REYST

Potential for District Heating as a solution to Fuel Poverty in the UK

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Faculty of Earth Sciences
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60 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Sustainable Energy (REYST programme)

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Abstract

Only 4% of the UK heat market is supplied via district heating. The UK government is currently exploring the opportunities for installing district heating as a key climate change mitigation strategy due to the efficiencies that it provides. Additionally, district heating has the potential to play a significant role in the reduction of fuel poverty levels in the UK by achieving cost savings. Fuel poor households spend more than 10% of their overall income on their fuel. Targets to reduce fuel poverty are set by the UK government. Due to the nature of fuel poverty, properties in small communities and energy inefficient dwellings are often affected. This study describes two decision tools currently utilised for assessing district heating potential in the UK. Their qualities are tested against a small scale and retrospective scenario on the island of Westray, Orkney, Scotland which was investigated as part of this work. After research into Icelandic methods and experiences, this paper offers possible adjustments to these tools to assess small scale and retrospective scenarios for district heating. Further work is highlighted for the development of these tools, the correlations between Icelandic and UK experiences, and the relationship between the locations of fuel poverty and the opportunities for district heating.

I declare that this thesis is solely my own work and it has never previously been submitted for contribution towards an academic award

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Ingrid Michelle Austin

PREFACE

Whilst working amongst the Northern and Western Isles of Scotland with the local Energy Efficiency Advice Centre, I encountered the pressing issues of fuel poverty and the situation that people can find themselves in due to energy inefficient homes, low income and high fuel costs. This leads to a situation of fuel poverty, and by definition by the UK government, occurs when a household is spending more than 10% of its overall income on fuel. Due to the island location of these homes, fuel costs are higher than mainland costs. The cost savings that district heating could present to the householder - due to its efficiencies - is an interesting solution to consider for these circumstances, however such locations provide the added complications of small scale communities, and have often older, and energy inefficient properties. Despite these challenges, I was inspired to explore district heating expertise in Iceland with a view to its application in the UK especially since the UK government is now actively considering the potential for district heating in the UK to assist with achieving security of energy supply, cost reductions and carbon saving. District heating covers 90% of Iceland's heat market and there is interesting potential for district heating in the UK which currently only stands at 4% coverage of the heat market. The Reykjavik Energy Graduate School of Sustainable Systems (REYST) has provided the opportunity to explore this topic in Iceland, which is worthy of further discussion in the UK.

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ABBREVIATIONS AND GLOSSARY OF TERMS

Anaerobic Digestion: the controlled and enclosed fermentation process by which biogas can be extracted from organic feedstocks and used to drive a turbine to create electricity (Risbridger and Harcus, 2009)

Central Heating: a heating system providing heat to several rooms usually via a radiator system in an individual property; sometimes referred to as "wet central heating", making the differentiation from central heating provided by hot air via venting.

CHP: Combined heat and power

Coefficient of Performance (COP): often used in relation to heat pumps, it is the ratio between the output and input of a heat pump; the higher the output over the input, the more efficient the heat pump

Community Heating: term sometimes used to refer to district heating

District Energy Climate Summit: Event held at the beginning of November to bring together the district energy community in Copenhagen. The event raised the profile of the role of district energy in the fight against climate change, prior to the Convention of the Parties (COP) 15 due to make an agreement on the global climate change in early December 2009.

District Heating (DH): District heating is a system where the heat for an area is produced centrally, and hot water or steam is transported to the buildings through a network of pipes (DECC, 2009).

ESCo: Energy Services Company

Feed in Tariffs: incentive to encourage small scale low carbon electricity generation up to 5MW capacity (DECC, 2009)

Fuel Poverty: A household is described as being in a state of fuel poverty if they are spending 10% of their overall income on their energy

Heat Demand: the amount of heat in kW which is required by the properties on the district heating scheme

Heat Demand Density: the heat demand in kW / ha, helping to determine the viability of district heating

Internal Rate of Return (IRR): the interest rate at which the costs of an investment leads to the benefits of the investment

Net Present Value (NPV): an indicator of how much value an investment holds through the means of a discount rate

Primary Resource Factor (PRF): the ratio between the fossil energy supply, and the energy used in buildings (EHP, 2006)

Renewable Heat Strategy: proposed strategy in the UK for the establishment of heat generation by renewables; district heating would become an important heat delivery method (DECC, 2009)

Renewable Obligation Certificate (ROC): is a green certificate issued to an accredited generator for eligible renewable electricity generated within the United Kingdom and

supplied to customers within the United Kingdom by a licensed electricity supplier. One ROC is issued for each megawatt hour (MWh) of eligible renewable output generated which are available for large scale low carbon energy technologies (Ofgem, 2007).

Retrospective installation of district heating: In accordance with Baron *et al* (2008), this work uses this term to relate to the creation of district heating in an area that already has existing housing.

Rural: The official definition of *rural* from the Oxford English Dictionary is: "in, or of, the countryside; pastoral or agricultural as the opposite to urban" (Hanks, 1996). The definition of rural therefore gives the impression of a distinct distance from other settlements, which, in the context of this study, can be taken into account to show the possibility of extending existing heat networks in other locations. In this discussion, *rural*, is regardless of distance according to Baron *et al* (2008). It is noted that the community definitions of sparse village/ hamlet, classic village and small rural town are all applicable to the definition of "rural" which in part specifically refers to small scale district heating schemes.

SAP rating: Standard Assessment Procedure rating used for determining the energy performance of a building

Storage heating: domestic electric heating via means of heaters which thermally store the heat in bricks obtained via cheap electricity tariffs

Turnkey contract: An agreement under which a contractor agrees to complete a product so that it is ready for use when delivered to the other contracting party (McCracken, 2005)

ACKNOWLEDGMENTS

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1 INTRODUCTION

This work seeks to facilitate district heating deployment in the UK with particular consideration for the issue of fuel poverty. In the UK, a household is described as being in a state of fuel poverty if they spend more than 10% of their household income on their heating bills annually. Households in this position strive to achieve affordable warmth through the means of increased income, improved energy efficiency and reduced fuel costs. By addressing the issue of fuel costs there is the opportunity to reduce fuel poverty levels in the UK because this core element is otherwise out with the control of the householder. Fuel Poverty is therefore a driving issue behind this work.

Moreover, this work seeks to demonstrate the need for district heating in the UK and why it has not been prevalent in the past. It is extended to address the main issues of fuel poverty and energy security which the efficiencies provided by district heating can address. Traditionally, an individual house would have several heat sources in different rooms. Then Central Heating became the established and allowed heating throughout a home from one system. Now the principle has been extended to cover several houses being heated from a single energy source within a community - this is termed District Heating.

District heating is therefore, the means by which heat from a single energy source can be distributed amongst several building. It is generally considered that such methods of community heating are more environmentally friendly and provide a cheaper energy source to the consumer due to the efficiencies that it provides (Baron *et al*, 2008).

The central heat source heats up a supply of water which is then carried between properties via a network of pipes. The property must have a wet central heating system installed whereby either water is directly circulated from the mains system around the property's radiators, or the radiators have an enclosed water circulation system which is then heated by the passing water system via a heat exchanger.

There are various constraints regarding the distance between the properties and indeed how many can be included in the scheme. The pipe length and diameter can vary depending on the type of property that is being linked. These factors incorporating the economies of scale must be considered in light of the potential for district heating in different locations. The overall cost of a district heating scheme is also largely dependant on the generation source that is being utilised (Jensson, 2009).

Due to the fact that the piping has to be buried, it is greatly beneficial for it to be installed as part of a utility package for a housing development when services are installed prior to building. However, it may be economically viable to retrospectively install a distribution system for district heating. It is also acknowledged that there is the possibility to distribute heat via electric cables.

District heating has many benefits including the assistance in the reduction of fuel poverty due to the efficiency gains and resulting cost reductions. Globally, district heating has a significant part to play in long term greenhouse gas emission reductions along with considerations for energy efficiency, renewable resources which international decisions are considered in the recent discussion in Copenhagen, in order to assist the requirement to reduce reliance on fossil fuels and create a shift away from climate change. It is for this reason that there are significant considerations for district heating in the UK which could be used to assist various communities with fuel poverty levels and carbon reductions.

This thesis therefore attends to the variables of adjusting the fuel provision options in the UK as well as tackling the pros and cons of the government provisions and structure which currently both permits, and indeed prohibits the deployment of district heating in the UK at present. The current UK government interest in the development of district heating demonstrates the desire to increase the current proportion of district heating in the heat demand from its current level of only 4% penetration of the UK heat market (EHP, 2009). Specifically, this work strives to consider remote housing clusters where fuel poverty is rife due to the necessity to import fuel with its associated transportation costs. The efficiencies gained from district heating used in conjunction with a locally produced energy source would play its part in reducing energy costs as well as carbon reduction. It would also provide customers with a heating service void of dealing with individual heating systems which is desirable due to the improved security of supply to the properties. The many benefits of district heating must be considered in the long term as there are important economic considerations to ensure that it is truly viable.

It should be noted that this work refers to district heating specifically rather than the overall concept of district energy which encompasses district cooling as well.

2 BACKGROUND

District heating serves to address the pressing climate change issues of current times. During the period of this research, in December 2009, the countries of the world met in Copenhagen to discuss solutions to human induced climate change. Having met in Copenhagen one month previously, the community representing district heating and cooling, put forward their key policy requirements for the facilitation of district heating for contributing to the alleviation of climate change. The reason that district heating and cooling is a key component in the discussions towards climate change is due to the efficiencies that it brings. This therefore means that greater CO_2 reductions are achieved especially when district heating is coupled with renewable energy. Moreover, the use of combined heat and power (CHP) allows there to be a use for waste heat from power plants or industrial processes which would be distributed by district heating. District heating deserves more recognition; however the implementation of its required policy infrastructure must be addressed. The recommendations from the District Energy Climate Summit for facilitation of district heating implementation on the world stage are therefore summarised thus:

- To pay more attention to heating and cooling markets, as well as to consistently monitor and explicitly address these by international agreements, cooperation mechanisms and national legislation.
- To prioritise action in urban areas and foster the integration of urban functions (waste incineration, industrial production, transport, services, household demands etc.) by promoting systematic heating and cooling infrastructure planning.
- To acknowledge district heating and cooling as important tool for climate change mitigation and the importance of financing new heating and cooling networks as well as the upgrading of existing networks where appropriate.
- To promote the integration of supply side and demand side policies, by focusing on system efficiency in terms of primary energy rather than on final energy use.
- To reinforce international research programmes to provide a long-term framework for benchmarking and transfer of best knowledge / legislative practice in district heating and cooling (District Energy Climate Summit, 2009).

It is a consideration that district heating, as a long term energy solution could alleviate fuel poverty (Baron *et al*, 2008). Projections of domestic energy prices for the UK show that this particular issue is uncontrollable. It is a variable which is out with the control of the domestic householder and its contribution to fuel poverty is inevitable. To address the particular issue of the cost of fuel it is necessary to seek cost efficiencies. End user efficiencies are one consideration, however the efficiencies that are possible through sharing the resource and therefore the efficiencies derived from using distributed heating, have the potential to reduce energy costs to the customer. This could be a major step in tackling fuel poverty. The full issue of fuel poverty shall be described later. Figure 1 highlights the rising energy costs that are contributing to fuel poverty in the UK. It should be noted that while this study concentrates on the merits of district heating relative to this issue, other energy saving methods are available. These can be achieved by individual users and are additional to district heating as considered in this work.

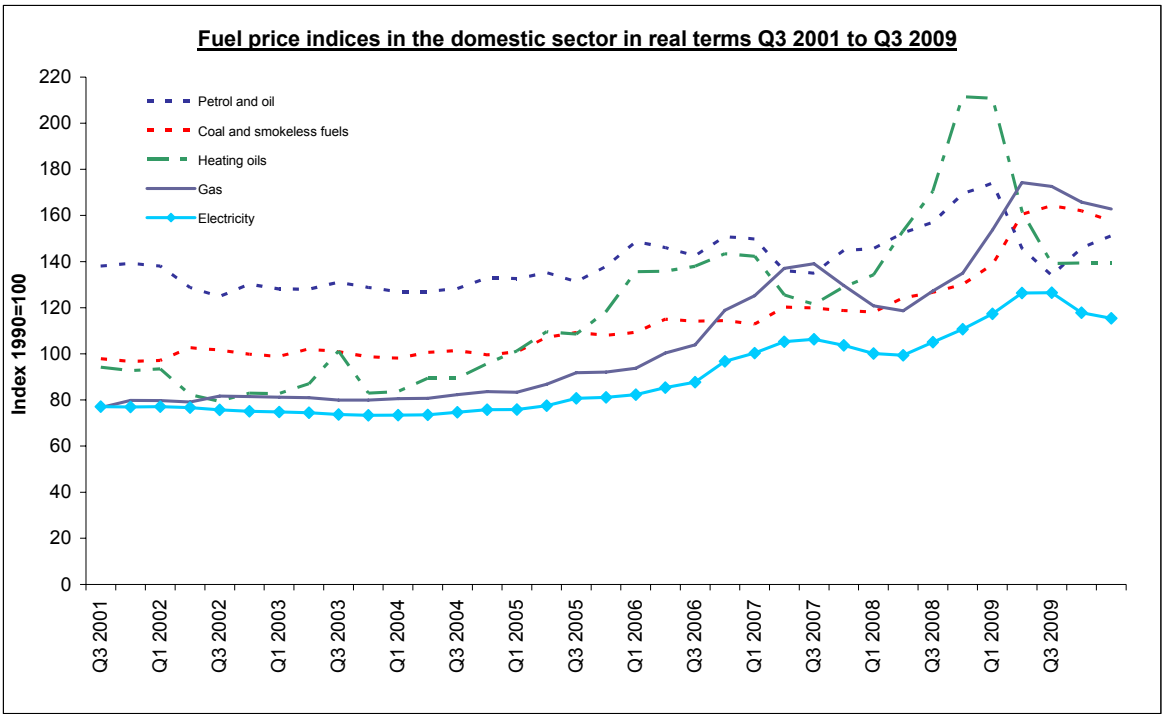

Figure 1: Rising Fuel Prices in the UK to 26th November 09 (DECC, 2009e)

2.1 Global Perspective on Historical Development of District Heating

The American Engineer Birdsill Holly is considered to be the founder of district heating and was involved in the first commercially successful scheme at Lockport, New York in 1877. This founded the Holly Steam combination company. The business and the rights to Holly's patent were eventually sold to the American District Steam Company, who continued operation for the next 80 years selling systems throughout the world (IDEA, 2009).

The average market share of district heating in Europe is 10% and the market share in north, central and Eastern Europe is 50% or more (Euroheat and Power, 2009).

Greenhouse gas emission targets worldwide are becoming critical and district heating can have a part to play in the reduction in CO_2 levels. The European Commission states that there could be a reduction in CO_2 by using district heating throughout the 32 European countries of 400 million tons annually (Euroheat and Power, 2009). Regardless of energy source, this represents the savings brought by the efficiencies of district heating. This is the fact that is now at the forefront of the minds of the decision makers. It is however, also possible to address the CO_2 life cycle through the use of primary resource factor (PRF) which defines the ratio between the fossil energy supply, and the energy used in buildings (EHP, 2006). This tool therefore considers the efficiencies gained as well as the energy sources which could be fossil fuels, renewables or waste heat (Euroheat & Power, 2009a). This can be used as part of a technique to allow an all round comparison between heating options throughout the whole energy chain. The lower the PRF of a technology, the lower its contribution to fossil fuel emissions as part of the overall process. The graph below (figure 2) shows the variations in the PRF for a variety of energy pathways.

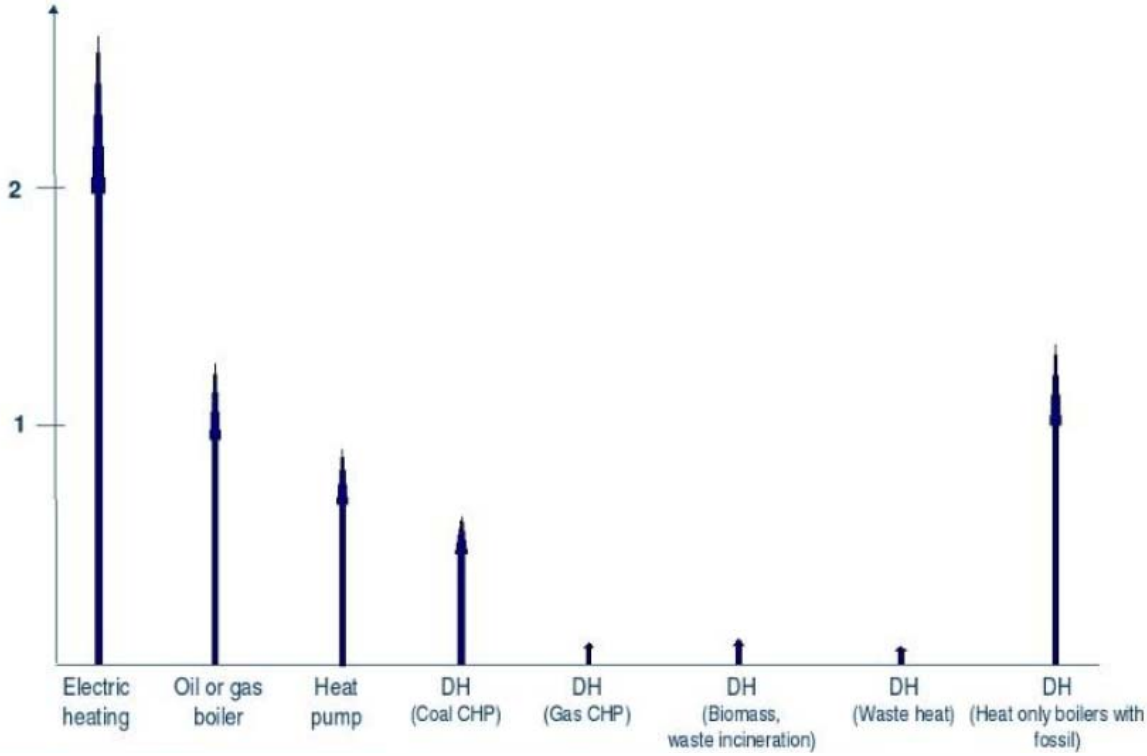

Figure 2: Primary Resource Factors for various heating options showing that the use of district heating (DH) gives a relatively low primary resource factor in comparison to other technologies (EHP, 2006)

District heating is a heat delivery method which requires commitment in policies in order to translate it into the infrastructure planning. Historically, district heating has not always been an attraction because the liberalization markets have focused on short term return on capital and therefore the long-term commitment for district heating has not been appealing (Euroheat and Power, 2009). It is a question of investment in district heating rather than a lack of energy sources. A key determinant of the progress that district energy makes is the consideration of the use of waste heat (Euroheat and Power, 2009).

The long term planning required for the infrastructure and investment for district heating has not always been given priority. Each country has its own agenda for its installation, and has achieved it in different ways. The European regulations are now encouraging this more, and the European Union set the Energy and Climate Change package in December 2008 resulting with the so called "20/20/20 targets". It is recognized that the district heating and cooling sectors will have huge potential for contributing to these targets (Jungbauer, 2009).

There are various ways in which these manifest themselves into national regulations. The UK government for example, is considering new regulations which are also good for working in conjunction with renewables, namely the Renewable Heat Strategy consultation. Where a quota of renewable generation is stipulated for the provision of heat, the use of district heating is then an ideal delivery method.

The following figure 3 shows the use of district heating in various European countries.

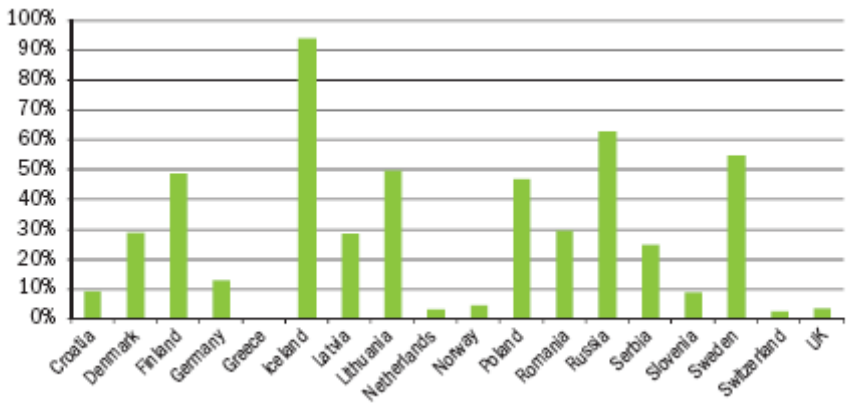

Figure 3: Proportion of the heat market that district heating serves for selected countries (Jungbauer, 2009)

It is noted that figure 4 shows that Iceland has high penetration of district heating at around 90% and comparably the UK has a minimal investment in district heating at only 4% (Smith, 2009). These comparisons are mainly due to the fact that Iceland has the use of the geothermal resources which are very well suited to district heating. The UK, on the other hand, has traditionally used individual heating systems encouraged by different energy policy priorities. The range of countries listed are those which are of colder climates and therefore in the heat market. Mediterranean countries, for example, don't feature in this list.

The International Energy Agency has advocated district heating and cooling in their research annexes since 1983. They promote the benefits of district heating by increasing knowledge about the use of distributed energy (IEA, 2009). However, government policies around the world, have not always favoured district heating as an energy investment since it is very much a local, and community solution. A local solution that is to the benefit of a community is not encouraged by the general policies that prevail under the liberalized markets current in the UK. The alternative of a power plant project would otherwise have the capital and the ability to absorb losses more readily than if the energy was provided at a local level (IEA, 2002). Local solutions such as district heating need to be accessible through the appropriate policies that would introduce attractive incentives for local schemes with an appropriate financial support mechanism to cover initial costs. This would increase the potential for district energy in these circumstances for the benefit of the community and the wider government goals that would ultimately allow district heating to have a significant effect on energy saving, country by country. This must be facilitated by an acknowledgement of district heating and cooling in various layers of policy (IEA, 2002).

2.2 Advantages to District Heating

International studies show that district heating prices are lower than prices for individual systems using natural gas – however this is dependent on the locality and its circumstances (Euroheat and Power, 2009). This is primarily due to the efficiencies in the system whereby the energy required to heat 1 home individually can be delivered via district heating to 3 homes to meet the same energy demand in each (Bjorn *et al*, 2009).

The following table 1 summarises some of the benefits of district heating.

Table 1: Benefits of District Energy (IDEA, 2009)

Benefits	**Reasoning**
Energy efficient	Steam or water arriving at the customer is ready to use. It is 100% efficient compared with individual systems where natural gas or oil is burned which would only be 80% efficient. There is also the opportunity to use combined heat and power which is making use of waste heat from power stations or other industrial processes.
Environmentally sound	Air pollution, if any, is kept to the site of the plant
Easy to use and operate	Customers do not have to deal with fuel and system maintenance as it is centrally managed
Reliable	The efficient management system ensures the reliability of the system
Comfortable and convenient	Individual control is still possible
Lower life cycle costs	Where boilers are not needed in individual buildings therefore the maintenance is not needed on an individual basis
Design flexibility	Local community areas can be used differently since there is not the need for plant in each building
Social wellbeing	The provision of warmth and cooling facilities are able to provide customers with the benefits that are wide reaching
Low cost to consumer	On average, district energy prices are lower than natural gas prices, but prices vary and are subject to local resources

The use of district heating as a heat delivery method, with a variety of energy sources, makes it a versatile technology with the benefits of energy saving and greenhouse gas emission reduction. Renewables, waste heat and the use of CHP are the important energy sources which enhance the opportunities for the use of district heating.

Emphasis on the development of CHP plus the use of waste heat from industrial processes should not be underestimated and this can only be facilitated by the development of district heating. In the UK, for example, it is estimated that a loss of thermal energy of 2000MWh is occurring for every 1000 MWh produced by a coal or nuclear power plant due to the fact that it is only 35% efficient (ICE, 2009).

2.2.1 Comparison of individual systems and district systems

District heating is often regarded as providing an opportunity for cheaper energy costs for the consumer despite the high capital implementation costs especially in a retrofit scenario.

An example of the options for heating a community of 500 properties is shown in the graph shown in figure 4. It is shown that there is a higher cost of district heating at the initial installation at a cost of approximately £3m. A lifetime cost for these options can be

calculated using the data for the capital costs, maintenance costs and replacement costs and revenue streams, this gives a value for the whole life costings. Net Present Value (NPV) of the calculations is given to show the future costs and revenue streams discounted back to current values using the discount rate of 3.5% and a lifetime of 25 years. The lifetime costs are then shown to be £4m, rather than £6m, as it is for other options. The "do minimum" scenario suggests that the option of continuing with a (non-specified) existing system and not installing a new system is considered. It is shown that the existing heating system would therefore incur increasing running costs over time to match the expensive costs of electric or gas heating. This shows that the benefits of district heating are best demonstrated when the whole lifetime costs are taken into account, concluding that they are less when compared with the other options of storage heating or individual gas boilers (EST, 2003). This serves as the argument for investors like local authorities to consider district heating installations rather than any other alternatives for housing schemes.

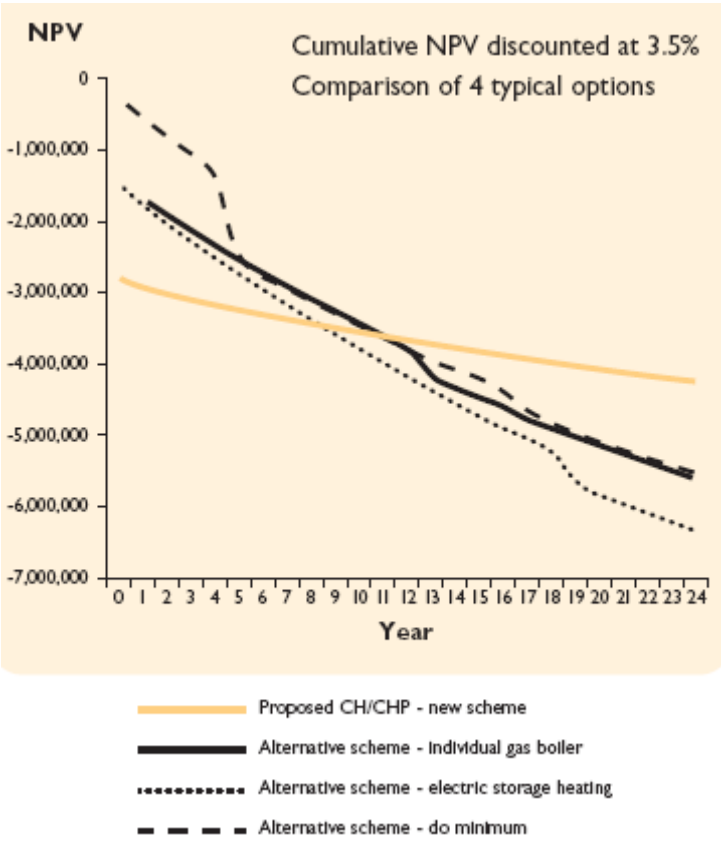

Figure 4: Net Present Value (NPV) showing the Lifetime Costs of Community Heating (CH) / CHP (EST, 2003)

It can also be considered that individual schemes are inferior to community schemes when there are fossil fuels to consider.

Individual customer costs would ultimately reduce in the long run as capital cost of the district heating scheme are paid off (Ragnarsson, 2004). This outcome of lower costs is favourable for fuel- poor households.

2.3 Disadvantages to District Heating

Whilst there are many benefits to district heating there are also some disadvantages which should be taken into account by policy makers. Such disadvantages are:

- High investment costs due to the network of piping required
- Retrospective installations are challenging
- Heat loss in distribution networks
- Requirement to have formal establishment to run the system

The high investment cost, as shown in figure 4, is a main drawback to district heating installations. The benefits for the long term investment must be recognised and funding must be achievable in order for it to go ahead. Retrospective installations can prove to be more costly and have the requirement to disrupt traffic management in established towns and cities as roads must be dug up. There is also the requirement for householders to be willing to make use of the new system in order to make it viable. They could also have to consider changing their heating system in order to be compatible with the district heating system for the neighbourhood. There may also be the requirement to address energy demand by upgrading insulation and thus improving the energy efficiency of the properties. Additionally, some heat losses would need to be considered in the design of the piping network however these could be minimal. Lastly, it is also required to have an overarching management structure to maintain and run the system, and attend to invoicing for example. This would require staff to provide this service, which could be associated with an energy services company or local authority, and could be funded through the revenue from the heating charges.

3 EXPERIENCE OF DISTRICT HEATING IN THE UK

Heat accounts for 49% of the overall energy demand of the UK (ICE, 2009). This is therefore a significant contribution to the CO_2 emissions from heating requirements alone. District heating has been used as a heat delivery method in the UK since the 1950s (Davies and Woods, 2009) however it has only achieved 4% penetration of the heat market (Smith, 2009). There are some successes and some failures of district heating in the UK. A subsection follows which outlines a summary of the existing schemes in the UK which serve as success stories and acts as inspiration for the continued use of district heating in the UK.

The UK has not historically had a heat law or a district heating law unlike Denmark, for example, which has had a district heating law since 1997 (Euroheat and Power, 2005). Table 2 shows the current policies pertaining to energy. The Combined heat and power association's (CHPA) promotes the use of CHP and district heating. Government policies outlined by the 2005 Handbook to District Heating and Cooling, show that the Energy white paper of 2003 dedicated a strategy for CHP to 2010 in April 2004. This was administered through the UK Government's Community Energy Programme in the UK from 2001 until 2006 which was delivered by the Energy Saving Trust and was an influential programme for encouraging community heating projects in the UK. This was to see the achievement of 130MWe of new CHP capacity in the district heating sector by 2010, however the programme ceased before the targets were fully realised.

Measures included in the strategy were:

- Revision of building regulations on energy efficiency to increase energy efficiency and incentivise CHP
- The CHP Quality Assurance Programme was set up (CHPQA)
- Obligation was set upon the electricity suppliers to promote energy savings by offering energy efficiency measures including CHP
- A target of 15% was set for the introduction of CHP in government buildings by 2010
- Planning Guidance for regional and local planning authorities stipulates that greater use of energy efficiency, district heating, CHP, renewables should be used in all new developments (EHP, 2005)

Table 2: Summary of policies in the UK (EHP, 2005)

Government Incentive	Description
UK Energy White Paper (2003)	UK's Climate Change Programme set a 10GWe CHP target for 2010
Home Energy Conservation Act (HECA)	Requires local authorities to achieve a reduction in home energy consumption of 20%. Local authorities report on their progress and it is then noted that CHP and district heating are the most helpful methods of achieving these targets.
Fuel Poverty Strategy	Householders paying more than 10% of their household income on energy are classed as "fuel poor". This strategy is dedicated to alleviating fuel poverty by addressing energy efficiency, maximising income and reducing fuel costs. It is recognised that there is a need for the reduction in fuel costs and the introduction of CHP and district heating is recognised as a key method.

3.1 UK Progress

There are current political considerations for district heating as a heat delivery method in the UK. As also acknowledged by Rytoft and Stromberg (2009) and Hawkey (2009), there is increased interest in district heating from the UK government.

These policies and changes in the UK sector are shown to be a persuasive diversion from the previous path of energy policies. The various drivers that are stimulating this change towards the use of district heating appear to be the high targets set regarding CO_2 emission reduction, as well as the prevalence of fuel poverty. As part of this, there are now strategic developments for heat supply. The UK Government is also a signatory to the UN Framework Convention on Climate Change (UNFCCC), whereby there is a legal requirement to achieve a reduction in greenhouse gases of 12.5% against base year levels by the period 2008-2012 which amounts to 682 Mt CO_2 equivalents. The proposed cap and trade emissions scheme promises that the consumption of heat and the imports of heat by participants would be exempt if it was derived from CHP. This would therefore incentivise the uptake of heat from CHP and therefore the requirement for DHC in the heat delivery market (Kerr, 2009).

The UK government has recently carried out a consultation regarding proposals for a Heat and Energy Saving Strategy (HESS). Consultation responses welcome district heating as an integral part of this (DECC, 2009b). Furthermore, the government has initiated additional studies regarding the feasibility of district heating in the UK, namely with regard to the potential and the cost of implementation (Davies and Woods, 2009). It is concluded that the heat density threshold, which is likely to be cost effective at an Internal Rate of Return of 6%, is 3000 kW/km^2. This would account for 20% of the overall heat demand of the UK (Davies and Woods, 2009).

There was a call for evidence on heat from the BERR (BERR, 2008) which was an important step in the process to determine what the requirements were for a policy on heat.

It is acknowledged that there are many facades to the position of district heating in the UK. A recent study by Hawkey (2009), employed the use of a Technological Innovation Systems (TIS) approach (Bergek *et al*, 2008; and Hekkert *et al*, 2007) to determine the current prospects for district heating in the UK. By inputting various factors at different levels of local, national and institutions, Hawkey (2009) outlines the various overlapping functions of the TIS. In summary, using this approach Hawkey (2009) determines that local authorities have a crucial part to play in deploying district heating throughout the UK. This falls into a number of areas especially regarding the planning policy responsibilities that they have, as well as the potential that they have for the undertaking of heat mapping that is possible for them to carry out for their localities. There is also the opportunity to develop Energy Services Companies (ESCos) in a variety of forms which local authorities are in the position to facilitate or host. Although as Hawkey (2009) notes current uptake of such ideas is sporadic, there are good examples of this practice in Aberdeen, Scotland for example. It is also highlighted that the presence of the liberalised market is a disincentive for private investors to dedicate funds to district heating as there are too many opportunities to connect to another option thereby reducing the heat demand required to justify a district heating system (Hawkey, 2009).

3.2 Outline of Two Influential Schemes in the UK

3.2.1 Lerwick District Heating Scheme, Shetland Islands, Scotland, UK

The Shetland Islands, 100 miles off the north of Scotland, are host to the most northerly district heating scheme in the United Kingdom. The town of Lerwick has a population of 8000 people. The following summarises the key points about the scheme:

- Operated by: Shetland Heat Energy and Power Ltd (SHEAP)
- Heat source: waste incineration
- Size: about 900 properties are connected (domestic and commercial combined)

The scheme has been growing since 1998 and serves domestic and non-domestic customers. Of the 960 customers there are 110 non-domestic customers which consume 62% of the total heat produced. These customers include schools, hospital, hotels and industry. The original district heating scheme design was by Danish Consultants, COWI (Martin, 2009).

The heat source is from the Waste to Energy Plant which annually diverts 22 000 tonnes of waste comprising, a) domestic waste from the waste stream for Shetland and Orkney, and b) commercial waste from the oil industry. This contributes towards satisfying the landfill reduction law in the UK/Scotland; the EU Landfill Directive. The incineration of waste is governed by the standards in the Waste Incineration Directive (WID) which is regulated by Scottish Environmental Protection Agency. The plant was carefully designed with the emission control in mind, and has met the emission requirements since its inception. The diversion from the waste stream is beneficial for Shetland Islands Council's landfill quota which is set nationally.

In 2005-2006, the following waste destinations were achieved:

Energy recovery	66%
Recycling	10%
Landfill	24%

As the landfill tax increases, it is beneficial to pursue further reduction of these landfill figures. The landfill tax in 2005/6 was £18 / ton and is due to reach £35 / ton in 2011/12 (SHEAP, 2006). The cost of transporting the energy source is also valuable for comparison. The cost to Orkney for shipping its waste to Shetland is £155/tonne including gate fees (Risbridger, 2009). It should also be acknowledged that CO_2 emissions also result from this process.

In April 2008, there were about 900 properties connected to the scheme, and the limits of the scheme are now becoming apparent with the requirement to provide an additional heat source. Water storage towers are being used, which have increased capacity by another 15MW at the back up boiler plant. Further district heating extensions are therefore possible and figure 5 shows recent installations in Lerwick during summer 2009.

Figure 5: District heating pipeline installation in Lerwick, Shetland Islands (Photo: Ingrid Austin)

The process of the scheme can be described as follows. The incinerator produces 6.3MW and 115°C water leaves the plant. Oil fired boiler is also used to supplement the thermal demand and is rated at 14.5MW. At the customer, heat exchangers are used to transfer the heat into the customer's wet radiator systems. Return temperatures for the water is 55°C and the flow contributes to thermal stores before circulating again.

Part of the success of the scheme is in its provision of a subsidised installation cost which makes it attractive to the householder compared to oil fired or electric storage heating. With the lack of natural gas in the islands, these are the only other options available to island residents. The installation of the required piping for the householder is approximately £3000. This is subsidised, and therefore reduced to £500 per household. This is similar to the cost of installing storage heating to a Shetland household, making it a competing option. A cost summary of the scheme is shown in figure 6 and the appeal of the cost reductions achieved for the customer is shown in figure 7.

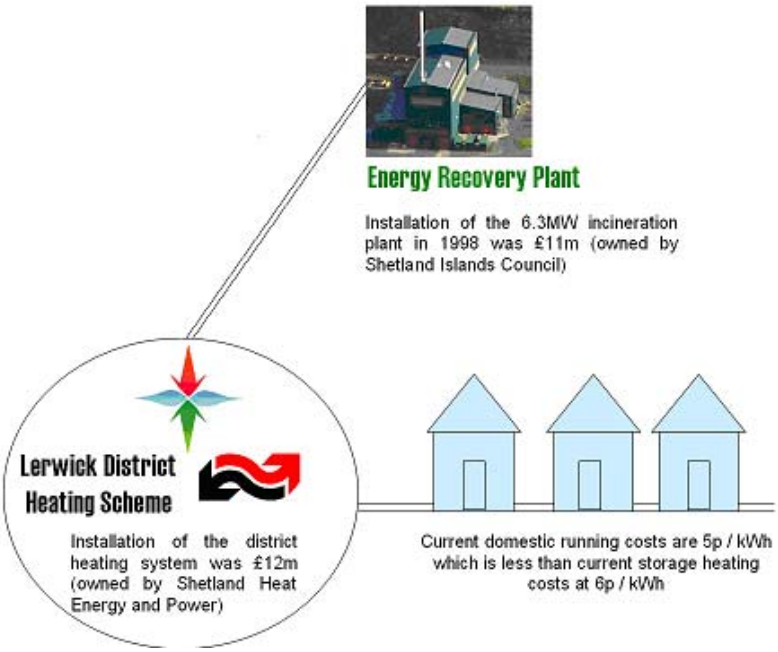

Figure 6: Lerwick District Heating Scheme with installation and running costs (Martin, 2009)

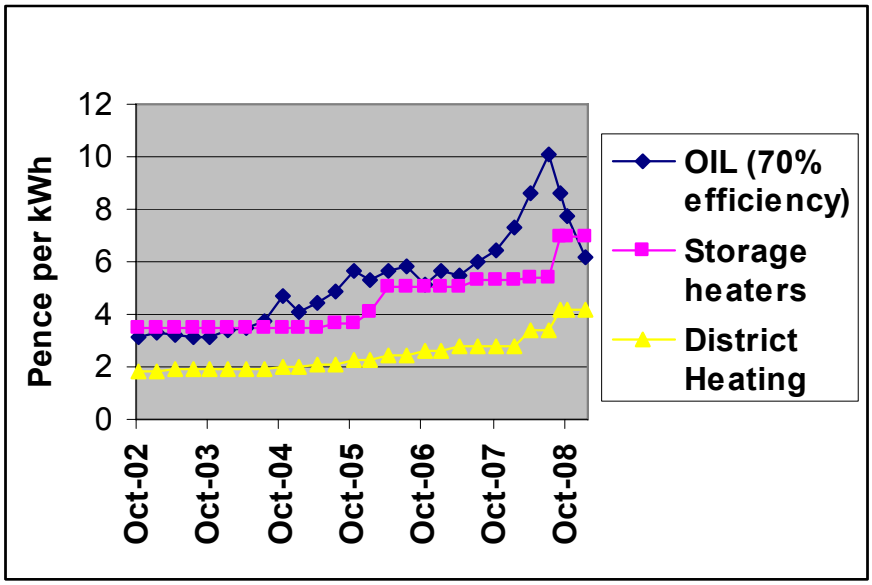

Figure 7: Heating cost comparisons in Lerwick, Shetland showing the lower district heating costs to customers to December 2008 (Martin, 2009)

3.2.2 Aberdeen City Council, Scotland, UK

Aberdeen City Council used of district heating in tackling fuel poverty levels in their high rise blocks of flats of which 70% of tenants were in fuel poverty. There are 4500 flats in 59 multi storey blocks, and due to high energy costs and poor energy efficiency of the building fabric, Aberdeen City Council found that their residential block of flats were prompting situations of fuel poverty for residents. Under the obligations of the UK Fuel Poverty Strategy, the local authority has since connected some residential high rise properties to district heating which obtains its heat from combined heat and power (CHP) using sustainable energy.

These were installed in order to address several issues:

- Expensive electric heating which could be reduced by half for the tenants
- CO_2 emissions could be reduced by 40%
- Warmer properties were to be achieved

The costs that tenants had before were £18.48 per week and after the successful installation of CHP they were reduced to £7.44 per week. The total cost of the scheme was £1.6 million of which £730 000 was supplied by the UK Government's Community Energy Programme which encouraged district heating at the time of installation (ACC & AHP, 2009). Further examples of good practice from Aberdeen are exemplified in their use of an energy services company for the operation of the district heating scheme – this is found in Appendix 4.

3.3 The Appeal to adopt further District Heating in UK

Further to the benefits as outline earlier, this section highlights the argument for district heating in relation to the UK. Historically, political restrictions have hampered the development of district heating in the UK. Since the 1970s, the security of North Sea oil and gas has not incentivised the development of district heating in the UK. In other countries such as Denmark, the requirement for imported energy was reduced where primary energy efficiency could be improved by using district heating. The technology is available as can be demonstrated throughout the world; however it is the economics of such investment that restricts how the implementation of district heating could be realized in the UK. This is especially with regard to the requirement for retrospective installation in UK towns and cities.

3.3.1 Existing Properties in the UK

Any comparison between requirements for heat demand between new build and existing stock must consider the energy efficiency of the properties. The quality of the existing building stock means that it is less energy efficient than new housing stock and this contributes to levels of fuel poverty. This in turn, reflects the heat demand density that results, and could therefore increase the demand from the district heating scheme that is required for existing stock; and therefore the necessity to consider retrospective installations of district heating. According to EST (2007), the UK has the oldest housing stock in the developed world, with 8.5 million properties that are over 60 years old. There is a need to invest in improving existing properties as the current rate of housing stock replacement is minimal and actually requires properties to last for 1000 years at current rates (EST, 2007). This therefore presents a challenge for the improvement of the UK's housing stock and their energy requirements.

It is therefore ultimately necessary to consider the reduction of the demand from existing properties. Methods for reducing the energy consumption of properties are to be found in simple low cost or no cost measures as promoted by the Energy Saving Trust in the UK which is outlined in appendix 3. It is also a consideration that the government incentivises the reduction in carbons savings which district heating can play a part in achieving; however it is acknowledged that new build schemes would have less of a contribution to carbon savings simply due to the increased energy efficiency met, as they comply with newer building regulations. Addressing the energy demand is important, prior to the design of district heating and the consideration of the energy source.

3.3.2 Individual Heating Options in the UK

Individual heating options in the remotes parts of the UK include oil heating, electric storage heating as well as the use of heat pumps. Heat pumps offer a good Coefficient of Performance (COP) rating and therefore a helpful contribution to reducing the cost of energy for a household. The EST has carried out a pilot study in which island locations were included, in order to ascertain the effects of heat pump installations on rural, fuel poor households. This option serves as an alternative in seeking solutions to fuel poverty. This Scottish Renewables Heating Pilot (Clear Plan UK, 2008) concluded that the use of heat pumps were beneficial in rural circumstances which are off-gas.

There is of course the high installation cost associated with the installation on heat pumps, which should be taken into account however the running costs are the main consideration in the investment. This high initial cost is however, not always an option for fuel-poor households that would therefore be required to source the funding from elsewhere or indeed from a suitable government incentive. Government incentive for the installation of heat pumps was previously offered under a grant funding scheme administered on behalf on the Scottish Government by the Energy Saving Trust, and was referred to in Scotland as the Scottish Community and Householder Renewables Grant (SCHRI), and in England, as the Low Carbon Buildings Programme. These grant funding opportunities have now been superseded by the new government schemes which cover UK as shown in table 3.

Table 3: Grant funding available in the UK (EST, 2009)

Country	**Assistance Package**
Scotland	Energy Assistance Package
England	Warm Front
Northern Ireland	Warm Homes
Wales	Home Energy Efficiency Scheme

Government assistance of up to £3500 per home is available to properties on benefits under certain criteria in order to assist with energy efficiency measures and heating systems. Even with assistance from such scheme it is not always possible to attain an affordable heating alternative. The previous scheme was beneficial as it was made accessible to the majority and encouraged specifically the inclusion of renewables for individual properties with the allocation of grant funding of up to 30%. However, this was a meagre contribution to what is sometimes a high cost. The added advantage of government incentives are beneficial to the long term investment in the technology which brings the payback time down and make the option more attractive.

3.3.3 Combined Heat and Power Opportunities

District heating can be used for distribution of the excess heat that is created in many industrial processes. Combined heat and power (CHP) has the potential to make more use of heat already produced from industrial processes via distribution by district heating. This is what is currently proposed to the UK government in discussions regarding the effective use of heat in the UK (ICE, 2009). There are many potential uses for heat in the UK from industrial processes. However it is highlighted that coal fired power stations that could provide heat via district heating systems which would benefit homes and businesses are not suitably located (ICE, 2009).

3.4 Government Incentive

The government incentive for the inclusion of district energy in the UK stems from 3 main policy drivers through the increased energy efficiency provided by district heating. This addresses the drive for reduction in fuel poverty, reduction in CO_2 emissions as well as increased security of supply. As noted previously, it is observed by Rytoft and Stromberg (2009: 103), that there is an increased interest in small-scale district heating schemes from the UK government.

The UK Government has recently set high targets for the adoption of renewable technologies and carbon reduction targets. Since heat energy in the UK for homes, business and industries accounts for 49% of the energy demand significant changes are required for the efficient use of heat and the production of heat energy in order to contribute to the government targets. District heating can improve the efficiency of energy use and can be the distribution method for a variety of energy sources. Despite this potential it is noted that the current use of district heating is minimal compared to many other countries and the market penetration in the UK is only currently 4% of the overall heat market (Smith, 2009).

Despite the lack of district heating in the UK historically, there is now an increased incentive which reignites the interest in developing district heating in the UK as a significant heat distribution method. During the time of writing in 2009, the UK government has carried out a consultation regarding proposals for a Heat and Energy Saving Strategy (HESS). Prior to the full consultation report and strategy development, early comments are available regarding the consultation responses. It is noted that district heating is a proposal in the strategy welcomed by various agencies (DECC, 2009b). Furthermore, the government has initiated additional reports regarding the feasibility of district heating in the UK where appropriate, namely with regard to the potential and the cost of implementation (Davies and Wood, 2009). This highlights the renewed consideration for district heating as a heat delivery method in the UK.

The heat demand alone is 49% of the overall energy demand for the UK. This is why the government is now considering the introduction of a renewable heat strategy to tackle this demand and its corresponding carbon emissions. In addition, the Scottish government specifically is advised to include the development of district heating in the wider heat strategy considerations and the Scottish Renewable Heat Strategy (DECC, 2009).

Additionally, current proposals such as **Feed in Tariffs** will incentivise the installation of small scale renewables and could play their part to achieve district heating for rural areas of the UK. Feed in tariffs offer a payment per energy unit generated at an agreed tariff depending on the size of the installation. This new proposal is designed to encourage small scale developments (under 5MW) and is a diversification from the original Renewable Obligation Certificate Scheme which will now specifically incentivise larger projects (DECC, 2009e). Table 4 shows the feed in tariffs for photovoltaic cells and table 5 shows the feed in tariffs for wind turbines at different scales. This shows that there is greater incentive for smaller installations. There are different tariffs for the other renewables technologies.

Table 4: Proposed feed in tariffs for Photovoltaic cells which encourage the small scale systems (Element Energy, 2009)

Size	Initial tariff (£/MWh)
Domestic	£400
4 - 10 kW	£380
10 -100 kW	£250
100 - 5000 kW	£250

Table 5: Proposed feed in tariffs for Wind Turbines, encouraging small scale systems (Element Energy. 2009)

Size	Initial Tariff £/ MWh
Micro	£300
1 - 15 kW	£300
15 - 50 kW	£250
50 - 250 kW	£200
250 - 500 kW	£180
500 - 3000 kW	£143

Furthermore, the prospect of the newly proposed Renewable Heat Incentives are also promising for the use of renewable heat in conjunction with district heating at all scales of community (DECC, 2009g).

In identifying that there is a need for district heating in the UK - for the benefit of energy saving and carbon reduction. If district heating is to be pursued by the UK government, there is the need to address its implementation. It is therefore necessary to define an identification method. This work therefore serves to address this required mechanism and proposes a decision tool to facilitate the development of district heating in the UK. This needs to be applicable to new build sites as well as the retrospective installation of district heating, at a variety of community scales.

4 HOW DISTRICT HEATING IS APPROACHED

In order to design, and determine the feasibility for a district heating scheme, it is necessary to firstly determine whether there is another obvious heating option already in the vicinity. For example, if there is a gas network available, there would be a cheap heating source passing the properties which would be beneficial for the cost to the householders. However, it should be acknowledged that there may be other incentives like tackling landfill whereby incineration may be a desirable option and heating as a by-product. If district heating system is a serious option the full assessment process can begin. As described in figure 8, the energy demand for the scheme can be determined by identifying the properties that are in a potential client group. That determined, it is then necessary to identify the energy supply that can be used for the scheme from the resources available to the locality. The energy supply and demand must then be analysed to determine if the supply can meet the demand. It may be necessary to use a form of thermal storage to act as a buffer at times when there may be excess supply or reduced demand. The economic viability of a district heating scheme is achieved thereafter, by determining the cost of distribution from a central source versus the cost of individual heating systems. The government's financial incentives which are discussed in section 3.4 are significant as they provide a real difference when the work would otherwise be inappropriate or non-viable. In the decision making flow chart, it is necessary to show the points at which they are influential. Figure 8 outlines the design and feasibility considerations for the design of district heating in rural areas. This therefore makes the assumption that there is no access to a gas network which would therefore require the provision of alternative cheap heating solutions.

The decision making process requires that at different points the decision to proceed or alter the plans should be considered. There is particular importance in the considerations for district heating due to the fact that there are many variables, which all have to work together to ensure that the costs arrived at are viable. A sensitivity analysis is therefore a valuable tool in accounting for the variations that could occur and hence analysing the effect on the final cost. Variables such as the interest rate, energy demand, lifetime of the system, requirement to replace existing heating systems should all be tested to reveal their effect on the final cost to the customer, which ultimately determines the cost that the customer pays for their heating and can be compared to the other options available to the town.

The overall collection of decision making considerations is included in figure 8. This figure shows that the energy source and energy demand are initially considered at the same level however they should not be considered to have equal weighting. Indeed these two important stages are to be considered at similar points in the process however, there are certain considerations that are necessary for the demand characteristics which would determine whether or not a district heating scheme would be possible prior to the consideration of the energy supply. Factors such as distance between the properties, and overall heat demand density are key determinants for the distribution system's feasibility. It should therefore be noted that the energy demand should be prioritised when the sole purpose is to determine district heating suitability. It should also be noted however, that this process flow chart is easily adapted in cases where district heating could be deemed unsuitable in a community. In those circumstances, more remote properties could consider the merits of the available energy sources on an individual basis without the consideration for district heating.

Once established, there are various ways in which district heating schemes can be managed and there are the main methods by which they can be administered. An Energy Services Company can be established in order to administer the day-to-day running of the district heating scheme. Various business models can be used as the overall framework for this, however it is noted that there is the appropriate application of the social enterprise model, which lends itself to the nature of the community ethos of a district heating scheme. Appendix 4 describes the approach taken for the district heating scheme for Aberdeen City Council and the benefits gained by using the social enterprise model.

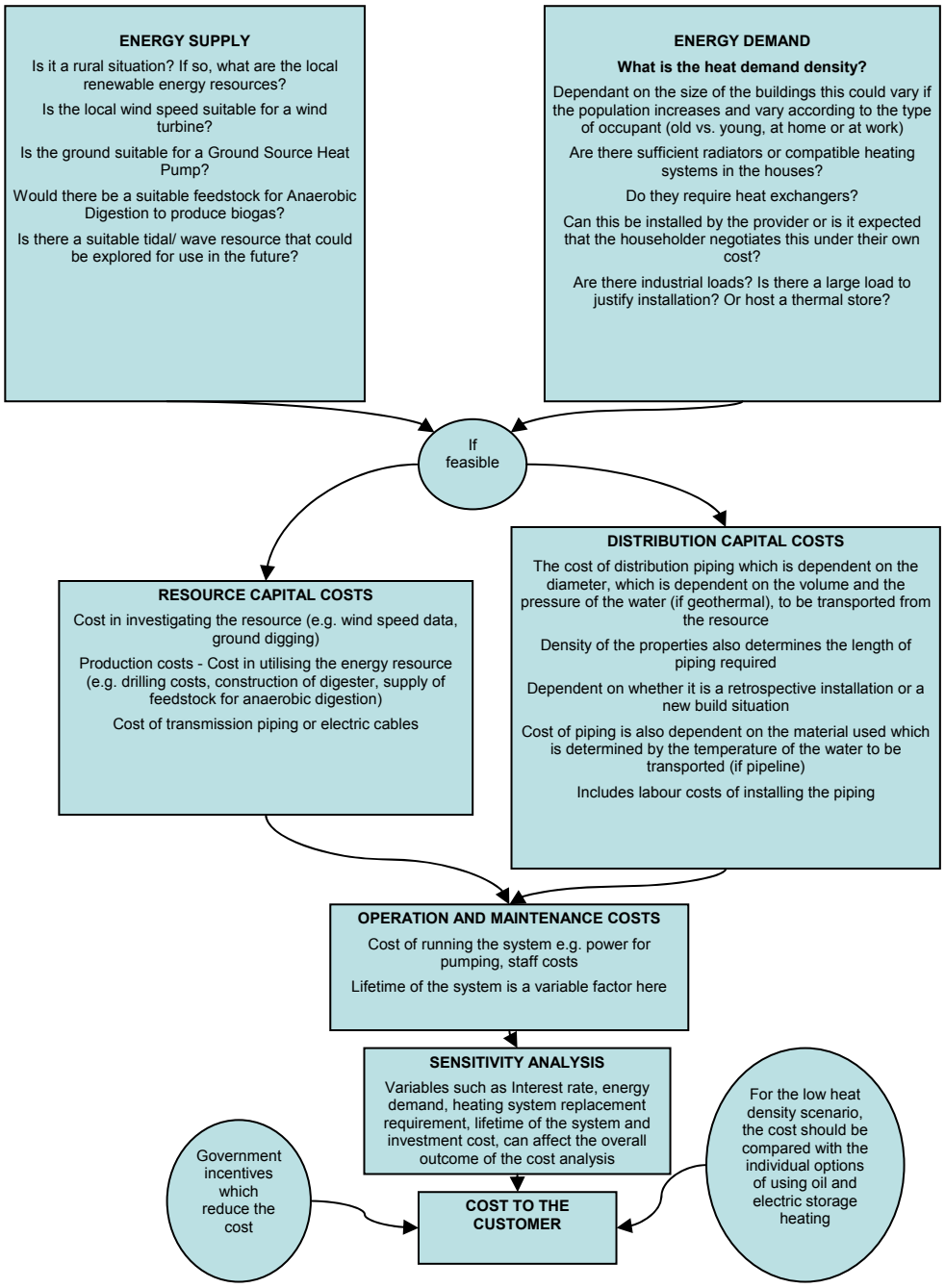

Figure 8: Design Process for District heating in rural areas away from access to gas networks (adapted from Ragnarsson 2009, Gunnarsdottir 2009, Elíasson et al 2003, Parsons Brinkerhoff, 2009)

4.1 Distribution Networks Cost Variations between Iceland & UK

It is found that there are a variety of cost variations for distribution systems between Iceland and the UK. Table 6 shows the costs for the UK

Table 6: UK District Heating Piping Costs

		Density (dwellings per hectare)	Pipe Length per dwelling (m)	Cost per dwelling (GBP)	Density x Cost gives cost per Ha (GBP)	Cost per Ha (ISK)	Variable factor from Icelandic calculation for cost of DH per Ha
Dodds (2008) as cited by Baron *et al* (2008)	High rise apartments	240	6.75	2500	600,000	120,000,000	20.2
	medium rise apartments	120	8	2800	336,000	67,200,000	11.3
	perimeter block of flats and townhouses	80	11	4100	328,000	65,600,000	11
	Terraced street of houses	80	13	5300	424,000	84,800,000	14.2
	Detached/ semi detached	40	19-24	8625	345,000	69,000,000	11.6
Shetland Existing examples Martin (2009)	1. Prosperous area	10	n/a	11000	110,000	22,000,000	3.7
	2	20	n/a	7500	150,000	30,000,000	5
	3	30	n/a	6500	195,000	39,000,000	6.5
	4. Terraced	80	n/a	5000	400,000	80,000,000	13.4

Table 6 shows there to be a wide variation in the difference between the costs for a hectare of district heating piping in the UK (Dodds, 2008) compared with the Icelandic figure of 29775 GBP/Ha as calculated from 3 areas of Reykjavík (based on 200ISK per 1 GBP) (Verkís, 2009). The pipes lengths as indicated by Dodds (2008) and cited by Baron *et al* (2008) are listed in appendix 5. The variation between UK and Icelandic figures is of a factor of 10, which is a vast difference which invites discussion. It is a worthy consideration that the Icelandic figures are representative of the fact that Reykjavík's system was developed as the city grew, and are therefore a result of the new build scenario. The greater Reykjavik area now encompasses approximately 200 000 people which is approximately two thirds of the whole population of Iceland which demonstrates that there was a particular influx of population as the city developed. This growth allowed the deployment of district heating piping network as the housing was built. The UK would require the deployment of retrospective heating piping giving vastly different costs which could indeed be in the ballpark indicated in table 6. The Icelandic figures use an average and this is justified with respect to the balance of small pipes and large pipes required to be used in the dense and less dense areas of greater Reykjavík (Verkís, 2009). It should not be forgotten that recent economic events have distorted the Icelandic (ISK) currency; however it is accounted for in the use of the Building Costs Index (BCI) which is adjusted every month for costs in Iceland (Statistics Iceland, 2009). These values are taken into account in the cost comparisons.

The reasons for these cost variations are somehow unexplainable when it is considered that the piping material is the same with often similar suppliers being used (e.g. Logstor). However there are ways in which costs can be brought down - for example the way that the contract is set up for the delivery of the installation could be "turnkey", meaning that the contractor would be supplying as well as installing the equipment. In the case of the Shetland market, their small island location tends to mean that the contractor does not need to take on board the responsibility for supplying the pipe material as it is unlikely that it could be used for another purpose within Shetland (Martin, 2009). This gives a reduction in costs as the contractor does not have the opportunity to hike prices to accommodate the supply of the materials. In addition, the client body can bulk-buy materials for several projects. Other ways that the cost can be kept down include the limiting of bends and joints in the piping system (Martin, 2009). However this is not necessarily prioritised in the design of a new housing area nor is it a consideration when it is determined to supply heat to an existing housing stock retrospectively.

Other considerations for the reduction of costs are (Martin, 2009):

- The fact that retrospective installations could indeed double the costs of the distribution system purely due to the necessity for excavation of the roads and services and diverting traffic on existing roads;
- Sharing the cost of the digging with other services that are being installed at the same time as the district heating pipes;
- Could be possible to bulk buy the pipes reducing costs by a third or even half. Having fewer joints and muffs including welding requirements reduces the costs also as exemplified in figure 9;
- If twin pipe are used then there are reduced civil costs

Figure 9: New district heating pipelines for a housing density which does not require pipe bends and other required fittings at new housing development Quoys, Lerwick, Shetland Islands, UK (Martin, 2009)

4.2 Energy Cost Variations via District Heating within Iceland

Figure 10 shows the relative customer cost of the different district heating systems in Iceland. There were assumptions made in the use of these figures, namely:

- The average house size used was 430m^3.
- The return water temperature used was assumed to be 35°C but was usually correlated to the inlet temperature between 30-40°C.

Given that the metering system is either volume or fixed flow rate, it must be noted that these relative costs are calculated by adjusting the costs provided into the energy extracted, and therefore the energy unit equivalent.

Steps:

1. The energy per m^3 is measured using the temperature drop between the supply temperature and return water temperature and used to give an annual figure
2. The demand temperature is calculated based on a temperature of 5°C yearly average for Iceland
3. This is applied to the given tariff per unit volume
4. By applying the tariff rate and the fixed rate, the annual cost to the consumer is calculated (Ragnarsson, 2009).

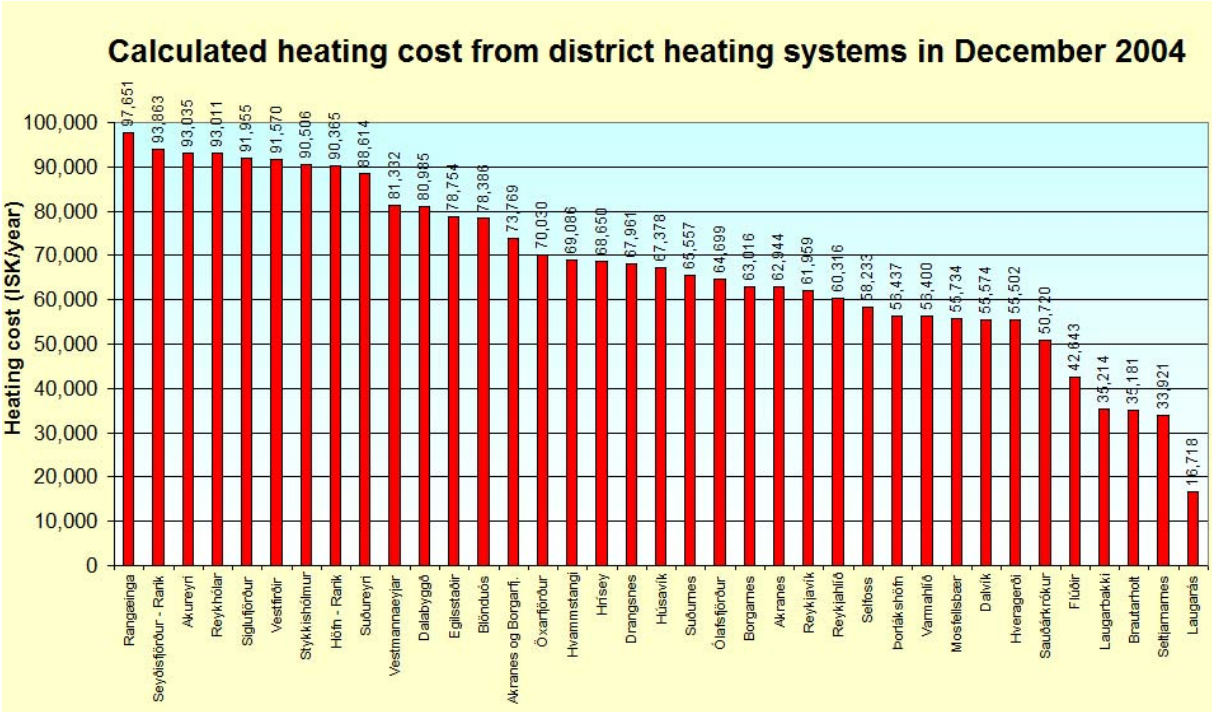

Figure 10: Calculating heat cost from district heating systems in December 2004 in Iceland (Ragnarsson, 2004)

The general pattern of the graph can be explained as follows; it is shown that the difference in the tariffs is due to the size and the age of the system. The tariff set by the provider of

course takes into account the installation costs of the network of piping and the utilisation of the energy resource. (In Reykjavik, for example, the energy provider and the distributor is Reykjavik Energy.) This therefore results in the tariff reflecting the overall investment. The older the system is, the less the cost of the system needs to be reflected in the price of the energy as it would have been paid back. Costs depend on when they were built. Geothermal district heating was developed in the larger towns in reaction to the oil crisis in the 1970s, and so larger schemes, such as Akureyri (population 16000) reflect higher costs which are perhaps due to the increased investment at that time which were still being paid off at the time of analysis. This may also be due to the fact that the Akureyri system is based on the use of 2 sources of geothermal wells which may also inflate the cost. This 2nd source was required after the original source was not found to be as productive as envisaged meaning the transmission pipeline was oversized (Jónsson, 2009).

These discussion points may also be subject to errors in the analysis, for example, the assumed return temperatures that are recorded may not reflect the true values. The distribution of the properties may also have a significant part to play in the ultimate cost of the system. It must also be noted that there are 4 schemes which differ to the geothermal and wet distribution schemes highlighted so far. Vestmannaeyjar (Westman Islands), Hofn, Seydisfjordur and Vestfirdir (West Fjords) all use electricity generated via hydro power. Vestmannaeyjar (Westman Islands) is therefore the scheme which is electrically heated from a central point and then the energy is transported via water pipelines in a closed system. The energy is metered by measuring the temperature drop across the scheme for the use by one property. This may be therefore an example of a conventional district heating system that would occur in the rest of Europe with the use of the energy metering rather than flow or volume metering.

Nevertheless, this exercise demonstrates the complexities of the district heating network and its relationship to cost. These examples will now provide the basis for further work regarding the cost of district heating in the UK.

5 FUEL POVERTY AND HEAT DENSITY

This section explores fuel poverty in conjunction with heat density, (heat demand density). Firstly let us consider fuel poverty as an entity in its own right. The relationship between fuel poverty and heat density is then considered.

5.1 Fuel Poverty Overview

The concept of "fuel poverty" is used in the UK to refer to a household situation which is spending over 10% of its overall household income to maintain an adequate level of warmth. This is regarded to be 21°C in the living room and 18°C in other occupied rooms (DECC, 2009). It is also sometimes referred to as "affordable warmth". Recently complied figures show that 4 million UK homes suffer from fuel poverty, which is about 16% of all homes (DECC, 2009).

The UK government has targets to reduce fuel poverty and achieve affordable warmth for all by 2018 (DECC, 2009c). Various proxy measures for fuel poverty can be used although it is important to acknowledge the 3 contributing factors to fuel poverty of figure 11. The root causes therefore are, low household income, high fuel costs and high energy consumption through, for example, energy inefficiency or behavioural traits or habits according to the type of occupancy. The solutions to these therefore are; the reduction of fuel costs, the increased energy efficiency of dwellings and the increase of household income through the maximisation of benefits allocated to the household as shown in figure 11. The responsibilities for these issues are devolved and are therefore divided between the countries of the UK. Energy efficiency is a devolved responsibility but the issues of fuel cost and maximising income are the responsibility of the UK government (EAS, 2009). Fuel poverty is often applicable to rural communities due to the lack of fuel choices available resulting in higher fuel costs. It could therefore be considered that district heating could be a solution to fuel poverty due to the efficiencies, and therefore cost reductions, that it provides.

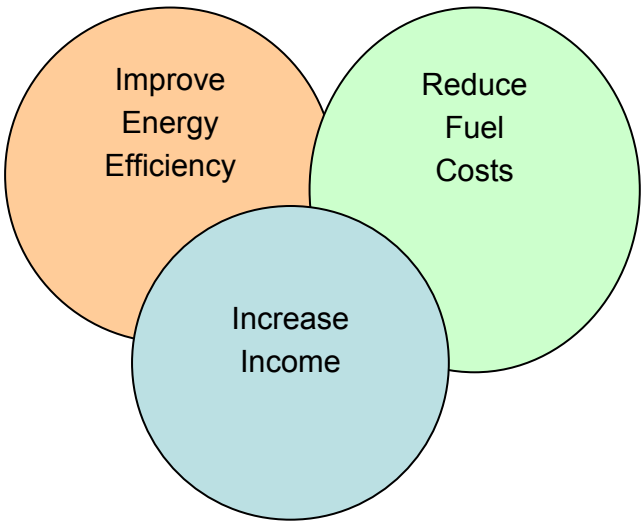

Figure 11: Fuel Poverty Solutions

The fuel poverty ratio is used as described by the UK Government (DECC, 2009c) as follows:

Equation 1

$$\text{fuel poverty ratio} = \frac{\text{fuel costs (usage x price)}}{\text{income}}$$

A household is therefore determined as being in fuel poverty if the fuel poverty ratio is greater than 0.1. Based on this, the fuel poverty ratio can be used as a numerical value in analysis for exemplifying purposes in this work.

Fuel poverty is a major issue in the UK and is exemplified in figure 12 for England specifically. It shows that there is a high level of the fuel poverty in the areas of the south west and the north of England. London has the least fuel poverty which is not surprising as there could be a greater likelihood to have access to the gas network, increased income and newer housing in the city. The UK Fuel Poverty Strategy stipulates the requirements posed upon local authorities to achieve reductions in fuel poverty. It is therefore possibly to monitor the levels of reductions achieved over time since it was initiated.

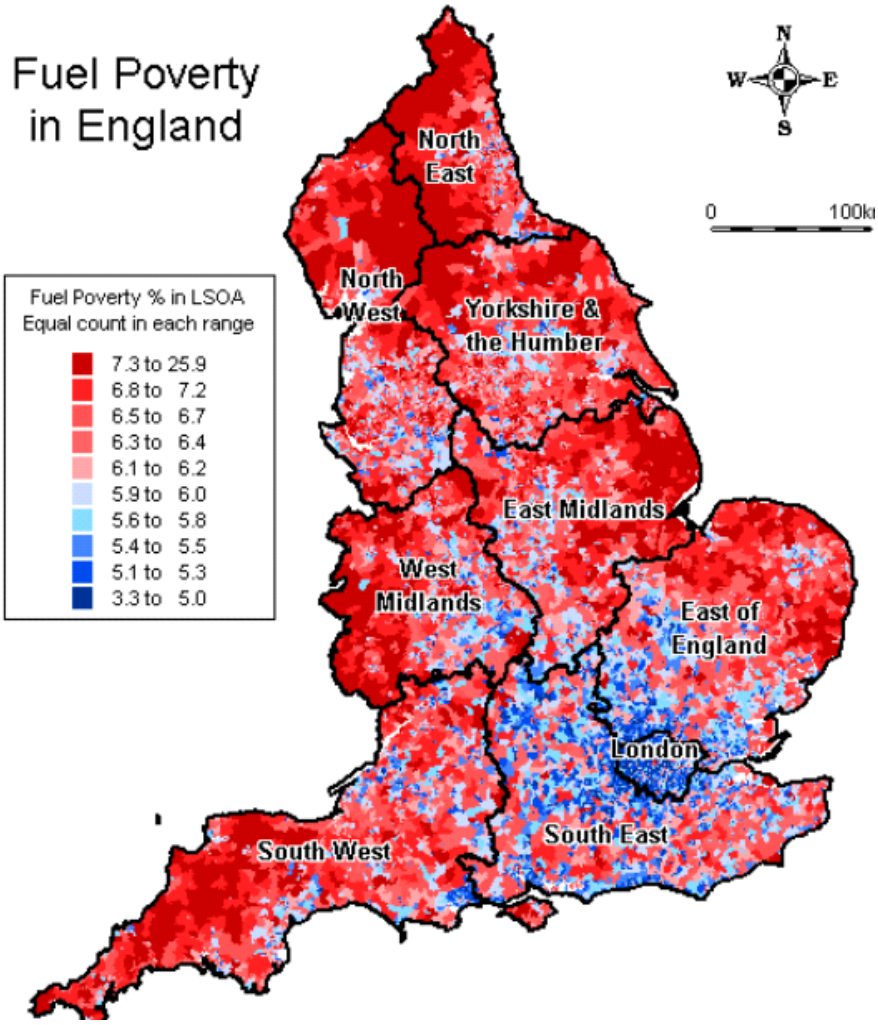

Figure 12: Fuel Poverty in England (CSE, 2003) - the darker the red, the more severe the fuel poverty

In Scotland, there was a fuel poverty mapping exercise carried out for each of the 32 local authority areas (Alembic Research/ EAS, 2004). Figure 13 shows one of these, the Orkney Islands area. This is a useful tool for highlighting the correlation between remote areas and their risk of fuel poverty when broken down into ward level.

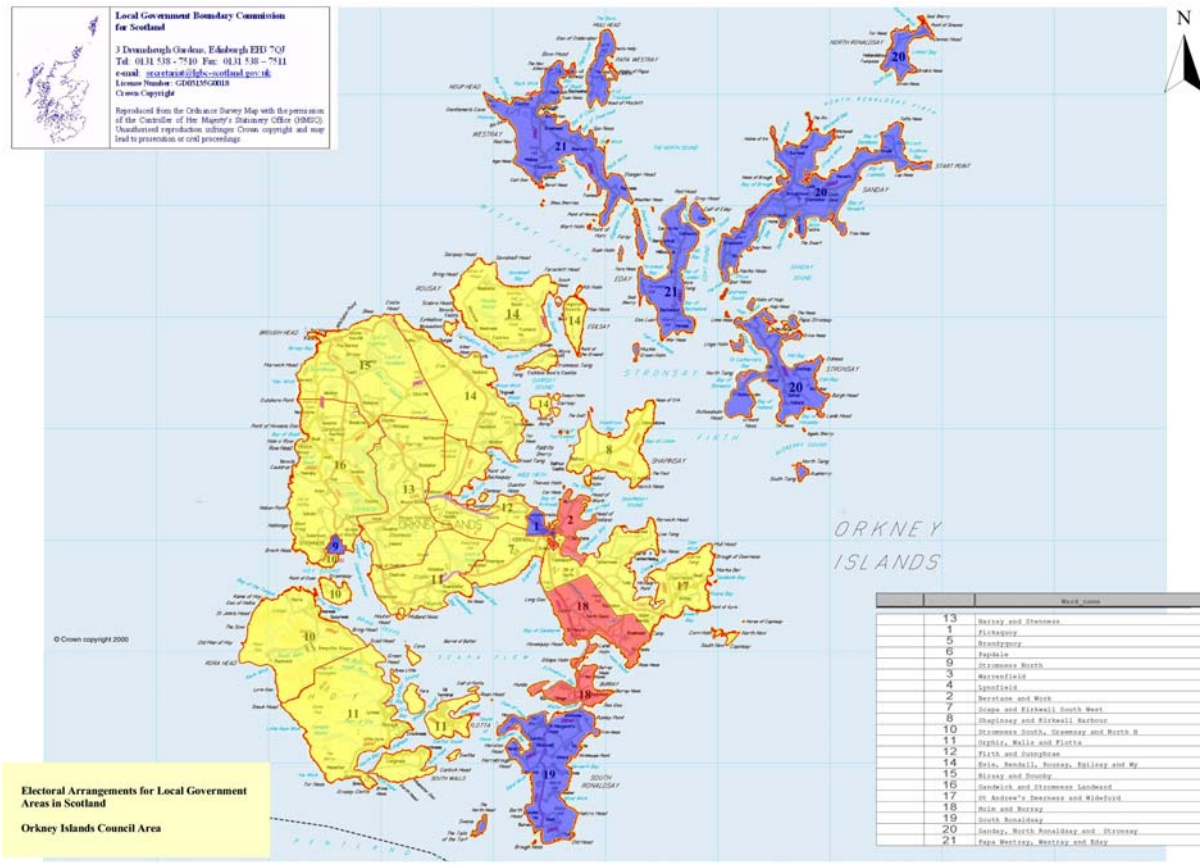

Figure 13: Fuel Poverty levels in Orkney, Red = most at risk, Yellow = medium risk, Blue = least at risk (Alembic Research, 2004)

Distributed energy allows there to be individual cost savings where the investment is shared amongst the members of a community. Cost savings due to the scale of the equipment and also the investment allow cost savings to be made in heating costs. Of course not all communities are suitable for district heating and there will be other fuel poverty solutions in light of the overlapping nature of solutions shown in figure 11 as well as other options for energy cost reductions. District heating however goes beyond fuel poverty with far-reaching benefits. District heating serves to address other policy issues such as security of supply because the available fuel goes further, as well as achieving the CO_2 emission reduction targets due to energy efficiency plus the ability to use an energy source that is low carbon. The most effective measure is to reduce the cost of fuel thus reducing fuel poverty. However there are also other solutions available which include the improvement of energy efficiency of the housing stock and the increase in income for householders – this is often referred to as income maximisation.

5.2 District Heating, Fuel Poverty and Heat Density

To apply district heating to rural areas which are likely to suffer from fuel poverty, it is useful to explore heat density.

Heat density is given by the following equation:

Equation 2

$$\text{heat density} = \frac{\text{annual heat demand in kWh/ 8760}}{\text{area of the properties in km}^2}$$

If heat density is defined as heat demand divided by area, then it can be stated that the higher the heat density, the more cost effective district heating becomes (Davies and Woods, 2009). Heat density can be used as a tool to determine areas for cost effective district heating. Figure 14 shows the types of communities around the UK. This reflects the population density and hence heat density for the domestic market. The areas which suffer most from fuel poverty are often those which are most rural and have the lowest population. For example, 22% of urban households and 38% of rural households in Scotland are in fuel poverty (Scottish House Condition Survey, 2009).

Using the case study of Gill Pier, Westray, Orkney the comparison between fuel poverty measures and the heat density can be made. In 2004, the Orkney Islands local authority area had the second highest rate of fuel poverty out of the 32 local authority areas in Scotland (OIC, 2004).

This can show the relationship between heat density and fuel poverty figures for the case study area of Gill Pier, Westray, Orkney which is a rural area with hamlet status as shown in the figure 14 below.

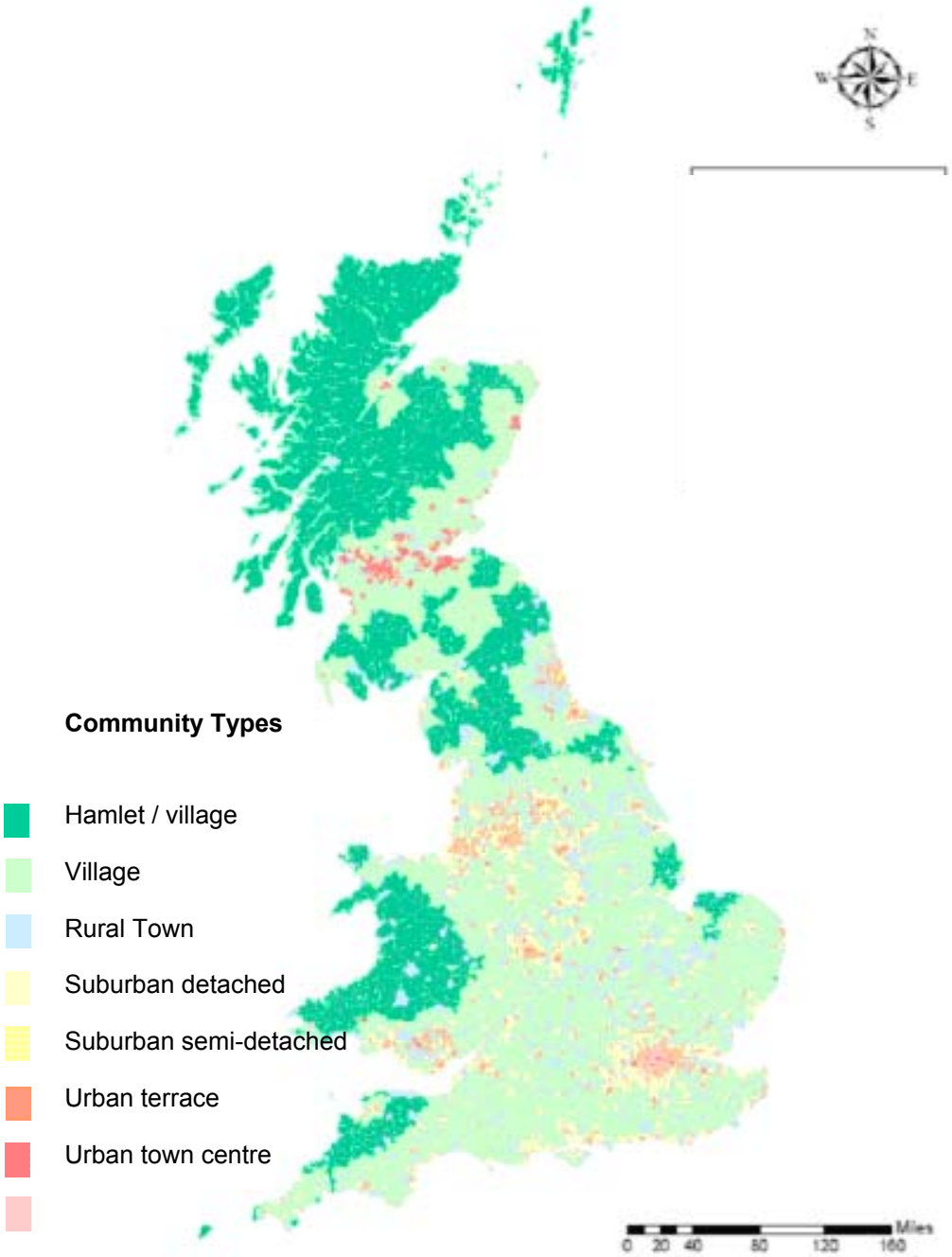

Figure 14: Communities in Scotland, England, Wales (Baron et al, 2008)

5.3 Mapping Fuel Poverty and Heat Density

In order to demonstrate the opportunities for district heating in situations where fuel poverty is likely to occur it is useful to consider the possibility to map these together. This has been carried out for the greater London area (Centre for Sustainable Energy, 2009). This work is being carried out as part of the London Energy Master Planning requirements and will act as a resource for boroughs to assist in identifying decentralised energy opportunities. The tool has the capacity to determine the localities which suffer most from fuel poverty and what can be the best correlation of the use of district energy from a cost saving point of view in order to assist the most vulnerable fuel poor households. This can be seen in figure 15.

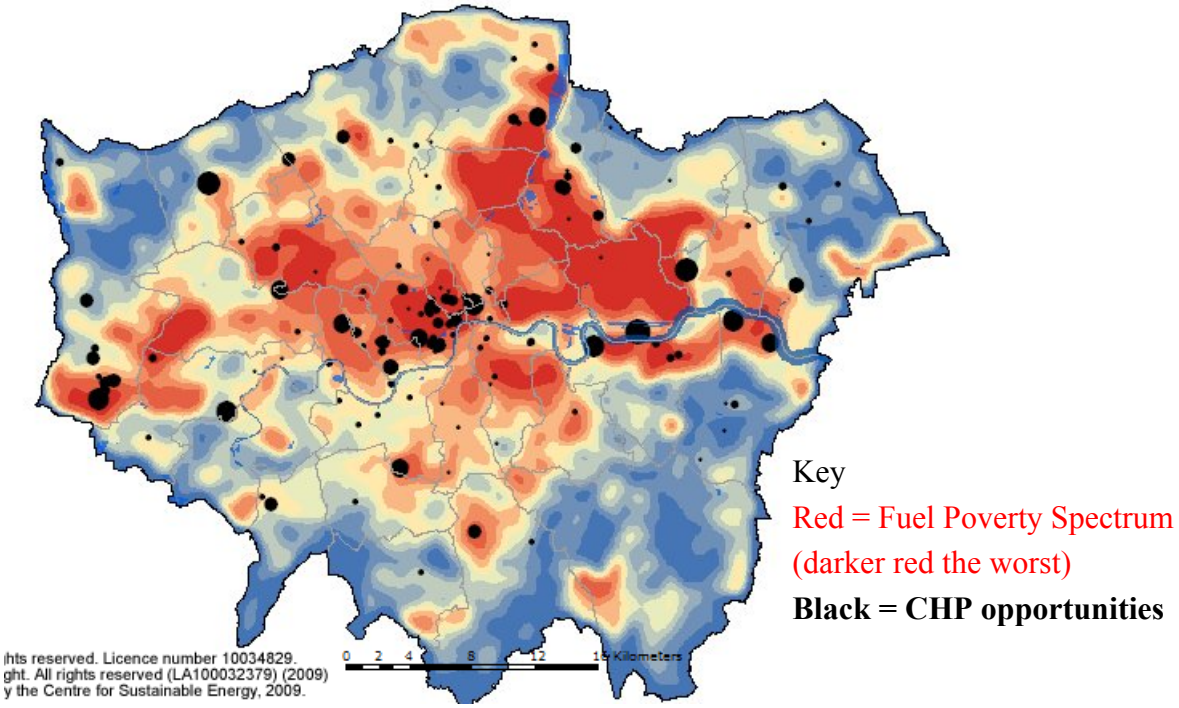

Figure 15: London Heat Map (Centre for Sustainable Energy, 2009)

Figure 15 shows the severity of fuel poverty in the red spectrum and opportunities for Combined Heat and Power (CHP) marked with black spots sized according to their MWh output. The coincidence is therefore shown to correlate well for the London area. This is a very good tool in demonstrating the relationship between the fuel poverty levels and the potential for its development as a tool for the wider country would be extremely beneficial in allocating resources for the use of district heating as a solution to fuel poverty and indeed demonstrating the frequency of its coincidence with rural areas.

5.3.1 Evidence of Rural District Heating Success

Thus far, this section has outlined that there are correlations between the incidence of dispersed community types and the incidence of fuel poverty levels. On first appearances district heating may not be the most obvious choice to a rural situation due to the likelihood of the density of the properties. This therefore highlights the necessity to explore the possibilities for district heating as a solution to fuel poverty in these areas that have a low heat demand density. Although the concept of district heating is known to be most cost effective where there are areas of higher heat demand density, there are many examples of successful small scale rural district heating schemes that are useful to draw on. It is also noted that small scale schemes provide the best opportunity to promote the use of local resources and therefore have the potential to include renewable technologies (Dotsch and Jentsch, 2006). This therefore makes a profitable scheme where there is a chance that local sources can be used for the energy production. It is noted that common energy sources for low heat density district heating schemes are biomass and biogas. In light of the subsidies that are available in Germany, for example, the cheapest choices are biogas or biomass CHP plants, with the best benefits arising from the use of feedstocks such as manure and waste (Dotsch and Jentsch, 2006).

6 METHODS AND TOOLS

6.1 Methodology and Techniques Undertaken

Having identified the need for a mechanism to implement district heating, it must be considered how to design the tool. It is firstly important to consider the usual process of designing district heating on a case by case basis. Here the requirements for district heating are outlined in order to highlight the many facets to be considered - rendering the design process far from simple. Reasons such as cost, economies of scale, optimal number of homes for the system to be efficient, suitable balance between supply and demand, the opportunities for expansion, the allowances for fluctuating demand, (occupancy, base load and summer load), digging for new piping requires co-ordination to do so between utilities and planning etc, suitable energy source available. This list highlights that there is no simple solution for determining the locations and scenarios for district heating schemes.

This section outlines two tools for assessing district potential in the UK, which use different approaches. The following chapters then allow their application to a small scale community, in order to provide comment on their merits.

6.2 Review of Existing Tools

There are various tools available with the aim to assist the process of decision making for the placement of district heating in different locations. Table 7 aims to summarise these with the emphasis on the requirement for their application to scale of community.

Table 7: Comparison of selected tools and their design purposes

Tool	Country	Description / Purpose	Retrofit / new build	Scale aimed for	Suitable for rural scale?	Source
Baron *et al* for the Energy Saving Trust	UK	To determine the suitable scales for technologies and for distributed energy via pipelines	retrofit	Community of 5, 50, 500	Yes	Baron *et al* (2008)
Scottish Government Toolkit developed by Parsons Brinckerhoff	UK	To determine suitable opportunities in the UK for district heating in new built scenarios	new build only	Approx. 1000	No	SBSA/ Scottish Government (2009)

The tools summarised in the table outline their different purposes. It should be emphasized that Baron *et al* (2008) are analysing the scope for district heating from a perspective of overall scope for the potential in the UK (from the top down) with consideration for existing and new build schemes. Whereas the Parsons Brinkerhoff (2009) tool determines a methodology to assess schemes on an individual basis according to the scale and density of the development plus the energy resources.

6.2.1 Community Level Assessment by Baron *et al* (2008)

A techno-economic study was carried out by Baron *et al* (2008) which assessed the potential for district heating at the community level specifically. This method encompasses the necessity to consider the implementation of district heating from an economic as well as technological perspective. Here the technological portion of their tool is considered in particular, however the outline of the overall approach is firstly described. Figure 16 shows the diagram of their project outline which emphasizes the benefits of community investment of the technology versus the individual investment in addition to the benefits of distributing the gains from the energy source.

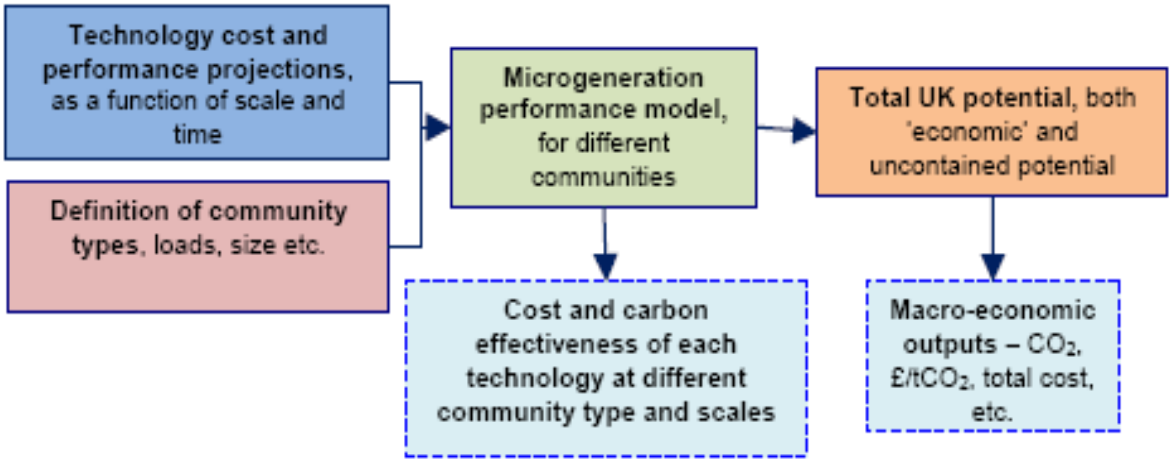

Figure 16: Assessment approaches (Baron et al, 2008)

The overall aim for Baron *et al* (2008) is to determine the total UK potential for district heating on an economic basis, both on a cost perspective and for the cost of carbon dioxide. They adopt a definition of different types and classes of community which can also be scaled at a variety of magnitude. There is also a variety of renewable energy resources considered.

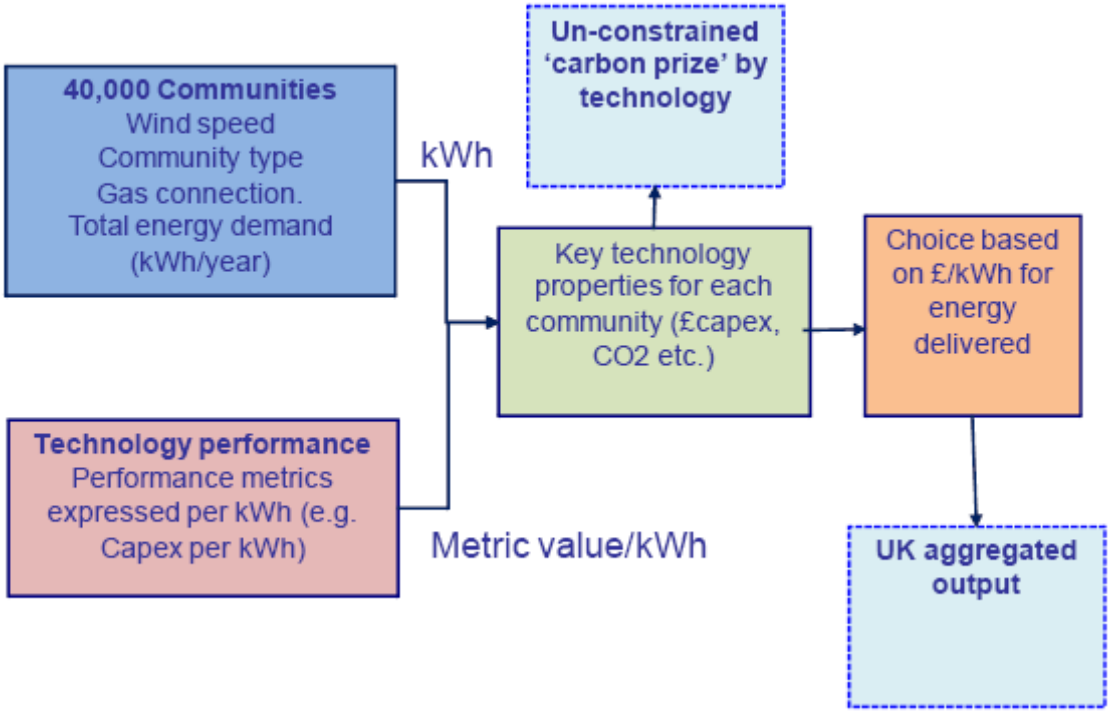

Figure 17: Overview of methodology for distributed energy potential for the UK (Baron et al, 2008)

Figure 17 shows that there is a multitude of aspects to consider in devising how appropriate the application of district heating can be. With regard to the technology decisions, the technique utilized by Baron *et al* (2008) encompasses the requirement to show the technologies appropriate for different community types and sizes. In order to achieve this, they have identified community types and the technologies that are appropriate. There is also the requirement to show that the technology is sized and therefore costed for each community type. These then allow areas of the UK to be identified for the application of district heating in a mapping exercise for a series of policy scenarios. This work is also focused on the retrospective installation of district heating supplying existing buildings in the UK.

Their method for identifying community types was derived from existing methods where populations less than 10 000 were defined thus: hamlet, village or rural towns. These are derived from the Office of National Statistics (ONS) and Scottish Neighbourhood statistics (SNS) (Baron *et al*, 2008). Proxies were also used for Scottish data where it was not possible to find the data recorded in the same manner. Figure 14 previously referred to is an outcome of this.

Their method for identifying technologies has the ability to assess different sizes of communities including small scale schemes of 5 properties. This same tool can be used for individual heating options. There are many methods for deriving the technologies that would be suitable, primarily with regard to the economics of operating that technology in a variety of settings at different sizes regardless of the distribution options. Using certain assumptions, long term considerations can be made for whole life economics and carbon emissions performance of implementing district heating in the UK (Baron *et al*, 2008).

It is then noted that it is possible to determine the cost reductions for a variety of technologies as indicated in table 8. This highlights the importance of acting as a community in light of the savings available rather than acting as individuals. It proves the

use of community action, which then leads to the district heating and shared heat provision.

Table 8: Savings met by a community of 50 sharing capital costs (after Baron et al, 2008)

Technology	**Saving Benefit if acting as a community of 50 rather than individually**
Solar Hot Water	34%
Photovoltaic	7%
Wind	18%
Ground Source Heat Pump	18%
Air Source Heat Pump	21%
Biomass	36-41%

Combining the energy sources and the discussed technological techniques allows the link between the energy demand and the energy sources to be made. They have determined the district heating potential for the regions of the UK at 4 levels being the individual level, communities of 5 homes, communities of 50 homes and communities of 500 homes (Baron *et al*, 2008).

Generally Baron *et al* (2008) concludes that there are indeed savings to be made from acting as a community with shared energy provision. For example, collaboration of a community of 50 dwellings makes a saving of 34% for solar hot water panels when compared to the individually installed systems. The conclusions drawn by Baron *et al* (2008) indicate that the most effective carbon saving from district heating installation in the rural situation would be one for wind turbines at the size of 100kWe to 500kWe (wind speed 6.5m/s at a of hub height 25m). On a large scale, this would be possible with the use of gas CHP.

The reason that this work is significant to this study is that there is a great deal of emphasis on the community basis. Their method for addressing the rural community is particularly of interest as it shows there is a particular possibility for rural community heating which some studies (for example, IEA, 2009) perhaps do not emphasize. This therefore goes some way to address the portion of these properties which are suffering from fuel poverty in the UK.

Note on the definition of "rural"

In the application of Baron *et al* (2008) to the example of the case study of Westray there is the consideration for what they refer to as "rural". The official definition of *rural* from the Oxford English Dictionary is: "in, or of, the countryside; pastoral or agricultural as the opposite to urban" (Hanks, 1996). The definition of rural therefore gives the impression of a distinct distance from other settlements, which, in the context of this study, can be taken into account to show the possibility of extending existing heat networks in other locations.

However, more specifically in the context of this discussion, *rural*, is regardless of distance according to Baron *et al* (2008). It can be used to identify different community types as well as different sizes which are outlined in table 9. It is noted that the community definitions of sparse village/ hamlet, classic village and small rural town are all applicable to the definition of "rural" which in part specifically refers to small scale district heating

schemes. This could be somewhat confusing, however the purpose is to identify the types of communities whereby the size varies but the density stays the same. The larger the community type, the more likely there would be the presence of larger users (e.g. schools) as an initiating load for the demand, and for the potential for hosting a central pump house. It should be noted that the heat density and the size of the scheme determines the main attribute for the district heating design within a settlement while the distance from other settlements determines the possibility for connection to their scheme . This is assuming there is not a more convenient possibility for CHP using a nearby existing nearby power plant.

Table 9: Community Types as identified by Baron et al (2008)

	Existing community type	1 Individual	2 Small community	3 Medium community	4 Large community
A	Sparse village/hamlet	1 detached unit	2 detached units	5 detached units	10 detached units 1 farm
B	Classic Village	1 detached unit	5 detached units	30 detached units 1 town hall	100 detached units 1 pub 1 church 1 town hall
C	Small rural town	1 semi-detached unit	5 semi-detached units	30 semi-detached units 1 town hall	500 semi -detached units 10 small commercial units 1 pub 1 church 1 town hall
D	Sub-urban - detached	1 detached unit	5 detached units	50 detached units 1 church	500 detached units 2 churches 2 pubs 1 GP 1 primary school
E	Sub-urban semi-detached	1 semi-detached unit	5 semi-detached units	50 semi-detached units + 1 church	500 semi- detached units 2 churches 2 pubs 1 GP 1 primary school
F	Urban - terraced	1 terraced house	5 terraced units	50 terraced houses 1 community centre	500 terraced houses 2 pubs 2 churches 1 community centre 1 GP 2 commercial units
G	Urban -town centres	1 flat	5 flats	50 flats 5 commercial units	500 flats 50 commercial units
H	Urban - dense	1 flat	5 flats	50 flats (1 block)	500 flats (10 blocks) 2 commercial units 1 GP 1 leisure centre
	New build				
I	Urban - dense	1 flat (purpose built)	5 flats (purpose built)	50 flats (1 block)	500 flats (10 blocks) 2 commercial units
J	Estate	1 semi-detached unit	5 semi-detached units	50 semi-detached units	500 semi-detached units

6.2.2 Heat Supply Options Assessment Tool by Parsons Brinkerhoff (2009)

This section outlines the Scottish Government's toolkit for assessing the possibility for district heating in new build situations, which was developed by Parsons Brinkerhoff (2009). The tool is designed to be used universally by developers and planners and so serves as a screening tool in determining the best potential energy source for the development. The tool is therefore configured for people who may not have technical knowledge. It is divided into four levels; firstly, assessment of the key indicators of district heating requirements, secondly detailed heat load assessment and profiling, thirdly fuel technology options and finally comparative economic analysis (Parsons Brinkerhoff, 2009). These stages occur before the detailed study is carried out by external consultants.

Table 10 outlines the stages that are included in the tool, the primary aim being to devise an energy strategy for a new build area - including the consideration of district heating.

Table 10: Heat Supply Options Assessment (Parsons Brinkerhoff, 2009)

1	OUTLINE OPTIONS ASSESSMENT	Key Indicators based district heating assessment
2	HEAT SUPPLY OPTIONS ASSESSMENT	Detailed heat load assessment and profiling
3		Fuel / Technology Options
4		Comparative Economic Analysis
5	OPTIONS ASSESSMENT	Detailed optioneering / business case / financial modelling
6	PLANNING SUBMISSION	Submission of Energy Strategy

Figure 18 shows the flowchart of the outline options assessment detailing the decision points suggested. Notable thresholds are for example to firstly note whether the type of buildings are residential or commercial which therefore determines the load. If a location is purely residential, then the system determines that a housing number of 100 dwellings at a density of more than 50 dwelling/ ha would merit a district heating system. If there were less than 100 dwellings then there would need to be a greater density of properties at 75 dwellings /ha (EST, undated). If this was not possible it would be necessary to ensure that there was an existing district heating system to link into, or an anchor load present (for example a swimming pool or hospital) with a significant and constant heat demand to merit the establishment of a new system. There are then some constraints recorded for example, if there are specific obstacles that would inhibit the digging for the distribution system, if there are other utilities present, or if there is site protection allocated to the area. The system then suggests whether the energy source can be determined and considers whether there is a gas connection or renewable energy resource available. The possibilities of district heating can be disregarded if the development characteristics are not suitable or indeed if an energy resource is not realistic.

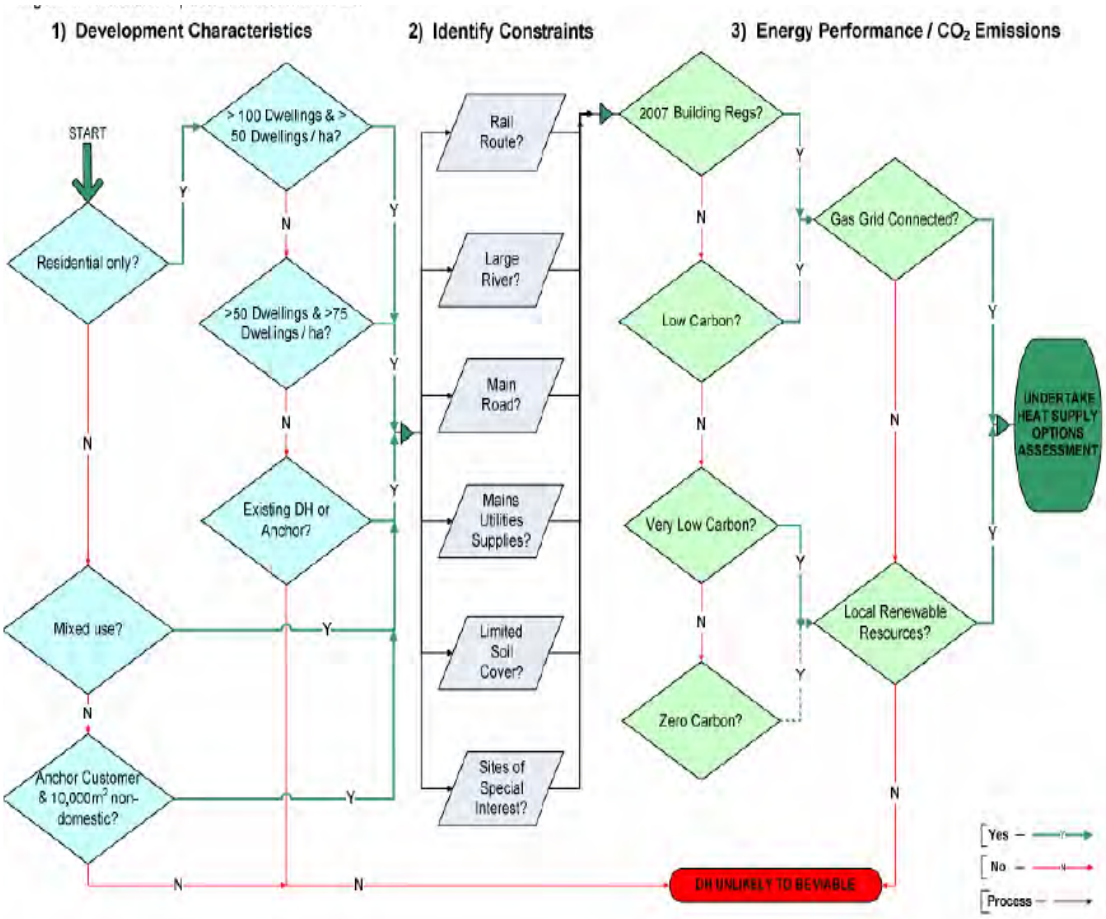

Figure 18: Outline Options Assessment Tool Flow Chart (Parsons Brinkerhoff, 2009)

The Outline Options Assessment is then followed by a full heat supply options assessment if it is determined that there is a suitable heat demand, combined with a suitable energy source (Parsons Brinkerhoff, 2009).

7 OUTLINE OF SMALL SCALE CASE STUDY AREA – WESTRAY, ORKNEY

Westray is one of the northern isles of the Orkney archipelago off the north coast of Scotland. It is 1 hour 20 mins by ferry from the main town of Kirkwall on the Orkney mainland and it has a population of approximately 600 people. Westray's location in the Orkney archipelago is shown in figure 19.

Figure 19: Orkney Islands archipelago showing Westray, the most north westerly island (Ordnance Survey)

The Gill Pier is located around the bay from the village of Pierowall and includes 11 properties including 4 commercially used properties including a bakery, fish processing factory, doctor's surgery and harbour master's property (figure 20).

Figure 20: Properties along Gill Pier, Westray, Orkney Islands (Photo: Ingrid Austin)

Energy sources for the case study area are the options of electric storage heating, or oil central heating (NWIEEAC, 2004). The heating can be determined to be an important consideration in this area especially when these options are increasing in cost. It was determined in 2002 that 70% of all properties in Orkney had central heating (SHCS, 2002). There are figures recorded for the heating methods of choice for the year 2003 are given in table 11.

Table 11: Orkney's Energy Consumption in 2003 (NWIEEAC, 2004)

Energy Source	Consumption per year	Energy
Fuel Oil	1 585 000 Litres	68490 GJ
Solid Fuel	Consumption of Coal: 5000 tonnes / year	205355 GJ
Electricity	157 GWh	566784 GJ

This energy balance will have varied with more housing developments in the islands bringing the benefits of increased energy efficiency, combined with the use of heat pumps and other renewable technologies which are used on an individual basis.

7.1 District Heating Design for Westray, Orkney

The case study area would consider a district heating installation with the use of the good local wind resource as well as utilising the experience of anaerobic digestion on the island. The proximity of the shellfish factory and the bakery could allow them to contribute to a thermal store which would then supply the properties along the road. There would then be scope to expand the scheme in the future if there were sufficient demand (and supply) available.

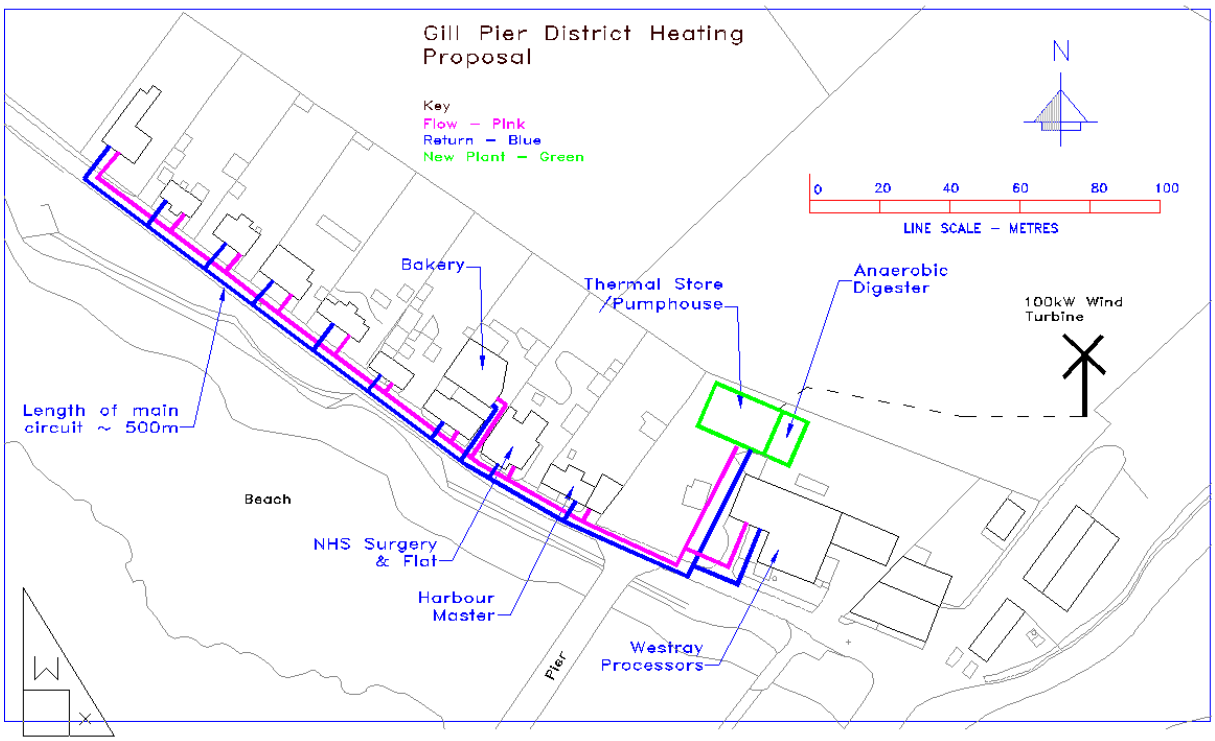

Figure 21: Gill Pier District Heating Proposal

Figure 21 suggests a possible district heating scheme with retrospective installation of piping under the road. The total piping length for flow and return is approximately 500m. A 100kW turbine is suggested for the contribution to the supply. Energy demand for Gill Pier, Westray was found to be 500 000 KWh annually which is described in Appendix 1.

7.1.1 Analysis on Energy Demand Results for Gill Pier

As carried out by Davies and Woods (2009), design heat load from the NHER program can be compared with the actual radiator sizing in a typical family home in Westray. The design heat load is defined in Appendix 2. NHER software was used to produce an energy rating for the property. The figures were calculated after inputting the information for a detailed survey using the extended data facility of the program. The case study used was a 4 bedroom 2-storey house with oil-fired central heating. Typically, it would be considered that such a property would be appropriate for simple adaption to comply with a district heating scheme. Table 12 below outlines the comparable figures found. The NHER software calculated a design heat load of 9.94kW for the building. After measuring the surface area of the radiators and using the product information on the Myson radiators installed in the property, the power output of each radiator can be given as shown in table 13. The total of all 8 radiators gave a total power output of 10.5kW. This shows that the radiators have been designed to provide 5% more power than is required. This is consistent with textbook advice on the overall sizing design of radiators which advises that radiator designs which exactly match the heat load would not heat up quickly enough (Holloway, 1999).

Table 12: Comparison between NHER Software and Actual Heat Load calculations

4 bedroomed 2-storey Property	**kW**
Design Heat Load (NHER software)	9.94
Radiator heat load (from actual measurements)	10.50
Boiler size suggested by NHER	15.00
Boiler size (actual)	19.00

Table 13: Product information on Myson Radiators (Myson, 2009) Radiator types are DPDC = Double panel, double convector. SPSC = single panel, single convector.

Room	**Rad Type**	**Size (m)**	**Radiator Output (W)**
Living	DPDC	1.2 x 0.6	1967
Living	DPDC	1 X 0.7	1869
Bathroom	SPSC	0.6 X 0.4	347
Extension	DPDC	1.2 x 0.6	1967
Bedroom 1	DPDC	0.9 x 0.6	1467
Bedroom 2	DPDC	0.6 x 0.6	969
Bedroom 3	DPDC	0.6 x 0.6	969
Bedroom 4	DPDC	0.6 x 0.6	969
		TOTAL	**10524**

It was also calculated by the NHER program that the boiler required for the property could be sized` at 15kW. The actual rating on the Eurostar boiler was 19kW. An installer would choose to oversize the boiler to be on the safe side. The purpose of this is that it would allow a house to be extended and piping extensions could be run to more radiators in the future.

7.2 Application of Baron *et al* to the Westray Case Study

As has been outlined in the preceding chapter regarding the work by Baron *et al* (2008) (section 6.2.1), it is necessary to consider community benefits. Firstly, Baron's analysis must be noted to be a procedure for assessment of the potential for district heating possibilities anywhere in the UK. It therefore has the overall aim of calculating the UK potential by setting parameters for typical circumstances set in different policy scenarios. It is therefore an analysis for overall potential rather than the examination of the individual scheme, and its likely suitability for district heating. In this way, the retrospective application of district heating can be considered for the existing housing. Therefore an assessment of the case study can be achieved by inputting into their model the costs and energy measures for the relevant community size which best reflects the Westray situation. Since the Westray case study scenario is a group of 11 properties (commercial and domestic) the band of 5 property size used by Baron, is perhaps best for comparison as the next grouping of 50 properties is on another order of magnitude. Baron especially emphasizes modeling of the energy sources, including renewable technology performance. This allows an assessment of the cost of various technologies at different scales, prior to

the consideration of the distribution system. The elements from the outline in the previous section can now be applied to the case study of Westray.

The factors considered are:

- Energy Sources for rural areas: Local wind speed should be greater than 5.5 m/s otherwise it is not viable to have a wind turbine. The Westray area has an average wind speed of 7 m/s at 10m mast height (Whyte, 2009), which is over the threshold of required wind speed.
- Demand: Baron *et al* acknowledges that there is a higher requirement for overall heat demand than electricity demand in the UK. The demand for the Westray scenario of 11 properties is 500 000 kWh/ year.
- Community type of classic village, at a scale of small community, would apply to the case study scenario with the allocations identified by Baron *et al* which is classified as community B2 in table 9.
- Gas network access: Westray is not on the gas network due to its remote location

The conclusions drawn by Baron *et al* (2008) indicate that the most effective carbon saving from district heating installation in the rural situation would be one for wind turbines at the size of 100kWe to 500kWe (wind speed 6.5m/s at a of hub height 25m). At the 5 property level, it is suggested that there is not a strong case for district heating even with policy support (Baron *et al*, 2008). However, it must therefore be determined where rural cases have appropriate technologies and appropriate support to make district heating viable.

While Baron *et al* are particularly focused on the small community it is noted that they do not highlight the density of the housing clusters. While it is their aim to determine the overall potential for district heating they have omitted to include a provision for house density. That said, while their method establishes an overall target, it must be acknowledged that the requirement to determine the suitability for a particular or individual community is not addressed. There is therefore a requirement to maintain the community focus as Baron *et al* does, and consider the density of the properties as a key determinant of the potential for district heating on a case by case basis.

7.3 Application of Parsons Brinkerhoff to Westray Case Study

The case study area can be used as a basis for comparing the tools provided by Parsons Brinkerhoff (2009) and Baron *et al* (2008). Here, the process as shown in the flow chart by Parsons Brinkerhoff (2009) is applied to the island situation of Westray. However, in order for the comparison to be fair, the fact that there is an existing development in Westray should be ignored and the assumption made that there is a district heating proposal for a new build scheme on the island. By doing so, it is acknowledged that an existing housing development would result in higher costs for the distribution system due to the retrospective installation, and is therefore compared separately.

By using the same small rural case study, it can be determined whether the use of different elements produces the same outcome.

A theoretical new build scenario is taken from the case study of Westray, and is applied to each of the decision stages of the Outline Options Assessment Tool from the flow chart given by Parsons Brinkerhoff in figure 18. This is the initial screening process carried out by developers in order to assess whether district heating should be considered in a full assessment for new build. The results are depicted in table 14.

By taking the key decision points in the flow chart in figure 18, the theoretical new build situation can be applied to Gill Pier, Westray. Table 14 therefore correlates the flow chart decision with the facts from the case study and shows whether it allows progress to the next decision in the flow chart.

Table 14: Application of a theoretical low heat density development on the island of Westray to the decision process for new build (Parsons Brinkerhoff, 2009)

	Flow Chart Decision (Parsons Brinkerhoff, 2009)	**Applicable Case Study Fact for theoretical new build at Gill Pier, Westray**	**Allows progress to next decision stage**
Development Characteristics	Residential only?	No	Yes
	Mixed use?	Yes - there are 4 commercially used bldgs	Yes
	Anchor customer & 10 000m2 non-domestic?	The crab factory (1000m^2) and bakery (<1000m^2) would be the most significant users on the network.	No
	50 dwellings and >75 dwelling/ ha?	Only 11 properties	No
	Existing district heating?	Only individual heating systems	No
Constraints	Rail route? Large river? Main road?	No physical obstacles	Yes
	Mains utility supplies? Limited soil cover?	It is possible that the sewage system could be redirected but not in the near future	Yes
	Site of Special interest?	No	Yes
Energy performance and CO_2 emissions	2007 bldg regs? low carbon? Very low carbon? Zero carbon? as recommended for future building standards in the Sullivan Report	In this new build scenario, there is the certainty that new Scottish building regulations would apply which entail reduced carbon and hence reduced demand from DH.	The resulting demand as stipulated by new Scottish building regulations would dictate the feasibility of district heating.
	Gas grid connected?	No, the island is an off-gas area	Yes
	Local renewable resources?	Yes, there are the options of anaerobic digestion and wind turbines for the location.	Yes

As table 14 indicates, there are three major points at which the development characteristics do not lend themselves to the likelihood that district heating is suitable for the example of Westray and that progress to the next stage of the flow chart is therefore not suggested. The development characteristics imply that the case study example is not likely to be cost effective due to the lack of large heat loads in addition to the small number of properties and the density at which they are laid out. Moreover, as the venture would involve the installation of a new heat distribution network, the likelihood of suitability appears to be low according to the parameters chosen by Parsons Brinkerhoff (2009). This result from the Outline Options Assessment Tool discourages the user to further consider district heating for the new development and the user would not proceed to the next stage of the full heat supply options assessment (table 10). This decision is therefore based on the demand, size and density when considering the development characteristics.

8 RESULTING TOOL SUGGESTIONS

8.1 Developing an Assessment Tool for Small Scale District Heating Opportunities

In the consideration of a future for district heating in the UK, it is necessary to address tools to facilitate the implementation. Based on the tools reviewed in the previous sections in conjunction with the case study, it is possible to identify and combine their key elements applicable to a new tool and provide an avenue for adopting district heating for small scale scenarios. It is identified that there are two physical community characteristics that must be addressed. Due to the nature of fuel poverty, it is often that the community characteristics of small scale and therefore low heat demand density and that they are usually existing properties. This therefore requires attention for the retrospective installation of district heating, and careful consideration of the size of the scheme that is feasible.

Two tools have been highlighted which facilitate the deployment of district heating and it is here that some of these elements are considered for the design of retrospective, small scale schemes specifically. The importance of these various elements is observed and highlighted.

Firstly, table 15 summarises the differences between the tools and the required elements are highlighted, making the distinction between retrospective and new build situations.

Table 15: Summary of Elements covered by Baron (2008) and Parsons Brinkerhoff (2009) Y = yes they are included

		Retrospective	**New Build**
		Baron *et al* (2008)	**Parsons Brinkerhoff (2009)**
	Element Considered	**Community Scenarios**	**Decision Flow Chart**
Demand	number of properties	y	y
	heat demand density		y
	community type	y	
Energy Source	gas network	y	y
	local renewable resource	y	y
Distribution	costs of the distribution network	y	y
	constraints to development		y
Comparison	NPV compared to individual options / lifetime	y	y

Regardless of the development's status, it is noted from the table that heat demand density is considered by Parsons Brinkerhoff (2009), whilst it is not specifically addressed by Baron *et al* (2008). Conversely, community type is defined by Baron *et al* in order to provide a method to tackle the nature of community size and style by suggesting a classification. This is tackled by Parsons Brinkerhoff by the means of thresholds as stipulated by previous research, adopting this as their assumption. With particular regard

for the application of district heating to small scale schemes, it is noted that the scales that are considered are no lower than 50 dwellings with a threshold density of greater than 75 dwellings per hectare which is based on Energy Saving Trust data (EST, undated).

Further to table 15, it is noted from these observations that Baron *et al* (2008) emphasizes the importance of energy source in their analysis which addresses the needs of the development regardless of scale and the other criteria which determines the energy demand. This importantly highlights the possibilities of savings when acting as a community for the investment of a new energy source (e.g. wind turbine) - regardless of the specific district heating benefits. On the other hand, it is noted that the full assessment process by Parsons Brinkerhoff (2009) involves incomplete consideration of the energy sources and some valuable considerations are omitted (Parsons Brinkerhoff, 2009).

By the process of applying the elements that are found to be associated with the existing tools, there are some considerations which can be emphasized for rural examples in light of the application of the case study, Westray. This is useful in order to identify the requirements of small scale schemes and decision in the future. The following subsections therefore outline the importance of each of the elements included in the tools reviewed:

8.1.1 Gas Connection Availability

An existing heat source could be the first choice for connection. The connection to the gas network could provide cheap heating fuel which would compete with the installation of district heating and therefore be the first point at which a positive decision regarding district heating installation would stumble. Where there are already 77% of residential houses connected to the gas network (DUKES, 2008), there is the opportunity to expand this network in appropriate locations provided there is gas to be sourced for the future.

8.1.2 Number of Properties

Number of properties is considered alongside heat demand density by Parsons Brinkerhoff (2009). This acknowledges that there is an element of scale to be considered along with the density. As noted, the thresholds that are considered show that a housing number of 100 dwellings at a density of more than 50 dwelling/ ha would merit a district heating system. If there were fewer than 100 dwellings then there would need to be a greater density of properties at 75 dwellings /ha (EST, undated).

8.1.3 Heat Demand Density

In principle, the higher the heat demand density for a locality the more cost effective the district heating. However, the possibilities for low heat densities and the provision of district heating have potential scope in certain circumstances where, depending on the energy source available, the economics make sense perhaps mostly in off-grid situations whereby there is competition with diesel generators.

Community size and community type are elements determining the heat demand density. In the circumstance of a small scale scheme there is the necessity to ensure that the cost can justify the scheme as there may be a fine line between the appropriate investments for an area. The considerations of community size and community type by Baron *et al* (2008) are very useful approaches to the decision making process regarding the scale to which district heating can be applied to communities.

8.1.4 Energy sources

Energy sources are important considerations to ensure that a district heating scheme is viable. It is deduced that this requires some refinement in order to develop its application to small scale schemes specifically. It is identified that there is a lack of variation for the included energy sources with, for example, anaerobic digestion options being omitted. It is noted that some fine tuning would be necessary to establish the correct scale that would be required for such a rural tool (Parsons Brinkerhoff, 2009). It, for example, is not applicable to the rural case study area, especially due to the particular omission of biogas/ biomass which may be favourable options in rural settings, which are often farming communities.

8.1.5 Costs

Ultimately, cost is the most important determinant of any energy provision. Typical costs for district heating systems must also take into account the distribution system as well as the cost of utilizing the energy resource itself. This is described in figure 8 earlier. In the case of small scale schemes this must be especially considered due to the fine balance between success and failure of schemes at this scale. There may be situations where there are the requirements to take advantage of subsidies or tax benefits that are favourable and indeed the use of the local resource that is to be utilized. There are some examples of the use of waste, farming subsides, and government incentives (section 3.4) for renewables which all make the use of a scheme with low heat demand density viable at the inception.

8.2 Flow Chart Option

To determine the suitability of District Heating for a location, the decision process must make assessments based on the nature of the development; be it an existing development or a new build situation. The tool created by Parsons Brinkerhoff (2009) is for assessment of new build situations and could be adapted for application to retrospective installations. Where Parsons Brinkerhoff (2009) considers the application of district heating to new build situations as previously discussed in figure 18, the flow chart in figure 22 adapts this as a suggestion for addressing retrospective installations.

It should be noted that this proposal covers the fundamental requirements which can be taken as the basis for the development of district heating in existing housing areas. The flow chart below therefore initially proposes the steps as laid out by Parsons Brinkerhoff (2009) for the establishment of a district heating scheme. With special regard for the development's characteristics, there is the initial necessity to consider the existing heat demand, and if there is sufficient heat demand density to merit district heating as is outlined by Parsons Brinkerhoff (2009).

Figure 22 then expands this to highlight the data inputs that are required to consider retrospective installations, these are outlined below:

- Initially, surveys of the properties are needed to determine their condition and energy requirements. Importantly, it must also be disclosed whether the properties are either individually owned, or owned by a housing provider. In the circumstance of the properties being owned by one landlord, it is therefore easy to establish district heating as a shared resource with one obvious operator. However, it should be noted that for retrospective schemes where the properties are owned by individuals, the system must be acceptable to an adequate number of householders in order to make it viable. Piping extensions can be made available should the future householders wish to join the scheme. In some cases individual heating

systems must therefore be altered in order to be compatible with the community heating scheme and therefore may incur conversion costs to wet central heating systems.

- In the retrospective situation, there is also the acknowledgement that existing roads and services would have to be disrupted. The digging up of roads in conjunction with other utilities and services are also practical consideration for the installation process.
- Traffic management could perhaps be an issue on busy roads which will often occur in the densely populated areas – these will often be suitable for district heating.
- Factors such as the improvement of the building fabric of existing properties (e.g. improved insulation levels assisting to reduce overall demand), the compatibility of the existing heating systems with the district heating system delivery method must also be considered as they have an impact on costs which must be absorbed by either the customer or the operator of the district heating scheme.

When district heating is intended to serve existing properties it is required to consider these issues which add to the complexity of district heating in retrospective situations particularly. These considerations may indeed become determining factors in the establishment of the scheme as ultimately, it is reflected in the final overall cost.

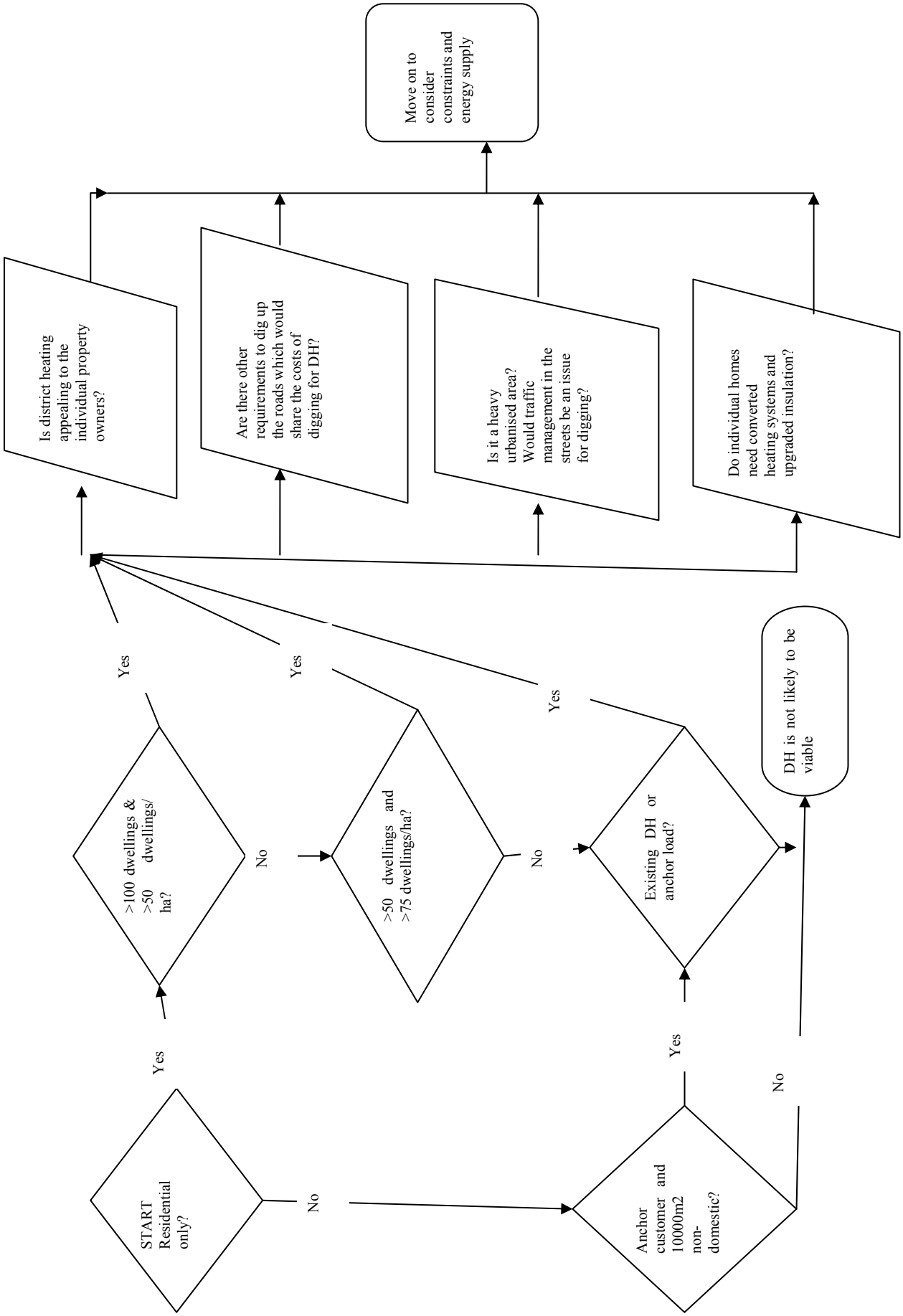

Figure 22: Flow Chart Decision Process expanded for Retrospective District Heating (adapted from Parsons Brinkerhoff, 2009)

9 DISCUSSION AND CONCLUSIONS

Carbon dioxide emission reduction, security of supply, reduction in cost (hence tackling fuel poverty) are the main driving forces behind the incentive for adopting district heating in the UK. In order to address fuel poverty, this work sheds some light on the particular cases of small scale, retrospective district heating installations. After examining existing tools and analysis methods for considering district heating feasibility in the UK, it is suggested that there is the need to doctor the obvious decision making processes in order to refine the tools for assessing small scale and retrospective district heating situations.

Tool Design for Small Scale and Retrospective District Heating

Through the methods carried out, the results show that there are various benefits as well as drawbacks from the two assessment approaches explored; Baron *et al* (2008) and Parsons Brinkerhoff (2009). Ultimately it is difficult to ensure that there is an assessment tool which encompasses all the required elements in order to be applicable to small scale as well as retrospective schemes. While the methods for the pipeline economic feasibility are transferable, it is particularly noted that energy sources vary in different circumstances, and this could be addressed so that they are encompassed in one tool. It is highlighted the gas connection, heat demand density, energy source and overall costs are vital considerations in the feasibility and ultimately the economics of district heating. These elements are therefore essential to refine for a tool which could encompass the application of district heating to small scale communities.

At the time of writing, the decision on the latest UK government proposals for renewable energy incentives is yet unclear. Whilst the economics of small scale district heating are often quickly dismissed as being unlikely to be feasible, small communities are waiting in anticipation to ascertain if the new feed-in tariff proposals could improve chances of investments in renewable technologies – for individuals and for communities.

Whilst studies such as Baron *et al* (2008) consider the overall UK potential for district heating in the UK from the top down, it is proposed that further work to consider the refinement of an all encompassing assessment tool should address the decision on feasibility from the bottom up by approaching solutions by inputing data on the community. To tackle this from the foundations established by Parsons Brinkerhoff (2009) is ideal, and refinements such as energy sources should be explored. The success of district heating in many other countries where multiple heating sources are used with district heating therefore provokes further exploration of resources from counties such as Denmark. Whilst Iceland has much success with district heating it must be emphasized that this is because it works well with the plentiful geothermal resources they benefit from.

It is then shown that there is the necessity to introduce further decision points for the inclusion of retrospective district heating in the UK to the flowchart process as outlined by Parsons Brinkerhoff (2009). This is especially important in light of the fact that it is estimated that housing stock replacements rates in the UK are minimal and despite current improvement rates, it means that they should last for 1000 years (EST, 2007).

In any tool refinement, in order to use the tool for application to fuel poor areas, a correlation with a fuel poverty assessment for the area should be considered. The method as established by CSE (2009) for the London area have excellent potential for combining

the information on district heating and on fuel poverty for the whole country. Having the ability to visually identify the fuel poor areas, then allows the assessment on fuel poverty to take place.

Arguments in Favour of District Heating for Low Heat Demand Density Areas

Further comment is worthy to the fact that the Parson Brinkerhoff (2009) tool is not fully encompassing for the examination of small scale district heating. It is not therefore a surprise to find that the Parsons Brinkerhoff (2009) tool indicates that there is not a viable option for district heating in the given rural case study of Westray. The reasons for this are given as the fact that for example it does not cover the likely energy sources which for example are anaerobic digestion and the refinements that would be required at the small scale considerations (Parson Brinkerhoff, 2009). However, it should be noted that there are some arguments in favour of district heating in Westray due to the fact that the island is a rural location and there is no gas on the island. Electric storage heating is the favoured option if a reliance of the grid is drawn upon. For island situations that are off-grid, district heating provides the benefit of primary energy efficiency. For instance, district heating would reduce the import of fuel to the island to run the diesel generator, and preferably change the energy source.

Furthermore, the neighbouring island of Papa Westray has had a study undertaken to determine the best method of energy provision (Whyte, 2009). It was concluded that there is scope for the use of heat pumps and wind turbines on the island in conjunction with ground sourced heat pumps. District heating could also become an option if housing density was high enough, and a portion of the village on Papa Westray is earmarked as appropriate (Whyte, 2009).

District Heating Trends between Iceland and the UK

This work has highlighted the variation in use of district heating between Iceland and the UK. The cost situation is approached and it is shown that there are different costs for the different schemes around Iceland. Although the cost of the Icelandic schemes are comparable due to the fact that there is the same energy source, there must be further comparisons made with the likelihood of varied energy sources being required in the UK. These cost comparisons therefore detail the requirements for an analysis of scale, which is approached by looking at Baron et al (2008). From the examination of costs from the UK and from Iceland for district heating piping, it is highlighted that perhaps a key expense in district heating deployment in the UK is due to the fact that it would have to be installed retrospectively. Since cost is a key determinant of district heating feasibility, these differences should be investigated further and compared with other country's installation costs.

In order to reduce costs there is the opportunity for several smaller schemes to be owned by a larger company. This means that their overheads can absorb some of the costs of the more expensive schemes therefore reducing the costs to the customer. In the UK, the lack of district heating schemes means that there is not a pool to draw from, however, as indicated an ESCo (Energy Services Company) can be run on a social enterprise or business model. An overarching body to administer the heat schemes in the UK which could be in the form of the local authority or indeed an energy company. This format would address the issue of the rural schemes being small, and therefore incurring higher costs as a result which often impacts on the customer. This is one way to address this issue of high capital investment and prevent it reflecting in the customer's costs.

While it is observed that geothermal is the main energy source for district heating in Iceland, an energy company (for example, Orkuveita Reykjavikur) could be both the

supplier and the distributor (for heat only). Therefore, it is a possibility that greater savings are arrived at purely because of this obvious and cheap, energy source plus the distribution method. It should therefore be noted that the variation in energy sources distributed via district heating in the UK would result in different energy prices.

Concluding Remarks

It is accepted that district heating is only suitable in appropriate communities. Various methods of determining these communities are derived through techniques as explored earlier. It is identified that both Baron *et al* (2008) and Parsons Brinkerhoff (2009) deal with the issue of energy demand; Baron *et al* (2008) denotes community classifications, while Parsons Brinkerhoff (2009) uses property numbers and density thresholds. After assessing these in conjunction with the case study location, this study suggests that there should be further research which could reveal that new cost incentives are applicable to these otherwise implausible small scale situations. With the pursuit of establishing a method to provide a greater consideration for smaller schemes it is also necessary to accept that each small scale case is individual and therefore perhaps difficult to apply set criteria of decision points for its suitability. It is these issues which require further attention in the future.

In suggesting the flow chart decision process for retrospective considerations, this study acknowledges that this list of additional requirements is not exhaustive; however it attends to the eventual requirements for district heating installations to be a serious possibility for the UK. Naturally, this requires special regard for the necessities of retrospective scenarios. This entails further refinements due to the complex mix of variables in the establishment of retrospective district heating and could well result in the requirement to treat each scenario individually omitting the temptation to generalise.

Fuel poverty may occur in remote areas where it is not so obvious that district heating would be cost effective. Where remote areas can have high transportation costs for fuel, they also have energy sources like wind. Urban areas lack the same opportunity to utilize wind power which may attract incentives. Government incentives, as outlined, help to bring the costs down in order to invest in district heating. It is for these reasons that district heating could become a consideration in the remote and rural parts, with some further assistance and tailor made advice to communities in the decision making process. Key further work would address the requirement for developing such a decision matrix for the small scale and retrospective situation specifically, with special regard for the economics. Mapping the correlation between fuel poverty levels and heat demand density is identified as being a useful method in identifying district heating opportunities where fuel poverty occurs. The overall impact that district heating can have on fuel poverty can therefore be determined. These techniques will ultimately allow assessment of the full potential for district heating as a solution to fuel poverty in the UK.

In summary, the requirements of further research for facilitating the deployment of district heating in the UK can be highlighted as follows:

- The cost of district heating piping networks between countries should be considered further as this investment is key to a district heating scheme's feasibility;
- The refinement of a decision matrix tool which either separately or inclusively addresses the requirements of small scale and retrospective district heating scenarios;

- The possibility of district heating solutions could be matched with fuel poor locations by firstly addressing the correlation between district heating opportunities and areas of low heat demand density through means of a mapping technique on the UK scale - as demonstrated by CSE for the London area

Ultimately the evolving government support mechanisms and incentives will have interesting impacts on the ultimate deployment of district heating in the UK, as fuel poverty, security of supply and climate change are addressed.

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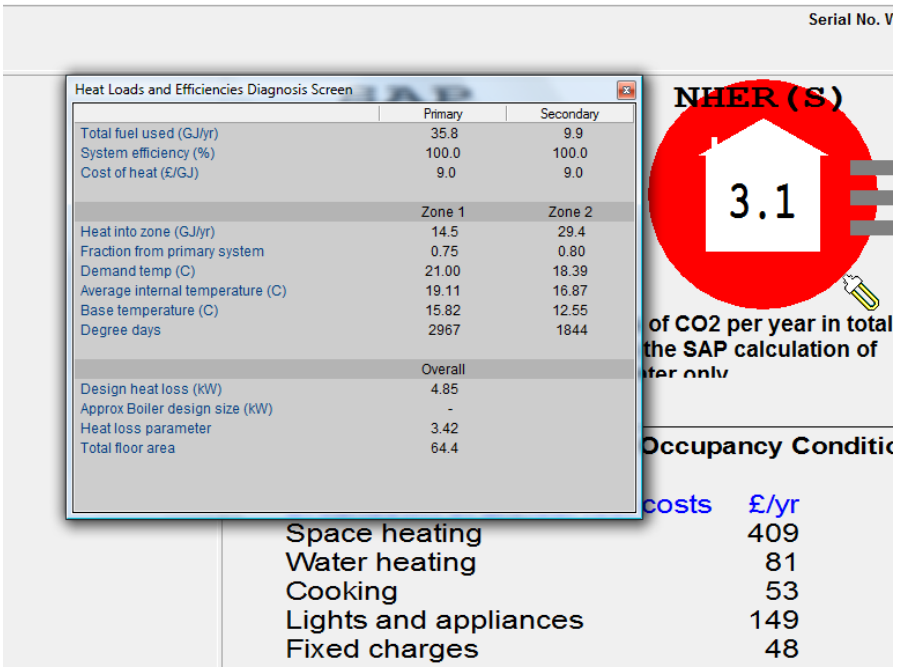
APPENDICES

APPENDIX 1

Energy Demand for Gill Pier, Westray, Orkney, UK

For the purposes of determining the energy demand to be fulfilled for the district heating scheme, each individual property on Gill Pier has been assessed for their current energy consumption. This is important in order to achieve a high level of efficiency in the district heating scheme overall. The domestic properties have been assessed using the National Home Energy Rating (NHER) software which then gives a design heat load for each property which can be used to compare consumption. Figure 1A below shows the diagnosis box which displays the information required for each property from the NHER software which was then used to gather results. Appendix 2 provides a definition of the design heat load. The commercial properties were organised to be assessed using the Energy Saving Trust Business Advisory Service (EST, 2009b). In this way, it is possible to obtain an impression of the energy consumed. It should be noted that in the scope of this work, it was not possible to carry out surveys for all properties however it is possible to take an average figure and use this for the complete set of houses.

Figure 1A: Heat Loads and Efficiencies Diagnosis Screen from the NHER software



	Primary	Secondary
Total fuel used (GJ/yr)	35.8	9.9
System efficiency (%)	100.0	100.0
Cost of heat (£/GJ)	9.0	9.0
	Zone 1	Zone 2
Heat into zone (GJ/yr)	14.5	29.4
Fraction from primary system	0.75	0.80
Demand temp (C)	21.00	18.39
Average internal temperature (C)	19.11	16.87
Base temperature (C)	15.82	12.55
Degree days	2967	1844
	Overall	
Design heat loss (kW)	4.85	
Approx Boiler design size (kW)	-	
Heat loss parameter	3.42	
Total floor area	64.4	

Results of district heating demand

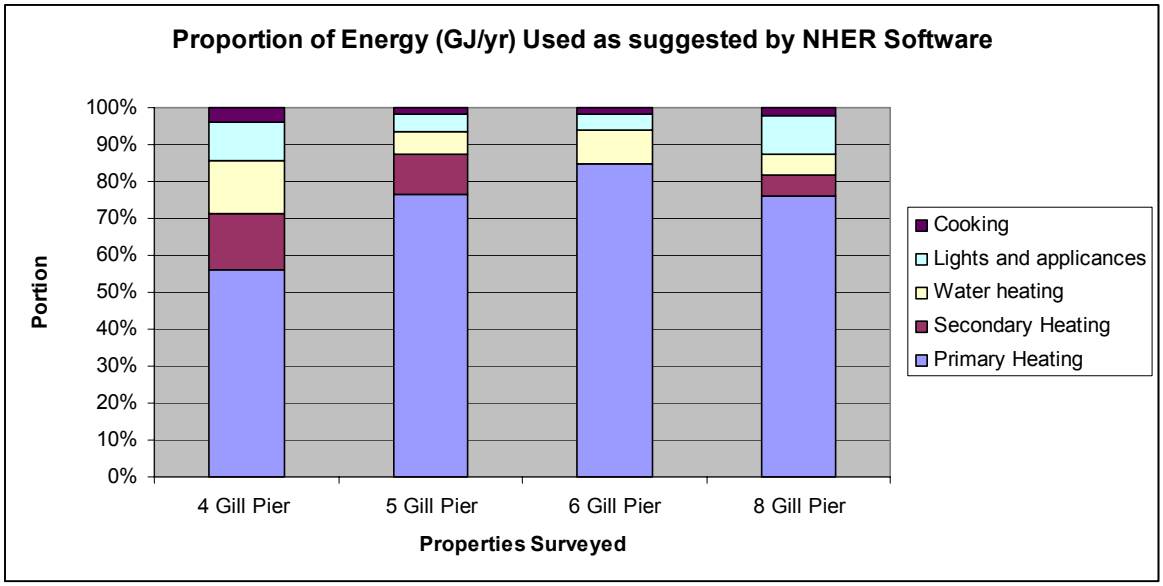
Table A1 shows the results of the consumption that has been carried out for the properties – both domestic and commercial.

Table A1: Breakdown of total demand for the 11 properties along Gill Pier, Westray

Type of Property	Address	Existing heating system	Energy for heating & hot water kWh	Notes
Residential	4 Gill Pier	electric	15,222	
Residential	5 Gill Pier	electric	30,806	
Residential	6 Gill Pier	Wet	71,639	
Residential	8 Gill Pier	electric	51,722	
Residential	3 Gill Pier	Wet	42,347	average used
Residential	7 Gill Pier	Wet	42,347	average used
Residential	9 Gill Pier	electric	42,347	average used
Residential	Harbours	Wet	24,188	
Residential / Surgery	NHS Surgery	Wet	83,074	
Industrial	Bakery	electric	60,116	
Industrial	Westray Processors	electric	60,479	
		TOTAL DEMAND	**524,287**	**kWh**

The NHER software allows the 4 domestic properties that were surveyed to be analysed to show the breakdown of energy use. It can be seen in Figure 1B that the primary heating constitutes the main energy requirement in the domestic properties. The primary energy can be therefore confirmed to be worthy of energy provision by the district heating scheme.

Figure 1B: Proportion of Energy (GJ/yr) as suggested by the NHER software



APPENDIX 2

Design Heat Load

The Design heat loss (also referred to as the design heat load) can be summarized as follows with reference to Plumbing Pages (2009). It identifies losses and therefore the design heating requirements for a property that includes:

Specific loss = fabric loss + ventilation loss

The design heat loss is therefore the amount of power which accounts for the heat losses via fabric and ventilation outputs from the house. This is the amount of power required to maintain the temperature inside the house. Fabric heat loss includes losses via the walls, floor, windows, roof from the inside to the outside of the property, and ventilation losses are included as are required to avoid health hazards as per building regulations.

Fabric loss is calculated using the different material's u-values which are calculated as the rate of loss of heat in watts per square meter of that element per degree centigrade temperature difference across that element. The equation is therefore:

Fabric heat loss (W) = U-value (W/ m^2 °C) * Area (m^2) * Temperature Difference (°C)

Ventilation loss is calculated using a ventilation factor which is taken as the specific heat of air at 200°C which is 0.33 W/ m^3°C to acknowledge infiltration or mechanical ventilation. The equation is therefore:

Ventilation heat loss (watts) = Room Volume (m^3) * Air change Rate * Temperature Difference (°C) * Ventilation Factor (w/ m^3°C)

The total of these values provides the heat load (or heat loss) value in watts.

APPENDIX 3

Domestic Energy Efficiency

Energy Efficiency improvements with savings gained for a domestic property are shown in table A3. Percentage of total saving demonstrates the most effective measure is solid wall insulation.

Table A3: Energy efficiency improvements for a detached house (EST, 2006)

Detached House	Saving (GBP/yr)			
Efficiency Improvement Measure	Min	Max	Median	Percentage of total saving
cavity wall insulations	210	250	£ 230.00	12%
solid wall insulation (external)	460	560	£ 510.00	27%
solid wall insulation (internal)	430	530	£ 480.00	26%
loft insulation (new installation)	210	250	£ 230.00	12%
loft insulation (top up)	60	70	£ 65.00	3%
floor insulation	60	70	£ 65.00	3%
replacement condensing boiler	130	160	£ 145.00	8%
hot water tank insulation	20	n/a	£ 20.00	1%
full heating control package	70	90	£ 80.00	4%
draught stripping	20	n/a	£ 20.00	1%
lighting	15	20	£ 17.50	1%

APPENDIX 4

ABERDEEN HEAT AND POWER LTD CASE STUDY: SOCIAL ENTERPRISE FOR USE WITH DISTRICT HEATING

An Energy Services Company (ESCo) can be run as a social enterprise or as a profiting business. The ESCO, **Aberdeen Heat and Power** is set up as a social enterprise.

ABOUT Aberdeen Heat and Power (AH&P) Ltd

AH&P was set up in 2002 for the people of Aberdeen, providing Combined Heat and Power (CHP).

The surplus income is to be used on 2 criteria:

- To reduce heat charges for the users of the scheme
- To roll it back into the capital for next developments

THE BOARD

The Board of 10 is based on the Housing Association model:

- Directors on the board, including 2 nominated councillors (never with the majority) and 2 tenant representatives who sit for 3 years at a time.
- Board is selected to provide the needs of a company and so includes people with the relevant skills e.g. finance, technical background etc
- Board members are volunteers but paid for expenses
- There are 3 Sub-groups: Development, Staff, Finance
- The board and its sub groups meet quarterly

DAILY OPERATION OF THE ESCo

Daily operation of the management and finance were initially managed by Janice Lyon before 2 paid staff were employed; a General Manager and someone for Administrator, Finance, and book keeping. They are paid from the income generated by the scheme. Paid staff were really needed from the beginning but was not factored in the initial start-up money requirements.

EXPANSION OF THE SCHEME AND FUNDING

Janice herself now concentrates on the funding exploration for expansions for the scheme.

The current arrangement is that there are 14 multi-storey buildings on Combined Heat and Power (CHP), 7 public and 1000 dwellings supplied using 3 separate heat networks. Further expansion would include the addition of another 2000 dwellings in multi-storey blocks. The optimal size of these is unclear, as the distance between the multi-storey blocks is greater and unknown values for the economies of scale come into it.

With this model, it is then possible to become less reliant on grant funding as time goes on.

For example, Janice has used 40% grants from the former EST "Community Energy" fund, for 3 of the initial developments. As she looks for £3.5m to fund the next stage (possibly the gasification of biomass), she finds that grants are required less and less and that the system becomes more sustainable and can be initiated by the use of surplus income. She may only need a 28% grant and next time it may only be a 20% grant. This is supplemented by the use of profit from the generation of electricity which is used to repay the borrowing.

The heating installation for an individual costs £6500 per dwelling. Janice Lyon of ACC has modelled the Aberdeen Heat and Power structure on that of Housing Associations and their financial model (Lyon, 2009).

APPENDIX 5

Table A5: Pipe lengths by Dodd (2008) as cited by Baron *et al* (2008)

Housing typology	Form	Net density	Pipe length	Cost
		Dwellings / hectare	Metres	£ / dwelling
High-rise apartment block	Corridor access, 10–15 storeys	240	6.75	£2,500
Medium-rise apartment block	Corridor access, 5–6 storeys	120	8	£2,800
Perimeter block of flats and townhouses	Stairwell / street level access, 3–4 storeys	80	11	£4,100
Terraced street of row houses	Street level access, 2–3 storeys	80	13	£5,300
Detached /semi-detached houses	Street level access, compact street layout	40	19–24	£7,700–£9,550