change (2.1%-2.7%) in capital cost between comparable scenarios with different average heating demand assumptions. This can be seen in the figure above by comparing scenarios 7, 16 and 25, which have the same geographic coverage and connection rate variables but have baseline, moderate reduction and high reduction heating demand assumptions respectively. This shows that there is a slight cost advantage in reducing user average heating demand, but that this is not significant enough to offset lower annual heat sales associated with demand reduction.

Split by user, the scenario capital costs clearly illustrate the cost advantages of high connection rates, in particular ensuring that a high proportion of users on each network branch are connected. The figure below shows capital costs averaged by the total number of network users. Scenarios with low connection rates are circled:
Scenarios with low connection rates have significantly greater per user costs than medium and high connection rate scenarios, showing the importance of connecting a high proportion of users per network branch. The average user costs are also decreased as the geographic network extends to increase the total number of users connected to the network. The outputs show that for scenarios with high and medium connection rates average per user costs are below £18,000.

The heat network costs were differentiated by user type so they could be compared to domestic and non-domestic equivalents. This was done by splitting shared costs, such as reactor heat extraction units between all users, but allocating specific connection and hydraulic interface unit costs based on user type:

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109 Low connection rate scenarios connect 50% of domestic users per network branch, while medium connection rate scenarios connect 90% of domestic users per network branch. Both variations only cover half of each geographic coverage area, in comparison with high connection rate scenarios with connect 90% of users in the a whole coverage area.
Table 22: Scenario Cost Estimates for Scenario by User Type.

These outputs show a range of between £11,292 and £19,494 for domestic users and between £22,853 and £48,158 for non-domestic users. For non-domestic users this is a very low cost in comparison with individual heating supply technologies of equivalent capacity size (i.e. 1,000kW in baseline demand scenarios to 800kW in high demand reduction scenarios). The non-domestic connection costs are at around £48/kW in comparison with £934 to £1,000/kW for non-domestic ground source heat pumps and £368 to £419/kW for non-domestic biomass boilers (Macadam, Davies et al. 2008; Parsons Brinckerhoff 2009). This cost difference is as a result of the relatively low cost of hydraulic interface units relative to their capacity, and other costs being spread across all network users. The spreading of costs has the opposite impact on domestic costs. Again,
the HIU and connection is relatively inexpensive, around £3,736, however shared costs increase the overall per user costs significantly. The following table illustrates the range of estimated costs for domestic ground source heat pumps as a reference point:

<table>
<thead>
<tr>
<th></th>
<th>Energy Saving Trust</th>
<th>DECC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Source</td>
<td>£6,000 to £10,000110</td>
<td>£5,000 to £10,000111</td>
</tr>
<tr>
<td>Ground Source</td>
<td>£9,000 to £17,000112</td>
<td>£7,000 to £13,000113</td>
</tr>
</tbody>
</table>

Table 23: Cost Estimates for Domestic Heat Pumps by Data Source.

The lowest domestic costs for heat networks fall in the high end of heat pump costs, however the heat pump costs are limited to the heat pump unit and its installation. A full comparison would have to take account of the following factors:

- While heat networks have expected operating lives of 40 years (with maintenance and repair required over this period), air source heat pumps have an expected operating life of 15 years, while ground source heat pumps are expected to last for 20 years (Macadam, Davies et al. 2008; Parsons Brinckerhoff 2009).
- The heat networks in the scenarios are expected to require no retrofit of user heating systems if water based central heating is in place and do not require building energy efficiency to be upgraded to work optimally. Heat pumps by comparison, are likely to require some modification, such fan heaters (if air to air heat pumps are used) or under floor heating, and a building with sufficient insulation and draft

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proofing suitable for low temperature heating. These costs vary based on building fabric (AEA 2012) and are not included in the Energy Saving Trust and DECC estimates (Macadam, Davies et al. 2008).

- Heat pumps would require additional electricity generating capacity in order to supply the same heating services as a heat network. For a full comparison with heat network costs, which include back-up generation and heat extraction, additional electricity capacity should also be taken into account.

The scenario outputs suggest that the heat networks with high and medium connection rates would be competitively priced for non-domestic users and more expensive for domestic users based on up-front costs, depending upon additional costs due to the factors discussed above. The evidence from focus groups and expert interviews (see Chapter 4 and Chapter 6) however suggest that up-front costs to users should be avoided in order to obtain high connection rates. The analysis above highlights the importance of high connection rates on the cost effectiveness of networks; therefore removing upfront user costs and using revenue from heat sales to pay capital costs may be necessary. Furthermore, this would have to be done while staying competitive with alternatives such as natural gas. The focus groups were unambiguous about the importance of providing financial benefits for users for stimulating high connection rates. The responses in the group suggested that a heat price at least 20% below the natural gas price would required to incentive enough domestic users. The next section considers the financial viability of the heat networks in the context of these requirements.

9.5.2. Financial Viability
This section uses illustrative assumptions about the potential financial performance of the scenario heat networks to consider the impact of heating demand changes, geographic coverage and connection rates on the financial viability of the networks. The

outputs are then used to discuss whether a heat network supplied by a new Hartlepool nuclear power plant would be financially feasible and under what contexts.

9.5.2.1. Financial Variables

Financial variables are open to significant changes over the periods typically considered in foresight scenarios such as the ones used here (Berkhout, Hertin et al. 2002). The following dynamics are likely to influence the financial performance of heat networks:

- Changes to taxation and subsidy, including a carbon price at either UK (as discussed in the Electricity Market Reform Act (DECC 2011) or European Union level, feed-in tariffs and Renewable Obligation Certificate (ROC) and enhanced capital allowances (McNaught, Williams et al. 2011). ¹¹⁵

- Material cost and labour costs. For example Macadam, Davies et al (2008) and Parsons Brinckerhoff (2009) estimate that the costs for manufacturing and installing heat network pipes will fall by 10% if a greater number of large heat networks are planned in the UK.

- Inflation and growth factors.

- Cost of heating relative to alternative technologies. Increases of decreases in the retail price of natural gas will influence how competitive the heat price is.

- The market price for nuclear electricity. The cost of heat for the heat network operator is sensitive to the price the nuclear operator would otherwise receive for lost electricity output. The ‘contracts for difference’ tariff proposed in the Electricity Market Reform or similar subsidy mechanism would fix this at a predetermined level for long periods (DECC 2011). However determining tariff prices and electricity payments will depend upon the price required by generators and the price government decides to set (AEA 2012).

In addition to these variable factors, different assumptions can be made about the build rate of a heat network and its annual operating costs. Assumed build rates may range from 1-15 years, depending on how long it is estimated a heat network will take to reach its full extent (Parsons Brinckerhoff 2009). This influences the financial performance of

¹¹⁵ This provides reduction in corporate tax for capital expenditure on combined heat and power.
the heat network depending on how much of the network is operating, and therefore bringing in revenue, at any given point. Operation and maintenance costs assumed in reports on UK heat networks including Macadam, Davies et al (2008), Parsons Brinckerhoff (2009) and McNaught, Williams et al (2011) are not specified. Furthermore in expert interviews, interviewees were asked about heat costs, but were unwilling or unable to give specific examples of annual operating costs. Some annual operating costs, such as the cost of heat extracted from the reactor site and the cost of electricity for pumping heated water through the network, can be based on electricity price assumptions. Other operating costs including employing staff, carrying out repairs and preventative maintenance and additional overheads such as insurance and property rental are more difficult to estimate. In this analysis simplified assumptions were used to provide illustrative examples:

- The development of the networks was assumed to take five years, with 20% of capacity connected each year. Revenues were adjusted for the first four years to reflect this.
- The cost of heat from the reactor site was based on the total heat extraction from the nuclear site (includes heat lost in distribution by the network) in the scenario. The Z-factor assumed for heat extraction (see Chapter 3) was then used to determine the reduced electricity output from the reactor site in the scenario (1 unit of electricity for every 8.3 units of heat extracted). A value of this lost electricity output to the nuclear operator was determined using an electricity generator price of £50/MWh. This reflected the high end of the wholesale market a value for baseload electricity generated in 2012.  

- The cost of pumping water through the network was based on the estimated electricity requirement (2% of transferred energy (Skagestad and Mildenstein 2011)) multiplied by the assumed electricity price. Following the example of the Beznau heat network the electricity for pumping is assumed to be purchased from nuclear operator at generator price (£50/MWh).
- Maintenance and other annual operating costs were drawn from the operating and maintenance costs estimated for the Copenhagen heat network upgrade being

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developed, equal to 1% of network capital cost per annum (Metropolitan Copenhagen Heating Transmission Company 2009). This makes the maintenance costs relative to size of network infrastructure.

Using these assumptions the following annual costs for each scenario were calculated. This table shows the annual costs at full network capacity. The rates were adjusted for first year (at 20%), second year (at 40%), third year (at 60%) and fourth year (at 80%) network sizes to have proportionately lower annual costs for pumping electricity and heat cost.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Operation and Maintenance</th>
<th>Heat Cost</th>
<th>Pumping</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,014,465</td>
<td>1,747,238</td>
<td>364,008</td>
<td>4,125,711</td>
</tr>
<tr>
<td>2</td>
<td>1,267,457</td>
<td>886,628</td>
<td>184,714</td>
<td>2,338,799</td>
</tr>
<tr>
<td>3</td>
<td>1,110,482</td>
<td>645,486</td>
<td>134,476</td>
<td>1,890,445</td>
</tr>
<tr>
<td>4</td>
<td>5,159,356</td>
<td>5,406,691</td>
<td>1,126,394</td>
<td>11,692,440</td>
</tr>
<tr>
<td>5</td>
<td>3,070,241</td>
<td>2,848,273</td>
<td>593,390</td>
<td>6,511,905</td>
</tr>
<tr>
<td>6</td>
<td>2,552,934</td>
<td>2,169,288</td>
<td>451,935</td>
<td>5,174,157</td>
</tr>
<tr>
<td>7</td>
<td>8,105,475</td>
<td>8,514,620</td>
<td>1,773,879</td>
<td>18,393,973</td>
</tr>
<tr>
<td>8</td>
<td>4,684,184</td>
<td>4,352,627</td>
<td>906,797</td>
<td>9,943,608</td>
</tr>
<tr>
<td>9</td>
<td>3,887,052</td>
<td>3,194,041</td>
<td>665,425</td>
<td>7,746,518</td>
</tr>
<tr>
<td>10</td>
<td>1,969,259</td>
<td>1,469,099</td>
<td>306,062</td>
<td>3,744,421</td>
</tr>
<tr>
<td>11</td>
<td>1,261,801</td>
<td>755,308</td>
<td>157,356</td>
<td>2,174,465</td>
</tr>
<tr>
<td>12</td>
<td>1,115,027</td>
<td>561,982</td>
<td>117,080</td>
<td>1,794,089</td>
</tr>
<tr>
<td>13</td>
<td>5,092,807</td>
<td>4,627,692</td>
<td>964,103</td>
<td>10,684,602</td>
</tr>
<tr>
<td>14</td>
<td>3,053,494</td>
<td>2,453,652</td>
<td>511,178</td>
<td>6,018,324</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 24: Illustrative Annual Costs for Scenarios.

<table>
<thead>
<tr>
<th></th>
<th>2,472,575</th>
<th>1,902,765</th>
<th>396,409</th>
<th>4,771,749</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>7,940,811</td>
<td>7,088,507</td>
<td>1,476,772</td>
<td>16,506,091</td>
</tr>
<tr>
<td>17</td>
<td>4,565,016</td>
<td>3,692,642</td>
<td>769,300</td>
<td>9,026,958</td>
</tr>
<tr>
<td>18</td>
<td>3,632,885</td>
<td>2,729,820</td>
<td>568,713</td>
<td>6,931,418</td>
</tr>
<tr>
<td>19</td>
<td>1,877,547</td>
<td>1,177,860</td>
<td>245,387</td>
<td>3,300,795</td>
</tr>
<tr>
<td>20</td>
<td>1,239,467</td>
<td>621,396</td>
<td>129,458</td>
<td>1,990,321</td>
</tr>
<tr>
<td>21</td>
<td>1,056,648</td>
<td>475,533</td>
<td>99,069</td>
<td>1,631,251</td>
</tr>
<tr>
<td>22</td>
<td>4,993,252</td>
<td>3,843,917</td>
<td>800,816</td>
<td>9,637,985</td>
</tr>
<tr>
<td>23</td>
<td>2,999,370</td>
<td>2,056,263</td>
<td>428,388</td>
<td>5,484,021</td>
</tr>
<tr>
<td>24</td>
<td>2,340,527</td>
<td>1,579,850</td>
<td>329,135</td>
<td>4,249,512</td>
</tr>
<tr>
<td>25</td>
<td>7,733,900</td>
<td>5,826,829</td>
<td>1,213,923</td>
<td>14,774,653</td>
</tr>
<tr>
<td>26</td>
<td>4,440,353</td>
<td>3,059,913</td>
<td>637,482</td>
<td>8,137,748</td>
</tr>
<tr>
<td>27</td>
<td>3,453,102</td>
<td>2,324,868</td>
<td>484,348</td>
<td>6,262,317</td>
</tr>
</tbody>
</table>

The illustrative annual operating costs show that while annual heating demand is reduced by almost 40% between baseline and high reduction heating demand scenarios, annual operating costs do not decrease by the same margin. This would be expected because the network operator is likely to have overheads such as staff costs and maintenance that are proportionate to the network size as opposed to annual heating services provided.

### 9.5.2.2. Payback Period Assessment of Financial Viability

These annual costs outlined in the previous section were used to explore the financial viability of the scenarios with different heat prices and interest rates on capital costs. The period of time a network would require to payback initial invested capital was used as means of comparing scenario financial viability. This approach highlights the significant
role of finance costs (shown as interest rates here) in determining the development of heat networks discussed in Chapter 4.

Four heat prices were used to consider a range of possible net revenues for the scenarios. The 2011 average per unit natural gas price, 4p/kWh, was used as a benchmark for the heat prices. This figure averages various combinations of standing charges and payment types into a per unit figure. \(^{117}\) To derive the price of heating services from natural gas, a high boiler efficiency of 90% was used. This resulted in a 4.4p/kWh price for natural gas heating services. A heat price of 20% below the natural gas heating price (3.52p/kWh) and 20% above the natural gas heating price benchmark (5.28p/kWh) were tested. A 7p/kWh heat price, as used by Macadam, Davies et al (2008), was also used for comparison:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>3.52p/kWh</th>
<th>4.4p/kWh</th>
<th>5.28p/kWh</th>
<th>7p/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,132,528</td>
<td>7,428,888</td>
<td>9,725,247</td>
<td>14,213,586</td>
</tr>
<tr>
<td>2</td>
<td>2,437,254</td>
<td>3,622,032</td>
<td>4,806,809</td>
<td>7,122,511</td>
</tr>
<tr>
<td>3</td>
<td>1,419,918</td>
<td>2,240,785</td>
<td>3,061,652</td>
<td>4,666,074</td>
</tr>
<tr>
<td>4</td>
<td>17,091,566</td>
<td>24,231,248</td>
<td>31,370,929</td>
<td>45,325,762</td>
</tr>
<tr>
<td>5</td>
<td>8,441,514</td>
<td>12,150,199</td>
<td>15,858,885</td>
<td>23,107,678</td>
</tr>
<tr>
<td>6</td>
<td>5,626,096</td>
<td>8,303,563</td>
<td>10,981,029</td>
<td>16,214,259</td>
</tr>
<tr>
<td>7</td>
<td>25,492,257</td>
<td>36,375,120</td>
<td>47,257,984</td>
<td>68,529,035</td>
</tr>
<tr>
<td>8</td>
<td>12,705,943</td>
<td>18,322,991</td>
<td>23,940,039</td>
<td>34,918,814</td>
</tr>
<tr>
<td>9</td>
<td>7,990,957</td>
<td>11,892,055</td>
<td>15,793,153</td>
<td>23,418,026</td>
</tr>
<tr>
<td>10</td>
<td>3,928,647</td>
<td>5,831,610</td>
<td>7,734,574</td>
<td>11,454,003</td>
</tr>
<tr>
<td>11</td>
<td>1,794,686</td>
<td>2,779,106</td>
<td>3,763,526</td>
<td>5,687,620</td>
</tr>
<tr>
<td>12</td>
<td>1,002,493</td>
<td>1,695,784</td>
<td>2,389,076</td>
<td>3,744,145</td>
</tr>
<tr>
<td>13</td>
<td>13,354,880</td>
<td>19,316,545</td>
<td>25,278,210</td>
<td>36,930,556</td>
</tr>
<tr>
<td>14</td>
<td>6,507,081</td>
<td>9,612,874</td>
<td>12,718,666</td>
<td>18,789,079</td>
</tr>
<tr>
<td>15</td>
<td>4,430,803</td>
<td>6,711,620</td>
<td>8,992,438</td>
<td>13,450,399</td>
</tr>
<tr>
<td>16</td>
<td>19,878,862</td>
<td>28,901,262</td>
<td>37,923,661</td>
<td>55,558,352</td>
</tr>
<tr>
<td>17</td>
<td>9,803,919</td>
<td>14,473,173</td>
<td>19,142,427</td>
<td>28,268,697</td>
</tr>
<tr>
<td>18</td>
<td>6,368,302</td>
<td>9,664,796</td>
<td>12,961,290</td>
<td>19,404,438</td>
</tr>
<tr>
<td>19</td>
<td>2,786,555</td>
<td>4,296,123</td>
<td>5,805,691</td>
<td>8,756,210</td>
</tr>
<tr>
<td>20</td>
<td>1,171,820</td>
<td>1,955,883</td>
<td>2,739,945</td>
<td>4,272,430</td>
</tr>
<tr>
<td>21</td>
<td>651,427</td>
<td>1,217,143</td>
<td>1,782,859</td>
<td>2,888,577</td>
</tr>
</tbody>
</table>

Table 25: Annual Net Revenue. Based on annual heat sales at each price minus annual costs.

The table shows the annual net revenue of the scenarios after annual operating costs have been deducted based on the four heat prices. These outputs show the expected lower net revenues in scenarios with medium and high heating demand reduction. The decrease in net revenue is greater than the decrease in heating demand by around 5% as a result of maintenance and staff costs not reducing in line with heating demand.

To determine payback periods, the net revenues for the scenarios were over the 40 year expected operating period of the heat network were calculated. The first five years, when the networks are assumed to in the process of enlarging to full size, have lower net revues per year, increasing from 20% in the first year at 20% per annum. Between the fifth and fortieth year annual revenue is assumed to be constant. All of net revenue was assumed to be used to payback capital borrowing until all capital plus interest is repaid. Net revenues for the four heat prices were tested with three interest rates, 7.5%, 5% and 2.5%. The following figures present the outputs from Scenario 4 as an example:
The figures illustrate the influence of interest rate and heat price on the payback period common to all scenarios. In Scenario 4, under the financial assumptions used in the analysis, either a 7p/kWh heat price at 5% interest or a 5.28p/kWh heat price at 2.5% interest would be needed for the network to provide a positive financial return within a 30 year period.
Increasing the interest rate was observed to have amplified the impact of lower annual net revenue, as a result of lower average heating demand, in the moderate and high demand reduction scenarios. The analysis showed that with higher interest rates (5% and 7.5%) scenarios with moderate and high demand reductions would require very high heat prices to have sufficient annual net revenue to pay down capital borrowing while paying interest. For example, the following figures show outputs for a scenario with high geographic coverage, high connection rate but with the high heating demand reduction variation:

**Figure 66: Scenario 25 7.5% Interest**

**Scenario 25 (5% Interest)**

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This scenario illustrates the impact of the higher interest rate on scenarios with moderate and high demand reduction. It shows that for scenarios with lower average heating demand, higher heat prices are needed to augment annual net revenues to overcome annual interest accruement. This is because, while net revenue is lower than in comparable scenarios with baseline heating demand, capital costs and therefore annual interest payments remain similar.

The analysis suggests that, on the basis of the assumptions used, none of the scenario heat networks are likely to be financially viable without high heat prices (relative to current natural gas heating costs) and low interest on capital costs. This means two forms of support might be required from the UK Government and/or the local authorities in connected areas to provide the scenario heat networks at no up-front cost to users and at an attractively low price. Firstly government or the local authorities might have to provide or facilitate capital borrowing at a low interest rate (2.5%) the financial viability of the heat networks, particularly in scenarios with high heating demand reduction, would be greatly improved. Secondly, even with low interest rates some level of indirect or direct support subsidy would be required to ensure an affordable heat price likely to attract a high network connection rate. As with other low carbon heating technologies a form of support tariff would most likely have to be employed to mediate the difference.
between the heat price required by the network operator and an attractive price for users.

The Renewable Heat Incentive (RHI) is an example of a support mechanism that supports investment in low carbon heating technology. It pays energy users for units of low carbon heat they produce, which provides a return on investment to buy and install the technology and make the cost of heating services competitive with natural gas heating.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Size (kW)</th>
<th>Tariff (p/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Source Heat</td>
<td>&lt;100</td>
<td>4.3</td>
</tr>
<tr>
<td>Pump</td>
<td>≥ 100</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 26: Renewable Heat Tariffs. Paid over a 20 year period

If a similar support mechanism were established for the nuclear heat networks, network operators could be paid for low carbon energy they supply to users. A support mechanism similar to that of ground source heat pumps, of around 4p/kWh for 20 years would have a significant impact on the scenarios. At a 2.5% interest rate on capital costs and using the same assumptions used in the above analysis, several of the scenario heat networks would payback within a 30 year timeframe. The following figure assumes a user heat price of 3.52p/kWh with a 4p/kWh subsidy for the heat network operator (a 7.52p/kWh heat price for the operator) for 20 years and a 2.5% interest rate on capital:
Figure 69: Scenarios with 3.52p/kWh Domestic Heat Price plus a 4p/kWh Support Tariff Over First 20 years (2.5% interest on capital).

The scenarios are shown in the following table ranked by their financial return over the 40-year operating period. The outputs of this calculation show that the bottom seven ranked scenarios (described in the below table) would require a higher support payment, or have the payment over a longer payment. A lower subsidy or higher interest rate might be more appropriate for the top five scenarios, which under these financial assumptions perform strongly and would require less support:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Scenario</th>
<th>Variables</th>
<th>Number of Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>Baseline</td>
<td>69,200</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>Baseline</td>
<td>42,421</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>Medium reduction</td>
<td>69,244</td>
</tr>
<tr>
<td>4</td>
<td>13</td>
<td>Medium reduction</td>
<td>42,421</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>Baseline</td>
<td>34,668</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scenario</td>
<td>Reduction</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>Baseline</td>
<td>Medium</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>High Reduction</td>
<td>High</td>
</tr>
<tr>
<td>8</td>
<td>17</td>
<td>Medium reduction</td>
<td>High</td>
</tr>
<tr>
<td>9</td>
<td>22</td>
<td>High Reduction</td>
<td>Medium</td>
</tr>
<tr>
<td>10</td>
<td>9</td>
<td>Baseline</td>
<td>High</td>
</tr>
<tr>
<td>11</td>
<td>14</td>
<td>Medium reduction</td>
<td>Medium</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Baseline</td>
<td>Low</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>Baseline</td>
<td>Medium</td>
</tr>
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<td>14</td>
<td>18</td>
<td>Medium reduction</td>
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</tr>
<tr>
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<td>10</td>
<td>Medium reduction</td>
<td>Low</td>
</tr>
<tr>
<td>16</td>
<td>15</td>
<td>Medium reduction</td>
<td>Medium</td>
</tr>
<tr>
<td>17</td>
<td>26</td>
<td>High Reduction</td>
<td>High</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>Baseline</td>
<td>Low</td>
</tr>
<tr>
<td>19</td>
<td>23</td>
<td>High Reduction</td>
<td>Medium</td>
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<td>High</td>
</tr>
<tr>
<td>23</td>
<td>11</td>
<td>Medium reduction</td>
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<td>24</td>
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<td>Baseline</td>
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<td>25</td>
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<td>Medium reduction</td>
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<td>26</td>
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<td>High Reduction</td>
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<td>27</td>
<td>21</td>
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Table 27: Scenarios Ranked by Financial Performance at 2.5% Interest.
By comparing how the scenarios perform with a particular set of financial assumptions, two key trends were identified. The first is the expected impact of lower average user heating demand on the financial viability of the heat networks. In medium and high demand reduction scenarios annual net revenue is lower relative to capital cost. The second trend shows the significance of geographic coverage and connection rate. There are features of the Hartlepool case study and the nuclear energy component of the network heat that lead to larger than typical underlying capital costs that do not increase or decrease in relation to user numbers. Firstly the distances covered by the primary pipelines in the scenarios to connect demand centres to the nuclear site are relatively high in comparison with other heat networks. For example at Nottingham and Sheffield, the waste incinerators that supply heat to the networks are located near city centres where their connected demand is. The large heat networks of Berlin and Copenhagen have the majority of their thermal generating capacity within the city limits.\(^{118}\) Like the Beznau nuclear heat network, the thermal source in the scenarios is not embedded near users, increasing underlying network costs. Primary pipeline installation equates to between 11% and 26% of scenario capital costs and is largely unaffected by changes in user numbers within a geographic coverage area.\(^{119}\) Secondly, unlike the large gas and coal thermal power stations assessed by McNaught, Williams et al (2011) for heat network potential, heat extraction in the scenarios was assumed for two steam turbine plants, as opposed to one. Doubling the required heat extraction increased capital costs from £22 million to £44 million. This additional cost relates to the nuclear component of the network. Due to regulatory and technological complexity issues, unplanned shut downs can be longer for nuclear reactors than for combustion technologies. Therefore having heat extraction for both reactors on a site reduces risks of outages overlapping the heating season (Handl 1998). When combined these factors add significantly to capital requirements that are unrelated to the number of connected users,\(^{120}\) meaning


\(^{119}\) Some variation in cost arises from changes in pipe diameter, which relates to the number of users and average user demand characteristics.

\(^{120}\) As opposed to tertiary pipe network, user connection and back-up capacity costs that relate to the number of users connected and their average demand.
higher numbers of user connections are needed for financial viability than may otherwise be the case.

9.5.2.3. Summary of Financial viability
As discussed at the beginning of this section, financial performance is dependent upon several variables. The analysis used here can only be used to discuss possible trends and comment on the potential financial viability of the nuclear heat networks at the Hartlepool site in certain conditions.

The outputs from this analysis make it apparent that government or local authority support in the form of securing low interest rates for capital borrowing and augmenting the heat price for the operator through a support tariff is likely to be necessary. It also suggests that high numbers of users might be needed to connect ensure favourable financial performance. This feeds directly back to the level of support. The focus groups in Chapter 6 are unambiguous in indicating that only financial benefits, such as low heating prices without upfront costs, will encourage a high connection rate for domestic users. Reducing cost barriers for commercial and industrial users can also be assumed to improve the connection rate for non-domestic users. This would mean nuclear heat networks require financial input from government and local authorities. Heat networks are however not necessarily just a cost paid by governance institutions to greenhouse gas emissions. There are potential economic benefits, particularly for the local economy in the network coverage areas, to consider.

9.5.3. Wider Economic Benefits
While ostensibly aimed at supporting a migration to low carbon heating, the financial support for nuclear heat networks could also yield economic benefits at a national and local level. The initial construction of the network would provide jobs over the network development period. Based on evidence from UK, Swiss and Danish heat networks, a large heat network would provide around twenty full time jobs for network operation
and maintenance. Beyond the direct impacts from construction and operation of the network, there is the potential for other, broader economic benefits.

Any support mechanisms would, optimally, be aimed at ensuring high connection rates that increase the greenhouse gas mitigation potential of the technology and improve its financial viability. Unlike the Renewable Heat Incentive, the capital investment or borrowing for capital costs could be attributed to the heat network operator instead of households.¹²¹ In doing so the support mechanisms could provide affordable heating services (relative to natural gas) and reduce financial barriers to user connection. This would make the technology available to households that do not have capital to invest, or who are unable or unwilling to take on personal debt in order to replace natural gas heating systems. The combination of a support tariff and a stable price for nuclear electricity¹²² (from which the cost of heat for the network operator is derived) could also reduce the risk of shape increases in the heat price for users. Both facets of the nuclear heat network with a support mechanism have positive implications for fuel poverty reduction in connected areas. Although the primary major mechanism for fuel poverty alleviation, the Warm Home Discount Scheme, is paid for through a levy on energy suppliers¹²³, savings made by this scheme or a future equivalent, could be redeployed. Reducing fuel poverty also reduces mental and physical health impacts associated with under heated buildings and finance related stress (Milne and Boardman 2000; Gilbertson, Grimsley et al. 2012). As well as improving wellbeing, this would be expected to have economic benefits for local and national health care services (Gilbertson, Grimsley et al. 2012).

In addition to benefits arising from domestic user connection, stable long term heat prices could make the area served by a heat network more attractive to commercial and industrial users. It may provide a competitive advantage in retaining industrial and commercial businesses and attract new ones to the area.

¹²¹ Unless the support tariff is low and requires users to pay for their hydraulic interface unit and connection.
¹²² As the result of a contract for difference feed in tariff and/or typically low sensitivity to fuel price fluctuations, see Chapter 3.
9.6. Summary of Main Findings from Scenario Analysis

9.6.1. Utilisation of Nuclear Energy for Heating Services

The scenarios suggest nuclear energy from the Hartlepool could be used to supply up to 1.2TWh of heating demand annually. As shown in Table 16 this would represent a relatively large heat network in the UK, although not at the scale of large established networks in European cities such as Copenhagen. This would account for the energy demand of up to almost 70,000 users in the Teesside area and make a substantial contribution to decarbonising heating services in the area.

The analysis however also shows that only a relatively small proportion of the thermal output from the nuclear site in the scenario would be utilised annually. Furthermore this is significantly less than the 2.9TWh potential estimated by James and Bahaj (2009) in their study of heat supply from existing large power station sites in the UK. As discussed in detail in Section 9.2 the comparatively low demand met by the reactor in the scenarios reflects the technical aspects of heat network technology and the constraints this imposes. The disparity is as a result of James and Bahaj (2009) basing their analysis on total heating services demand within 10km of the Hartlepool nuclear reactor site and not considering the distribution of this demand or the constraints of thermal transfer through a heat network. The scenarios in this thesis go beyond the total demand in the vicinity of the reactor to examine its distribution through a heating services demand map to determine areas near to the reactor suitable for a heat network. The literature and best practice from existing heat networks shows the importance of having demand clusters that ensure efficient network operation (see Section 3.3) and consequently the approach taken in the research presented here provides a more accurate estimate of the potential energy demand met by a nuclear heat network. The research findings highlight the importance of conducting spatial analysis and applying the technical constraints for heat networks in conducting a robust assessment of the potential utilisation of thermal energy via heat networks.

9.6.2. Costs

The capital cost analysis for the scenarios shows large upfront costs for nuclear heat works, an issue foreseen as a result of the expert interviews undertaken to identify non-technical barriers to heat networks in the UK. The scenario analysis shows the importance of connection rate in
lowering the per user capital costs of a nuclear heat networks and for improving the financial viability of such a system. The analysis also highlights the difficulties in comparing heat network costs with heat pump technologies as a result of different system boundaries which can be applied (such as how network and generation costs are accounted for in heat pump costs). Despite this the research finds that in scenarios with medium and high connection rates, heat network costs per user are not dissimilar to heat pump costs, particularly if wider system costs – such as retrofitting under floor heating - are incorporated. To reduce up-front costs to users sufficiently to stimulate a high connection rate government support would be required to develop the system. This may be in the form of a low interest loan as well as tariff support as has been proposed for other low carbon heating technology through the Renewable Heat Incentive.

9.6.3. CO$_2$e Mitigation

The scenario analysis suggests potential for mitigating up to 285,000tCO$_2$e annually, should a nuclear heat network replace existing heating systems with current levels of heating services demand. As expected this saving reduces if per user energy demand falls (to 189,000 tCO$_2$e in the 40% reduction scenarios). The most useful comparison in terms of a heat network is a COWI consultancy study of the Copenhagen network. This report estimates the annual savings for the Copenhagen heat network to be 665,000tCO$_2$e. The Copenhagen figure is for a larger network that also provides cooling during summer months and is in comparison with oil (the heating fuel typically displaced by heat networks in Denmark) as an alternative heating option and not natural gas, which has lower associated emissions per kWh. Furthermore the Copenhagen scheme draws from several thermal energy sources around the city area. Consequently, with these factors in consideration, the potential CO$_2$e mitigation form utilising heat from the Hartlepool nuclear site is comparable with large established heat networks in Europe in the scenarios with high geographic coverage and connection rates.

9.7. Conclusions

The scenario outputs presented in this chapter suggest that the Hartlepool nuclear site would be suitable for a heat network in a number of circumstances. Overall the research found that in the scenario with the highest annual demand profile, heat networks would

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only marginally increase the thermal efficiency of new build reactors (an increase of 1.6%). This however is primarily the result of the imbalance, between supply from the reactor and demand from the local area, of thermal energy throughout a year. The scenarios did show however that the majority of heating services in three towns could be met by reactor thermal output. In scenarios with high geographic network coverage and high user connection rates, this research suggests that between 1,240GWh and 813GWh (depending on reductions in average heating demand) of low carbon energy could be supplied per year. This would save up to 286,000 tonnes of CO\textsubscript{2}e per year against current energy consumption in the Hartlepool area.

The research shows how important high connection rates and geographic coverage would be for achieving favourable energy efficiency and financial performances. It suggests these factors are more significant for nuclear heat networks than for other heat network types. This is a result of the installation costs of primary transmission heat pipes between reactor sites and demand centres. These costs are fixed regardless of the number of users connected and therefore the network benefits financially from a high number of users more so than a network with a heat source located nearer to energy users.

The comparisons between the scenario heat networks and alternative low carbon heating alternatives - that could otherwise use the electricity output lost in the CHP process - show heat networks can be a more efficient use of nuclear energy. Having a nuclear heat network would reduce the required ‘peaking’ capacity of the national grid during winter months in comparison with a future context where heating services are electrified.

By including the potential for significant reductions in average heating services demand as a variable, the scenarios were also able to consider whether heat networks would continue to be relevant if demand density if reduced (as argued in MacKay (2009)). The research found that even in a high demand reduction future heat networks could distribute thermal energy efficiently, with only up to 24% heat loss. The outputs show that if energy saving measures are applied before heat network development, the impact
of lower demand density on cost and efficiency can be largely offset by network design (such as narrower pipes and lower distribution temperatures). This research does however acknowledge that as average user energy demand reduces, higher connection rates become more significant, particularly in terms of financial viability.
10. Concluding Remarks

This chapter summarises the key findings from the three research themes and considers what they imply for nuclear heat network development in the UK. It goes on to suggest remaining knowledge gaps and areas of further study.

10.1. Summary of Key Results

The key findings from this research are that it is technically feasible to utilise nuclear energy for heating services in the case of Hartlepool and that local resident interpretations of the technology are not necessarily a barrier to the development of such a system.

The research shows that a heat network utilising energy from nuclear reactors at the Hartlepool site is technically feasible. The scenario outputs suggest that a network covering the three large towns in the area (Hartlepool, Stockton and Middlesbrough) can supply up to 1.2TWh of low carbon energy annually without prohibitively high heat loss from the network (in comparison with established schemes, see Section 9.3.2). The results show that there is sufficient demand density in these areas to enable the connection of up to 70,000 users without covering low density areas that would incur higher network heat loss. Furthermore, it indicates that even if very high levels of demand reduction are achieved, a network with a sufficiently high connection rate can still achieve energy efficiency levels (shown by heat loss indicators) that make it very competitive with heat pump alternatives at a system level (see Section 9.3.3).

The results from the focus groups show a surprising high degree of support for nuclear heat network technology, although with the caveats discussed in Section 7. A key finding was the ability of participants in the groups to see the risks of nuclear which were demonstrated by the Fukushima disaster just prior to the sessions as distinct from the risks they face from the Hartlepool facility. This observed phenomenon meant that even though concern about nuclear power might be assumed to be high following a nuclear incident, such events do not necessarily shape local resident views of their own nearby facility. This suggests a resilience in the established risk perceptions of the local nuclear facilities as acceptably low, which could be instrumental in enabling the development of a nuclear heat network. Furthermore the focus
group results suggest a positive role for lock-in to existing natural gas heating systems when users consider switching to heat networks. Although lock-in is often framed as being negative, the similarities in appearance, performance and function of heat network user interfaces may be an important advantage for enabling heat network technology generally.

Overall the research findings show there is potential to increase the role of heat networks as means of low carbon heating supply in the UK and that previous assumptions about reactor location and public perception as significant barriers to nuclear heat networks are not supported by the data presented here. The research does however show that major non-technical barriers, specifically in unlocking finance and enabling local authorities to take a leading role remain to be resolved. The techno-economic assessment presented in Section 9.5 shows that creating a viable economic model for such heat networks is a key challenge which requires further study. The following sections discuss the findings in relation to the three research questions posed in the Research Framework.

10.2. Non-technical Issues Influencing Nuclear Heat Network Development
The interviews carried out as part of this research theme correlated with the findings of previous studies of the non-technical barriers to heat networks in the UK. They highlighted the importance of market structure and available finance in constraining the development or extension of heat networks irrespective of thermal input technology. The interview responses suggest that significant changes to the existing market based approach to energy supply are needed to enable heat network development.

The research undertaken for this research theme also identified optimism amongst participants in the UK heat network industry that if local authorities are empowered to take a stronger role in developing energy infrastructure, this will benefit heat network projects. This also requires a shift in the way energy infrastructure is developed that will depend upon future changes in the governance of energy policy (particularly the level decisions are taken at) and how infrastructure is financed (a greater role for public rather than private investment).
A significant finding from the interview process was also the apparent limited effect a nuclear thermal source might be expected to have on the non-technical barriers to a nuclear heat network. From a regulatory perspective the extraction of heat from the steam cycle as opposed to causing interference with the reactor limits the potential complications of a change in use from a nuclear power station to a nuclear combined heat and power station. The experts who were interviewed as part of this research did identify any barriers that would be unique to nuclear heat networks, other than local resident responses and reactor location issues.

10.3. Energy User and Public Responses to Nuclear Heat Network Technology

Two findings from the local resident focus groups were particularly significant. Firstly, pre-existing and fixed (obdurate) views of technology could benefit, as opposed to hinder, heat network development. Secondly, concerns about nuclear risks do not necessarily mean nuclear heat networks will be interpreted negatively by local residents.

The similarities, for users, between the hydraulic interface unit (HIU) of a heat network and a gas combination boiler were identified as a key advantage for enabling user connection. The features of an HIU, such as instant hot water and a responsive thermostat (i.e. providing heat rapidly on demand), as well as its appearance and size compared, favourably with participant experiences with gas heating. Existing gas heating systems informed their criteria for assessing alternative technologies. The HIU’s ‘like-for-like’ qualities in relation to gas systems they would replace appealed to the group participants. This was preferred to technology alternatives that alter living spaces in a noticeable way (such as taking additional space) perform differently and require new competencies and knowledge to operate.

The focus group outputs also provided an insight into how the risks associated with nuclear energy might shape local resident responses to heat network developments. They indicate that residents can be aware of and acknowledge nuclear risks while at the same time overlook them to focus on cost and performance issues. This does not suggest
that there would not be public opposition to a nuclear heat network development as a result of nuclear risks. It does however make it clear that the technology would not necessarily be dismissed as dangerous and unsuitable for the local area. The focus group analysis shows that different meanings are available for nuclear energy in the Teesside context. This includes, most significantly from the heat network perspective, viewing nuclear energy as a local resource people might be willing to exploit.

10.4. The Suitability of Potential New Nuclear Sites for Heat Networks

The foresight scenario approach to nuclear heat network development in the Hartlepool area shows that the reactor’s location is suitable for a large heat network. This research suggests that almost 70,000 energy users could be connected to a heat network supplied by nuclear reactors on the Hartlepool site. Depending on changes in average user heating demand, up to 1,236GWh of low carbon thermal energy could be supplied annually. Against baseline energy consumption around 285,524 tonnes CO$_2$ could be saved annually if high user connection rate and high geographic coverage is achieved.

The scenario outputs also show that realising these high performing scenarios is likely to require significant initial capital investment at the beginning of the project with long term (around 30 year) pay back periods. This is a result of the high initial costs of the network, which are estimated to be as high as £810 million in scenarios with extensive coverage and high user connection rates. It also reflects the need, identified in the focus groups (Chapter 6), that heat prices need to be competitive with alternative heat supply to promote a the high connection rate the network requires.

Another key finding from the financial viability testing of the scenarios was that nuclear heat networks are likely to require higher connection rates than other UK heat networks. The analysis highlights the requirement for high user numbers to offset the additional network costs incurred as a result of the reactor’s location. The primary heat transmission pipelines to the heat user demand centres in the scenarios cover between 4km and 7km before reaching users. This is unusual for heat networks, because thermal
sources are typically situated closer to thermal energy users. It is however an unavoidable issue for nuclear heat network development in the UK as a result of potential new build reactor locations. The costs of primary pipelines do not change in relation to the connection rates within network coverage areas; therefore the financial performance of the networks is strongly affected by the number of users these costs are shared amongst.

The scenario research also found that the primary restriction on utilisation of nuclear energy is the transfer capacity of heat network pipes. As nuclear reactor sites in the UK concentrate output in a small area (building large reactors adjacent to each other) there is an unavoidable ‘bottle neck’ caused by the thermal transfer capacity of primary heat network pipes. Chapter 9 however suggest ways in which the limitations of pipe transfer capacity can be mitigated to enable further utilisation. This is an area for further research as discussed in Section 10.6.

10.4.1. **Utilising Nuclear Energy for Low Carbon Heating Services in the UK – Further Research.**

The findings from this research demonstrate that nuclear heat networks could be developed at the Hartlepool nuclear site. This suggests that similar networks could be feasible at the Heysham and Oldbury nuclear sites (see Figures 22 and 23 for analysis of potential demand centres near both reactor sites). Each case would have to be considered separately to take account of different geographic contexts. This is important not just for understanding heating demand distribution near to the reactor site, but for considering local resident reactions. As Figure 23 in Chapter 8 shows, the demand centres for Oldbury are located quite far from the reactor site. Unlike in the case of Hartlepool, and possibly Heysham, the Olbury reactor may not necessarily be considered part of the local area by the residents near Birmingham that a nuclear heat network would affect.

As noted in the previous section the concentrated nature of nuclear reactor output will limit the contribution nuclear heat networks can make to decarbonising UK heating
supply at Heysham and Oldbury. Moving beyond the nuclear reactor development pathways currently being promoted, there are alternative pathways for nuclear energy in the UK that would benefit nuclear heat approaches. They involve smaller, modular nuclear reactors with enhanced safety features that could be located closer to energy demand centres, that are either compatible with CHP or that are explicitly designed for heat networks (Göbel 1991; Jiang, Gao et al. 2001; Nagai and Shimazu 2005). These different concepts of nuclear development raise their own question, particularly with regard to public opposition in areas without previous nuclear experience. It would however provide additional opportunities to expand nuclear heat networks further.

**10.5. Contribution to Knowledge**

The research presented in this thesis makes an important contribution to understanding the potential for utilising nuclear energy for heating services in UK. The findings, as discussed above, fill important gaps in knowledge about the potential role of nuclear heat networks in the UK. Furthermore, the heat demand map and the mixed methods approach employed to answer the research questions are also a contribution to academic knowledge.

The heat demand map that was developed pre-dates the Department of Energy and Climate Change’s heat demand mapping project and can show domestic demand distribution at finer geographic scale. The research was also able to show the impact of changing heating demand as a result of energy efficiency measures on heat network performance indicators, which at the time of completion is not possible with the DECC tool. As argued in (Speirs, Gross et al. (2010) national scale energy models are ill equipped to take into account the spatial distribution issues that determine the suitability of heat networks in local contexts, and consequently heat networks are underrepresented in such models. This research shows how detailed spatial analysis of specific energy contexts, such as Teesside can lead to the identification decarbonisation opportunities that may be missed in national scale analysis. At the time of writing this is the most comprehensive study of the potential for nuclear heat networks in the UK and therefore has importance for policy makers. By answering the research questions posed
by Government documents such as DECC (2012) (*The Future of Heating: A strategic framework for low carbon heat in the UK*) about nuclear heat networks, this research can enable a more informed debate about the role of the technology in the UK energy mix. The approach used in this research can be replicated at other nuclear sites, and locations for future carbon capture and storage schemes in the UK to assess their potential contribution to low carbon heating services provision.

Furthermore the research presented here makes a contribution in terms of the methodological approach that was taken. The strong embedding of social science in the technical analysis, through using findings from expert interviews and focus groups to shape the approach and variables used in scenario development is an example of an applied Science and Technology Studies approach to analysing potential low carbon energy systems. To the researchers knowledge this is the only similar study to use this configuration of methods to assess a technology. The research method also included a novel amalgamation of interpretation of risk and infrastructure siting controversy literatures, using their shared interpretivist perspective and assumptions to apply them simultaneously.

Ultimately this thesis serves as an example of interdisciplinary research that draws on research methods and theory from diverse fields to answer important research questions. While this integration was challenging, the overall benefits in terms of the insights provided show why this approach to research should be encouraged.
Appendix A

Example Expert Interview Transcription

Conducted with the District Heating System Operator (DHSO) for the Beznau nuclear district heating system 09/03/2010:

(DHSO): We supply quite a large area, that’s really specialist with Refuna. But in this respect it doesn’t really matter that the heat comes from a power plant, or a nuclear power plant, whatever plant or heat...how the heat is produced, or where the heat is from. We are basically in charge of distributing it out in the pipes to all the communities and there to the houses.

Christopher Jones (CJ): Ok

(DHSO): Of course I can tell you some specific things, or if you have some specific question about our system.

(CJ): Yes

(DHSO): What I want to say or to...the difference of the different district heating net. Maybe it’s the size or whatever but, distributing the heat is not different if it comes from a nuclear power plant or from any other source.

(CJ): Ok

(DHSO): You know what I mean?

(CJ): Yeah I see, when it’s hot water and its going through the pipes it’s the same...

(DHSO): Right. There I can’t tell you much specific because you say you are looking for differences between nuclear and – I don’t know what kind of interviews you already did with other - district heating supplier companies.

(CJ): Some of the other things are such as waste incineration and geothermal energy. The difference in source may not matter. That would be something to find out from this as well. So that’s interesting in itself. In terms of specific questions, the scheme itself I understand from the website its been going for around twenty years or more now

(DHSO): Yeah the whole project started even in the seventies, but technically they started with around ’83 with the first part – or first suppliers – and ’84, ’85, 1984, 1985 they connected different communities and houses. So its more than 25 years.

(CJ): In terms of your view on district heating itself; what do you feel are the ben...advantages for customers as opposed to gas or oil or wood. Do you think there is an advantage to district heating?

(DHSO): Especially, Yeah that’s maybe kind of specialist to nuclear power plant there is no... even waste incineration its kind of lower level energy, what is, I don’t think its called waste energy...
(CJ): Waste heat?

(DHSO): Is it waste heat? Yeah I mean, or lost heat, a kind of process of the nuclear power plant. Its part of it so it kind of reduces the amount of electricity a little bit, the whole... efficiency of the plant is increased with the district heating. So one point is CO2 reduction and the use, or the better use, of a power plant, whatever power plant it is as long as more waste heat than reduction of other kind of energy mostly of electricity, I think.

(CJ): And do you think there is a benefit also for the homes connected to the scheme from a consumer...user perspective?

(DHSO): Yeah, basically one kind of advantage is the price level is very constant it’s not coupled, at least with us, with oil prices. So you’re independent from import of oil or gas so you have a local resource, a local source of heat. And what we have seen as well is really a very low...very low cost in operating the house stations, very low maintenance cost of the district heating stations for the customer itself.

(CJ): Yes

(DHSO): In the opposite would say to maintenance the whole pipes system...where we transport the...which is buried most, 100% of it which is the pipes which are buried to bring the water, these costs – maintenance cost quite, yeah, quite high.

(CJ): Yes

(DHSO): It’s a big part of the whole cost.

(CJ): When they were sort of...I’m not sure...if at that stage you were involved with the company but when they were sort of doing things such as laying the pipes and developing the scheme back in sort of the 1983 to 1985 was that an easy process or were there lots of difficulties.

(DHSO): No there quite a lot of difficulties, because I think...one thing which is very special with Refuna its we supply quite a wide area but... the density of the customer, because its not in a city there are different communities which are connected together and there is no... can I say that there, single houses are not forced to connect to this district heating, so its by there own if they want or not. So the density is not very high in this area where we are. The customers there are quite a lot of little customers, houses and not that much of industry or... how you call...familianhausen [German]? Like a...

(CJ): Perhaps larger houses or housing blocks?

(DHSO): Housing blocks, right. They are not that much so we have quite a low density, or average of power per connection, of power per customer.

(CJ): OK. I suppose ordinarily they connect to maybe flat blocks or maybe in a heavily populated area?

(DHSO): Yeah, if you have the situation that you have the heavily populated areas you can supply, or bring much more energy, with relatively short piping system. And building this piping system is quite expensive.
(CJ): In terms of ... you say it wasn’t a forced connection and people elected to join, was there a difficulty in getting people to join, or were people quite interested in the idea?

(DHSO): Yeah I think the idea was very interested, interesting and so, but, yeah, quite interested but even so it was by there own so if they can or they can’t so its very difficult to calculate, to, pay the investment.

Were people approached by the company directly? Or where there sort of community group or a...

(DHSO): Approach but mostly it was community groups yeah, within this different communities it was handled so we call from the about the main net, or main piping system which was originally driven by the Refuna and a local distribution net, that means within the community, this was handled for in, the most by this community. In the meantime this net and all the maintenance, so on, is sold or bought from the Refuna and maintained by Refuna.

(CJ): Ok...

(DHSO): It was really special with Refuna this sort of, is still owned by this communities. And originally these communities have maintained and driven their local net, but mainly means that there wasn’t any...technically wise there wasn’t any pumps or so something like this, just the pipes. And the pumps were handled from within the main net, handled by Refuna.

(CJ): Ok so they form sort of a local community bodies, organisations to help expand their own scheme and Refuna...

(DHSO): Right

(CJ): Fit the pipes?

(DHSO): Uh huh, and I think it was the only way how it, such a big area could be supplied, because they have looked within their community that...could find interested people and go to them and tell them the plans that they will come with a main pipe and where it was ideal to connect or that they could do the right dimension of the pipes, the dimensioning of the pipes.

(CJ): Alright, that’s quite different how it is in the UK with connection to similar things. With regard to...did, do you know if Refuna have to deal with, was there particular government legislation or local government bodies to deal with or...

(DHSO): No, I didn’t understand your question.

(CJ): Were there planning regulations or government policies to incentivise or...

(DHSO): No, basically nothing. That’s maybe a kind of problem that there are no really advantages which is for to do district heating. I think even in Germany also it’s different earlier and now as well, there were some interest but it was not really supported money wise. The communities, they helped a lot to manage it within this community and to drive the whole thing, but not really moneywise.

(CJ): Ok, that’s very interesting.
(DHSO): And the Refuna and the whole project when it was founded or it’s still 51% of the shares belongs to this communities. There were 9 communities

Yes

(DHSO): Which started...were involved in this Refuna project, yeah.

(CJ): Alright

(DHSO): And some are industries and then the shareholders. You might have seen them in the Gescheftspirits [?].

(CJ): With regard to the day to day operation of the district heating scheme are there particular key issues that make it challenging or quite easy to operate?

(DHSO): Sorry, I missed the first part of the question. What made it difficult to operate?

(CJ): Yes, are there particular issues that make it either difficult of easy to operate the whole system?

(DHSO): Technically wise, or commercially wise?

(CJ): Both.

(DHSO): Technically is...one thing is the geographics in the height, so the water has...it’s not flat here, so there, and we have in our pipes winter time we go up to 125 °C water that means we need to have some pressure, our pressure for not evaporating the water and to bring the water up to the higher level of the area and that’s about more than a hundred metres higher, so and there is need some pressure in the whole thing. Technically another difficulty is to operate this wide net I think something which is really special. We do not only have pumps in a central location so our net is built like a kind of tree, it starts in the middle with the, where all the water comes we have just basically just one source, the nuclear power plant. It’s not a system were we have different source heat sources which are supplying into this net it’s a single source and we have to bring it out to the branches. Our system is about...we have 130km of piping system and the pipes is an initial flow or heat water pipe coming back with the back flow, the second pipe, so there are 260km of pipes which have to be maintained.

(CJ): And is maintenance typically annually, weekly or monthly?

(DHSO): Yeah, we have some people which do this maintenance its not a continuous maintenance its more. We do have leakage separation or a leakage detection system within this pipes, these are isolated pipes there is isolation around and a leakage detection system. There might be different reasons that we do have leakages either from the pipes out of our water or as well from the outside. I mean these pipes, do you know how these pipes look like, kind of?

(CJ): I have seen photographs

(DHSO): Steel isolation and outside is plastic and it could be that water comes from outside pipes which destroys with the time they might get destroyed therefore you have to maintain or repair these problems. And repairing means burying out opening the system and so on. There are some valves and things which need to be maintained, so it is a continuous process. And a kind of cost.
(CJ): *I would imagine it is quite costly.*

(DHSO): It is, yeah

(CJ): *In terms of...*

(DHSO): There are a kind of fixed cost to maintain the whole system with pumps and so on.

(CJ): Ok. *And when the price is set for the heat for the customer are those costs incorporated into that price?*

(DHSO): Right, yeah.

(CJ): *And is the price...how is the price determined, if you don’t’ mind me asking?*

(DHSO): We get difficult with the terms again. They have to pay an annual fee depending on the connection power. Can I say that, do you understand what I mean?

(CJ): Yes

(DHSO): If you are a single house this is maybe 6kw a big one might have 50kw depending on the power you need you have to pay an annual fee. And then the power itself, the kWh, you have to pay, and the kWh is 5 Rappen [swiss money], 5.6 Rappen per kWh so its, to compare with the oil, last year where the oil went up it was...we were quite a lot cheaper, when the cost of the oil is quite low its more difficult. But there other studies which tells a lot about [] you do not just have to calculate the energy, when we talk about the oil fired heating system in the house you have to have the tank you have to have the chimney and other stuff. You have to buy the oil, so if you are lucky you buy it when it is cheap maybe you have to buy it when its kind of gambling and so on.

(CJ): Ok. *In the, you mentioned earlier the source of heat is unimportant to the scheme... I’ll try and rephrase this a bit better... in the UK people might be nervous about using heat from nuclear because they can be irrational, in that sense has that been an issue with Refuna?*

(DHSO): In the earlier days yes. When they started with the whole project there were different discussions, yeah, this project even...if you have checked where we are located about...geographically?

(CJ): *I’ve seen in on the map*

(DHSO): In the early days, in the seventies, before the Refuna itself was started there was a project called Transval, it was a bigger project where it was discussed to bring this heat water into the city of Zurich.

(CJ): *From Beznau?*

(DHSO): From Beznau to Zurich. And there the discussion was to be about bringing nuclear water into the city and so on. And I think that was probably one of...for sure it was not the only reason, but it was one of the reason why this huge project did not, was not realised. And so Refuna, which was a smaller package of this project which covers the surrounding of Beznau...I wouldn’t
say it was not a team [?] the population here was not really against this nuclear heat. But even so I think there was some kind of, can I say, lack of information or there were some informations that it is not contaminated water or whatever, that it is not possible that the different circulations...how you say?

(CJ): Circuits or loops?

(DHSO): Different circuits.

(CJ): Perhaps people may think it comes directly from the nuclear plant...

(DHSO): Yeah

As opposed to heat exchangers...

(DHSO): Yeah so that they have the same water that goes to the nuclear part which they have in the houses themselves. So there are several circuits, this was of course shown to the customer, or the public that they are different circuits.

(CJ): OK

(DHSO): Basically I think that sort of the idea of the original project I mentioned that was transval. You might find out information about this, I don’t know. Transportation of heat in the valley of Aare, that was the meaning. As I mentioned at the beginning would be quite a big difference of density of the needed energy. In the city it would be much higher. So of course the difficulty there would be to transport it from here to a big city. But then in the city you have a lot of customers where you could connect. Here with our project the difficulty to have not that much, not that huge customers which are spread over the whole region.

(CJ): Would you say this issue perhaps limits the potential for Refuna to grow further?

(DHSO): That’s sure one thing, and the investment for the connected, having more customers or the sold energy and there is as well some technical issues. I mean there was a kind of dimensioning when they started and as I said we are built like a tree, you would have to open to make it wider, this pipes, as well some investment, it’s not for free.

But of course here with the nuclear power plant there is a huge amount of waste or huge amount of energy which could even be better used, that’s always the discrepancy; having it here in dead central point.

(CJ): That’s a part of my study would...when we build the new reactors in the United Kingdom to think, to consider using the heat in a similar way to how it has been used in Beznau. Perhaps even on a larger scale if viable.

(DHSO): Just, from the side of the available amount of heat would be must bigger than it is used right now. I mean we have maximum power, our maximum power from around 75MW which we use, which we take from the power plant and on the other side this is the plant is I think 730KW electrically there are two blocks, you might know?

(CJ): Yes
(DHSO): Which gives us a technically wise a big advantage that we have, we can get heat from either block so that means during the refuelling time of the nuclear power plant we get our heat from the other block. We don’t even have to use...I mean we have to bring to the customer all year the heat, not just comfort heat, for fresh water, for heat water. So it’s needed as well during summer time and of course much less but during that time we get from, during the refuelling there is first goes one block and then later the other block so we get usually without any interruption. But for emergency, there would be a problem we do not get the heat from the plant we do have as well some, different boilers where we can produce heat and put into our system. But they are in case of emergency

(CJ): Of course, you have to maintain supply. Is it a problem with the difference between summer and winter demand? I imagine it’s quite a dramatic difference in terms of the amount of heat you supply?

(DHSO): Yeah, it’s around a factor of ten or even more. So that means during summer times we have to supply, we reduce the temperature but we have to supply the heat. On the other sides there is used much less the waste is higher than during the winter time of course. But of course I think this is with all...

(CJ): A common problem for all district heating I believe, from what I’ve seen so far.

(DHSO): Might be a little big different if you have some more industries which uses maybe for process some heat.

(CJ): Diversify the customer...That’s brilliant. We’ve covered the questions I wanted to go through, which as I mentioned before has been excellent and very useful. Is there perhaps someone else you could refer to speak to? Not necessarily in Refuna but perhaps the community groups or the power plant themselves. Do you think they would be interested in speaking to me?

(DHSO): I don’t know really. I don’t know why not! With the customer its just, maybe, I wouldn’t know who...there it’s a kind of difficulty. With the power plant you maybe first ask, they are a little bit bigger. They have a media centre where maybe you could try.

(CJ): This is Axpro?

(DHSO): Yes Axpro

(CJ): Ok, I’ll try to speak to someone there.

(DHSO): They can maybe give you some information there. At the moment you might know there is a discussion about...Norkfolger [?]...is it called succession of existing power plants?

(CJ): Yes, so the replacement of older nuclear sites?

(DHSO): Yes

(CJ): This is a discussion we are having in the UK as well. Will that have an impact on Refuna, if it is a no? and there is a decision made not to renew the nuclear?
(DHSO): Yes of course, we do not have any source! Easily said. No it’s not that dramatic, but of course it has because our source would go.

(CJ): Hopefully they will

(DHSO): Would have to produce in another way and of course...that’s what I said because the energy a big amount is waste energy, is quite cheap, especially compared to oil. But as I said the distribution the maintenance of the whole system and so on, is quite a big part of the at customer costs. If the source cost would rise a lot of course, it is even more difficult to support the whole system.

(CJ): Yes, I can imagine. Well, like I said hopefully that won’t be an issue.

(DHSO): I don’t think so. Basically there have to be another plant that produces power I believe, let’s assume, I don’t hope so, but maybe a gas power plant. There is waste heat as well so...

(CJ): But will that cost more, what with it being gas?

(DHSO): Basically the electricity cost is higher but I mean they do not need the main part of the gas for producing our heat, they would need the part for producing electricity. So therefore it’s still, I don’t know if it would be the same cost but would still be much lower than oil, directly needed for example. Which in my opinion makes no sense but, just, but as long as can use most part of waste heat the source heat cost should be reasonable. And that’s what I mean, it’s not really, as long as you do not burn any source directly only to produce the heat you should be able to increase the efficiency of the whole plant, so the source costs are not that directly connected to, if its gas or oil, wood or nuclear.

(CJ): Ok, good.

(DHSO): The issue is, is it waste heat or the most part waste heat in the whole system. With us its is ten parts or nine parts is waste and the one part is reduction of electricity.

(CJ): So your overall energy efficiency is a lot higher?

(DHSO): Yeah, it’s even much higher than a warmerpump [?] what is it called? Heating pump?

(CJ): Yes

(DHSO): Which has an efficiency of around 4 or something like that.

(CJ): Yes, the coefficient of performance can be quite, what we would call the coefficient of performance

(DHSO): COP?

(CJ): Yeah... that’s very good one to...

(DHSO): One to nine.

(CJ): Well, unless you had any further comments or questions for myself, I’m aware that I initially said I would only keep you half an hour or so and I’ve kept you longer. My apologies.
(DHSO): That’s fine. I hope, I mean, my English, we don’t need it for business, my English I have
some difficulties with my explanations, I hope it was clear enough. I don’t know if it would help to
supply, but you have probably seen the website, it is in German, there is some information in
German.

(CJ): I have a German colleague it’s just getting her to take the time to translate. Perhaps. I have
been able to get some information from the website which has been useful, it’s been good. Your
English has been very clear and it’s been very good for me because I was unsure whether I would
be able to get the information with not being able to speak German. It has been excellent for me

(DHSO): I hope there was some information and I really convinced that it is a good idea, a good
thing, to have this district heating, and I think they should be supported more from the
government. It is a source which is within the country and it is just increasing the efficiency of
existing plants.

(CJ): I completely agree. Especially because we have very strict carbon dioxide reduction targets in
the UK and perhaps presumably in Switzerland as well to reduce these greenhouse gas emissions.

(DHSO): It is diplomatic...the nuclear... there are discussions about how much CO2 are produced
with nuclear power plants, but basically as I said there the efficiency, if we use it for district
heating in addition almost no more CO2 is produced anyway. I mean, in my opinion it is very low
from nuclear power plant anyway and in addition if you use most part of waste energy it’s, if we
use it or not it’s not produced more or less CO2. That means when we use a lot of district heating
heat almost no more CO2 is produced.

(CJ): Yes. That would be the view I would have and then it replaces...in the UK we burn natural gas
and coal, it replaces those.

(DHSO): Yes, it replaces it almost 100% I mean with us there is no gas, no coal, no oil involved.
And even then if the plant uses some it is just almost no additional it really replaces a big amount
of oil, or gas. That’s really true. We supply about 150-160GWh

(CJ): Is that giga-watt hours?

(DHSO): Yes giga-watt hours per year. So that’s replacing, earlier on it was replacing oil. There
were just a few electric heat, electric heating. I don’t know in England it is maybe the opposite
wasn’t it? There were quite a lot of electric heating.

(CJ): We have about 7% of heating is electric.

(DHSO): 7%?

(CJ): Yes it’s mostly natural that is burned in homes for heat.

(DHSO): And here it was mostly oil in this region there is almost no gas. But it has historically
grown. I think that it was one reason there is no gas here is because there is heat, district heating
net here. And now-a-days it is maybe it’s the heating pumps which of course is the competition
its not as much the oil heating. And they’re, we said, heating pumps have a COP of around 4 we
do have around 8-9 and on the other hand we are discussing having a lack of electricity in the
future so, it’s yeah...
(CJ): And perhaps the heat pump is quite a big cost for the consumer?

(DHSO): Yes and it is comparable the cost of district heating I would say with the cost of heating pumps. There are some investments at the beginning and after that, as you said, from the electricity. Ok?

(CJ): Thank you

(DHSO): You’re welcome. Hope you are successful with your thesis.
Exert from Homeowners Focus Group Transcript; 19th April 2011-04-21

Facilitator (CJ) – Thanks for coming along and taking the time to come out here today. Just to give you a bit of background on why you’re here; I’m from the University of Manchester and I’m based in the School of Mechanical Aerospace and Mechanical Engineering, looking at some alternative heating options for homes and businesses and industry and the one I want to talk to you about today is quite applicable to this area so we’re holding a focus group here to get residents view on the issue. The structure of the group, should take about two hours, but depending on how things go might wrap up earlier; the structure is quite straight forward. Going to begin with a brief presentation that outlines some of the key context and some of the general reasons behind the study and we will go into a 15-20 minute discussion on heating in homes and the different options. I’ll then present a particular alternative in another 15-minute presentation and we’ll then discuss that until the end. Is everyone ok with that? Does anyone have any questions about who I am and what we are doing today? Great, well I’ll just jump in and do some more talking for a bit.

I’ll just dim the lights down a little bit (4:00)

So we’re mainly concerned with heating in the home, which for the purposes of today is your hot water and your central heating, or how you heat your home. Just going to run through three of the main issues for why we are looking at alternatives to our present system. We’ve known for a while that inadequate heating, especially in a climate such as this can lead to physical health impacts, particularly respiratory and heart problems, pneumonia and other health issues. Excess winter mortality, which is the number of people who die in winter because of the temperature difference is quite high for northern Europe and there is also a growing body of work on the impact of damp, drafty poorly heated homes on mental health as well. The second big one is the expense of heating, which can lead to some financial hardships where people may choose to not adequately heat their home to the World Health Organisations recommended 18-21°C – I’m not sure what that is in Fahrenheit – but that is the band that is considered necessary to keep healthy. Some people can’t afford it so they choose not to use their heating and because of that it leads back into this first bullet point (on the PowerPoint slide). The third bullet point is the impact of using fossil fuels for heating. (6:00) There has been a lot of work done on the impact of that on the global climate and at a local level with pollutants such as NoX and sulphur at the local level. So those are some of the challenges.

In the UK we rely on natural gas for most of our heating. Does everyone here have gas heating? Or do some have electric?

Participant (#1): Gas

#2: Gas
CJ (7:00): – In most cases people have gas, so obviously it is a bit percentage of the Pie (pie chart of UK energy consumption on screen). This is coupled with the fact that many homes in the UK have quite a low performance rating when it comes to their thermal performance, that’s things like loft insulation, how well walls retain the heat, things like the floor and if you have a draft through the door or windows etc. Most of our housing stock is pre 1990s is still around often with poor performance. (8:00) The other thing to bear in mind is that since 2006 we have gone from a country that had a reserve of natural gas on doorstep – in the North Sea – to a country that has started to import gas from other markets, international wholesale markets. Obviously as the North Sea decline in productivity that amount of imported gas against domestic supply will increase.

The reliance on natural gas and also the cost and availability of natural gas on heating, this (chart of natural gas prices 1996-2009) is from the Department of Energy and Climate Change, which is the Government body responsible for keeping these statistics. This is just compiled from average bills from the three main ways of paying for gas heating. As you can see in all three cases since about 2004 up to about now the average price per kWh of gas has gone up quite a bit ahead of inflation, practically doubled in this 5 year period (points to 2004-2009). It can be quite a volatile market, it goes up and down quite a bit. The thing to note from this is around-about here (points to 2001) the government had a policy to eradicate, or eradicate wherever possible fuel poverty, where if a households spends more than 10% on energy bills they are considered to be in fuel poverty (9:40). They may decide not to use heating services or think twice about using the heating. And that number (fuel poverty) was down to just under 2 million in 2003 (10:00) and in spite of measures to drive that down, its risen to about 3.3-4 million in 2008 depending on which statistics that you use.

(10:21) Another thing is the physical supply, whether the network can cope with very cold winters and do we have enough storage domestically and we either need to build more storage or diversify. This is just from last winter (slide of Metro article on gas supply shortage Jan 2010). It was a harsh winter but not so uncommon. In this situation all that happened was industrial users were told to stop using gas so that there wouldn’t be a disruption for domestic users, but obviously not an ideal situation to be in. And finally in terms of the UK contribution to greenhouse gas emissions, heating from the domestic, service and industrial sector are quite a big proportion of our energy use. As 80% of that is natural and some oil etc it is quite a big contributor to the UK’s carbon dioxide emissions. And the UK Government has adopted a policy to reduce the carbon dioxide emissions from the UK, by 2050 to 80% of what they were in 1990. And that will involve a concerted effort to reduce the carbon dioxide emissions from heat which is a big contributor.

So there are three key challenges for the UK identified by the government, the International Energy Agency and various charities and non-governmental organisations. (12:22) And they are to diversify supply, to be less dependent on gas, or at least diversify where we get gas from. And to stabilise costs to stop an increase in households experiencing fuel poverty and to meet with the wider climate change legislation that has come in about reducing carbon dioxide emissions.

(12:57) The main strategies identified for looking at this are firstly to change how we use heating to be more effective and prevent loss through the roof the loft and what-have-you. That (points to list of energy efficiency measures) is not an exhaustive list there is a whole raft of things you can
do to improve thermal efficiency and thermal performance. So that’s the first thing, then the next thing to look at is how we change supply and there are some of the options (points to list on slide). First is electric heating, people might know about that, tends to come as standard in new build flats, just like an electric radiator or air blower in a room and if that is powered by a low carbon electricity grid, then that might be an alternative. Biomass boilers, has anyone heard of biomass? Its typically pellets of wood compacted fed through a hopper into a boiler quite similar to a gas combi boiler in the way it heats your hot water and get your heating from that boiler. Ground source and air source heat pumps, essentially work the other way around to an air conditioning unit. They take low temperatures from the air or ground and compress it to make it into a higher temperature to use in the house. It can be a slightly confusing concept but the idea is you put in one unit of electricity and get about three units of heat out, because the compressor draws in heat from either the ground or the air to heat the home, and that in conjunction with an efficient heating system can be another solution (15:09). Solar thermal, I don’t know if you have seen any of these around but they are starting to spring up here and there, are basically black cylinders on a roof fitted closely together and they use solar energy from the sun to meet some or all of your needs depending on the sun available. The one we will focus on for the rest of today is district heating, has anyone come across it?

#3: No

CJ: It’s probably the oldest one, apart from biomass, but it is fairly uncommon in the UK at the moment. I’ll talk about it more later, but it is essentially distributes hot water to homes and the home has a unit similar to a combi boiler that takes off heat for your hot water and heating. And so, does anyone have any questions about what we just went through?

What about the three challenges highlighted at the start of the presentation? The three key challenges for heating services, highlighted here to diversity supply, stabilise cost and reduce environmental impact. Does anyone have any thoughts on those three issues? Do people want to add to those or think some are more or less important? Is everybody happy with those as a set of goals?

#1 (17:25) There is nothing we can do about it, whoever is going to do something about it, the government or whoever’s going to set it up and doing anyway aren’t they? So houses is going to be built with new technology in the future while everyone else is going to be left with the old technology as it is, we’re not going to be able to afford the new technology, cos it’s not going to be available to you, costs thousands of pounds.

CJ: OK so the availability of new technology?

#1: Yeah, cos you’re going to have to pay for it aren’t you? So you’re not going to do that you’re just going to carry on with what you got. It’ll be put in new houses so that the natural progression is the houses will have it put in anyway so you’ll be buying new houses unless you’ve got plenty money to put it in yourself, I assume. (18:08)

CJ: Anyone else have any thoughts on that?

#2: I’d agree with that cos, erm, the old boiler that I had for about 5 years the people who came and serviced it said you need a new one, you need a more efficient one, eventually we did get a
new one, but that’s cos we could afford one. But generally the price of them, I’m not sure how that’s going to affect, I mean new houses like you said will be different won’t they? They’ll be built to better standards.

CJ: Ok. Was anyone familiar with the kind of information in that presentation? Was any of it new or surprising?

#2: it wasn’t surprising, no. Apart from things like district heating, I’d never heard of that.

#3: Yeah

#1: I’d never heard of it

#1: Is it supplied free?

[Laughing]

#4: Nothings free!

CJ: There is a case, because district heating comes at a community level, the cost is spread across lots of different users instead of you yourself buying a system to add to the house, can lead to a lower cost and you can pay through the energy you use over the lifetime of it...

#1: But how do you get it?

CJ: It has to be installed, I’ll probably come back to that a bit later to describe how

#2: Is that by gas then?

CJ: It can be there are lots of different ways of providing it.

#2: It seems to me like a conflict of interest because the providers wouldn’t want us to become more efficient would they? Because if we pay less they get less profit. Although I suppose the government could have some say in that (20:10)

CJ: So in terms of the issues included in that presentation, just thinking about heating in general, do you think that some of those issues are applicable to your own heating systems?

#1: Mine’s old and knackered and on its way out but I can’t afford to change it so you just have to carry on paying.

CJ: Is there a point where the cost of keeping that one going, will there come a point when you swap?

#1: just have to keep paying to get it fixed. It’s cheaper than £3-4000 for a new system. Cos if you’re paying £60 every now and then or £100 for a plumber to come and fix it you’re going to pay the £100 aren’t you?

#5: Keep calling them out it’ll be more money though

#6: Yeah
#1: It’s still £3 or 4000 I can’t afford.

#5: Ah, know yeah

#1: that’s what I’m getting at, it’s not just me, it’s country wide isn’t it?

CJ: *Discussing cost there, what about things like health and mental wellbeing?*

#6: I didn’t think it would affect sort of physical or mental health problems

#5: I didn’t think it would either

#7: Unless you don’t have any at all

#6: I know about the wages for the old age pensioners cos they reduce the heating cos they can’t afford it, but I wouldn’t think it would be linked to physical or mental health problems.

#8: I think coldness can be a bit of a mood suppressant, sometimes you can be depressed just if you’re cold and you’re energy levels are consequently down.

#6: I don’t know anything about that.

#7: There will be a number of houses in the country that are damp though won’t there?

#6: Oh yeah, the big old ones.

#9: Even though they get money for the heating there are still old people climbing into bed with hot water bottle, some of them (inaudible) not using the heating.

CJ: *The UK Government spends quite a substantial sum on these cold weather payments, depending on whether they get it or use it is another thing. We have a poor track record with Excess winter mortality. You all seem to be healthy people, so this might not be such an issue at the minute, but the cold can make you quite sick or more susceptible to those issues. What do people think about the third point on environmental impact?*

#2: I’m sure I just read an article about the fact fossil fuels, are they going to run out in twenty or thirty years time or something, I’m sure there is some danger of us not having fossil fuels much longer, read that recently. Didn’t mention (inaudible 23:12)

#8: Aren’t the oil reserves drying up as well? They estimate 50 to 70 years or so, there’ll be no more?

CJ: *Well, I’m not an expert on that*

[Laughter]

CJ: *I know there are a lot of different ideas on when we reach the peak with what is available and what is left. But what I can say is our domestic reserves of oil and gas are – in what the oil and gas industry call decline – in that remaining supplies are increasingly difficult to find, lots of little ones. We’re at that stage now. There is still oil and gas to be had from the North Sea but it’s passed*
peak, peaked in 2004 – 2006 so increasingly we’ll have to start importing from the global market. What do people think about importing more?

#4: It costs more money won’t it?

#1: We’re already doing it. We pump it into our country then over to Germany and they pump it back over to us. We pump it into the country at a cheap price pump it over to Germany and send it back over at double the price. I work in the power industry so I know that that happens. So we’re actually buying our own gas back at double the price. Sounds stupid don’t it.

#4: Do they do anything to it?

#1: It’s exactly the same gas. Goes all the round underneath the sea, to Germany over to Norway then back down into England and we use it at double the price. Because everything has been privatised. But does anyone really bother about the climate change? As far as I’m concerned, turn your heating up you turn it up. Most of us aren’t bothered about whether the turn the heating alters the climate control or whatever. If you want to be warm you want to warm, whether it affects the climate or not.

#8: It’s because there is not a defined end point to it. Nobody has said the climate – for want of a better word – implode or be destroyed in certain year, for instance 2013, 2015. If it was more imminent and a substantial body of scientists said yes it’s going to happen then and there will be significant consequences then we would be more worried, but it’s something we only relate to abstractly, I don’t think we sort of worry that much about it. (25:47)

#2: People just switch off

#8: Yeah, exactly

#7: People are concerned when they watch it on the telly then they switch over and watch something else

#1: I’ll put the heating on when I want to use it. I think most people are like that.

#8: I think most people are like that

#1: You drive to work, you’re not bothered about the consequences of it.

#8: There is no sense of being directly responsible is there? If you leave the gas on, the gas on for too long or whatever fuel source potentially emits a harmful substance if you leave it on for too long. There is no sense of direct responsibility, it’s not illegal it’s not even deemed immoral is it?

#1: It is working at the minute because of the price of the fuel isn’t it. They have sorted that problem out by pricing you out of putting the damn heating on, so they’re solving the problem of the climate aren’t they?

#8: Right

#1: Make it so dear you can’t put it on.
#8: Fair enough

#4: You can’t take your car anywhere. The price of petrol isn’t going down I assume it’s so that people don’t use the car for short journeys.

#1: Cost

#10: It does bother me, I’d like to be more energy efficient but then it comes down to cost. I would like solar panels, it is something that I would like to do, but it’s very expensive to do it, so even if you’re aware that what you do does affect the climate you just think ‘well I can’t afford to do anything different.’

#2: I think there is some scheme to do with solar panelling because I’ve seen them going up all over the place, but I don’t think you see your money back off it for quite a number of years...

[Murmur of agreement from a few others.

#2: It comes back to what you were saying earlier doesn’t it? If you’re going to spend money on it whether or not you’ve got money to do it.

#4: You put it into the grid then you get the money back in five years time, then you start to feel the benefit of it. But if you pay now quite a substantial lot to...

#1 A lot to start with which people can’t afford.

CJ: Is it fair to say then, of the three; the health the cost and the environmental impact, the cost is always the main consideration? It would probably be the same from my point of view as well. That’s good so in terms of your awareness of alternatives, had you heard of any of these? Starting with the improving household efficiency.

#4: Yeah

CJ: What have you heard about that?

#4: Government schemes

#10: I’ve had a few people knock at my door about getting loft insulation for free, cos if you don’t work you can get that done for free.

CJ: Yeah

#4: When I got my done, my old boiler died, so I got a new boiler and I got all the insulation done got of it done and then my bills shot up high. I actually complained to them, if I’ve had all this done how come my bills so high? (29:00)

[Noise of agreement from a few participants]

#1: A lot of people do make the effort; double glazing loft conversions and everything. But I think most people have done double glazing over the thing but it hasn’t made the bills any cheaper.

#4: no
#1: So I think most people have that anyway


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