Decarbonising heat in buildings: 2030–2050

Summary report

for

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Annex A District heating background and methodology

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This report summarises the results of analysis provided to the Committee on Climate Change to inform the review of low carbon heat as part of the CCC’s International Aviation and Shipping Review. The scenarios are indicative only and are not necessarily consistent with the final scenarios developed by the CCC and published as part of the IA&S Review.

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1 Introduction

This report summarises the results of a study into potential pathways to decarbonise heat in UK buildings by 2050, undertaken by Element Energy and AEA for the Committee on Climate Change. Full details of the study are provided in an accompanying report.

1.1 Context

This study was commissioned in the context of the CCC’s aviation and shipping review, which will advise the UK Government on the inclusion of emissions from international aviation and shipping (IA&S) in carbon budgets. In its Fourth Carbon Budget report, the CCC recommended that the UK Government should accept the principle that emissions from IA&S are included, but noted that further analysis is required to establish methodologies for their inclusion.¹

Given the limited scope for abatement in the aviation and shipping sectors, an overall target of 80% greenhouse gas emission reduction by 2050 is likely to require deeper cuts in other sectors. This study builds on previous work on renewable heat undertaken for the CCC (which considered potential uptake to 2030), extending the timeframe to consider pathways for decarbonising heat from 2030 to 2050.

The long term future of low carbon heat deserves consideration now to understand to what extent decarbonising heat supply is possible, and the characteristics of a decarbonised heat sector in the UK. Such analysis can inform nearer term decisions on how to prepare for long term ambitions and highlight potential implications for other sectors.

1.2 Aims and scope

The primary aims of this study are to:

- Revisit and extend existing analysis of potential uptake of renewable heat to 2030.
- Explore the long term options for decarbonising heating and cooling in the UK.
- Create scenarios for decarbonising heat to 2050 and illustrate the associated impacts in terms of costs and interactions with other sectors, notably power generation.

A scenario-based approach is used to understand the implications of alternative mechanisms to decarbonise heat supply in buildings in the UK, including the associated costs and technical challenges. An overview of the methodology is provided below.

The period of interest for this study is 2030–2050. The 2030 starting point in terms of renewable heat uptake in the UK is informed by previous modelling undertaken by the CCC and used in the Fourth Carbon Budget report.² The focus of the current study is heat use in UK buildings across the residential, commercial / public and industrial sectors, excluding industrial process heat.³

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¹ The Fourth Carbon Budget, Reducing emissions through the 2020s, Committee on Climate Change, p.101, (December 2010).
² Decarbonising Heat: Low-Carbon Heat Scenarios for the 2020s, NERA & AEA for the CCC (June 2010).
³ Options for decarbonising the process heat sector are being evaluated in a separate study for the CCC.
Broadly speaking, there are two main options for decarbonising heat supply to buildings. One is a building-by-building approach (where low or zero carbon heat supply technologies are installed in each building), and the other involves linking multiple buildings together and serving the demands via a community or district heating scheme, fed by a source (or multiple sources) of low carbon heat. In this study we consider both approaches in order to explore the role of community / district heating in the long term supply of heat to UK buildings.\(^4\)

### 1.3 Methodology

Previous studies for the CCC have projected the uptake of renewable heat to 2030 using traditional forecasting techniques. For this study, which focuses on the period beyond 2030, a scenario approach was deemed more appropriate than an uptake model, as it allows us to examine the impact of various alternative futures. The **scenario approach** involves defining the proportion of the technical potential for renewable heat reached by 2050. With the 2030 starting point (in terms of renewable heat uptake) set by results of previous CCC analysis, we extrapolate between the two dates to understand the implications of defined scenarios relative to a baseline.\(^5\) This includes calculating metrics related to economics (resource cost), CO\(_2\) emissions from the heat sector, and wider energy system impacts (e.g. fuel demands). The overall approach is summarised in the following diagram.

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**Figure 1: Scenario approach – overview**

Further details of the scenario approach and the methodology for assessing the potential for district heating are given in the full report.

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\(^4\) District heating currently plays a small role in the UK’s heat sector, meeting around 2% of heat demands. The opportunity to use district heating as a delivery mechanism to supply heat from low carbon sources provides an incentive to consider its potential in detail.

\(^5\) The scenarios are defined to represent alternative futures, for example maximising the technical potential of building-scale renewable heating options, or exploiting the estimated economic potential of district heating.
2 Heat demand projections: 2030–2050

2.1 Overview

Given that the scale of the challenge of decarbonising heat supply will depend on future demands for heat, we must first establish a baseline for thermal demand projections over the period of interest. Gaining an understanding of the potential impact of demand reduction measures is an important first step in assessing the role of low carbon supply options. Efforts are underway to improve the energy efficiency of the UK’s building stock, which currently accounts for a total heat demand of around 613TWh/yr across the domestic and non-domestic sectors, as shown below.

![Thermal demands of buildings in the UK by sector in 2011 (TWh/yr)](image)

*Data source: NERA / AEA for the CCC (2010).*

**Figure 2:** Approximate thermal demands of the UK’s building stock by sector

The diagram below summarises some of the principal factors that influence total carbon emissions arising from meeting the UK’s buildings’ thermal demands.

![Factors influencing carbon emissions arising from meeting thermal demands of buildings](image)

**Figure 3:** Factors influencing carbon emissions arising from meeting thermal demands of buildings

As this diagram suggests, thermal demands are dictated by various factors and of course there is a high level of uncertainty associated with forecasting future heat demands. We
therefore consider future demands under Low, Central and High energy efficiency scenarios.

2.2 Energy efficiency scenarios to 2050

The domestic sector energy efficiency scenarios involve setting the amount of the technical potential achieved for a range of (retrofit) energy efficiency measures, including:

- Cavity wall insulation
- Loft insulation
- Solid wall insulation
- Double glazing
- Draught proofing

The main differentiating factor between the Low, Central and High domestic energy efficiency scenarios is the level of solid wall insulation rollout. The Element Energy Housing Energy Model was used to estimate the effect of the energy efficiency measures to assess the potential aggregate impact on thermal demands in the domestic sector.

For consistency with previous CCC analysis, we assume limited potential for retrofitting energy efficiency measures in the non-domestic sector beyond 2030 (as much of the technical potential is assumed to be exploited by this date). Instead, the non-domestic energy efficiency scenarios are differentiated by varying the demolition rate assumption, i.e. the rate at which old, inefficient buildings are replaced with thermally efficient new builds. Further details related to the energy efficiency scenarios are provided in the main report.

2.3 Thermal demand projections

The projected thermal demands of UK buildings (excluding process heat in industry) under each energy efficiency scenario are plotted below.

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6 For consistency with previous CCC analysis we assume the technical potential of cost-effective insulation measures such as cavity wall and loft insulation is saturated by 2030.
The equivalent thermal demand figure for 2011 (i.e. buildings in all sectors excluding process heat) is around 480TWh/yr (see Figure 2 above). We can see that even with ambitious energy efficiency rollout projections, the scope for reducing UK buildings’ thermal demands is limited. Low carbon supply is therefore likely to be crucial in any efforts to decarbonise the heat sector.

Note that underlying these projections is an assumption that the UK’s population (and building stock) grows substantially by 2050. A critique of this (and other) assumptions is provided in the annex to the main report.
3 Definition of scenarios for low carbon heat supply: 2030–2050

3.1 Baseline

All scenarios for low carbon heat supply are evaluated against a defined baseline. The baseline, like the scenarios, takes a 2030 starting point from the CCC Central scenario developed to inform the Fourth Budget analysis, which shows renewable heat meeting around 35% of total thermal demands in 2030 (including process heat).

Under the baseline the overall share of heat demand met by renewable heat is maintained at approximately the same level to 2050. This represents a future with minimal further ambition for renewable heat beyond 2030 and provides a useful starting point against which alternative scenarios are compared.

Table 1: Contribution of each heating technology to total thermal demands in buildings in 2050 (all sectors) under the baseline

<table>
<thead>
<tr>
<th>Thermal demand met in 2050 under the baseline</th>
<th>Proportion of total thermal demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas boilers</td>
<td>207</td>
</tr>
<tr>
<td>Oil boilers</td>
<td>21</td>
</tr>
<tr>
<td>Direct electric</td>
<td>34</td>
</tr>
<tr>
<td>Heat pumps</td>
<td>155</td>
</tr>
<tr>
<td>Biomass boiler</td>
<td>14</td>
</tr>
<tr>
<td>District heating</td>
<td>45</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>2</td>
</tr>
</tbody>
</table>

Other features of the baseline include:

- **Thermal demand projections**: based on Central case energy efficiency scenarios for each sector.
- **Fossil fuel prices**: gas and heating oil costs from DECC (IAG) forecasts (2011). Central case values (variable element) used in the baseline.
- **Electricity prices**: from CCC’s power sector modelling (core scenario).
- **Fuel carbon intensity values**: from IAG guidance for gas and oil; provided by the CCC for electricity (consistent with the selected power sector scenario).

3.2 Decarbonisation pathways

Various scenarios were developed to represent alternative routes to a low carbon heat future. The scenarios represent exploitation of different levels of the technical potential for renewable or low carbon heat sources and have been developed to be consistent with other CCC analysis. For example, the recently published Bioenergy Review states that:
Scenarios for global land use which take account of required food production suggest that a reasonable UK share of potential sustainable bioenergy supply could extend to around 10% (200 TWh) of primary energy demand in 2050.\(^8\)

Furthermore, the CCC’s view is that the bioenergy available in the long term will be best used in other sectors (such as industrial process heat or in the power sector with carbon capture and storage). Based on the thermal demand forecasts (presented above), these figures suggest that bioenergy may have a relatively limited role to play in the long term decarbonisation of heat supply in the UK. With such a restriction in mind, the following core scenarios were developed to explore the impact of exploiting the technical potential for renewable or low carbon heat.\(^9\)

- **Policy extension** – existing policies are assumed to continue to 2030 and beyond, incentivising the uptake of mainly building-scale renewable heating options. There is no further uptake of district heating relative to the baseline; instead the technical potential for building-scale renewable heat is fully exploited by 2050.

- **DH, constrained** – represents an alternative future with strong support for developing district heating networks. The majority of heat supply for these networks comes from thermal power stations and the potential is constrained by the number of stations in existence and in reasonable proximity to heat loads.

- **Electrification** – scenario in which uptake of building-scale renewable heat is restricted (to approximately half the level in the policy extension scenario); instead thermal demands are switched to direct electric heating by 2050. DH uptake is as per the baseline.

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\(^8\) *Bioenergy Review*, the CCC, p.9 (December 2011).

\(^9\) With limited availability of bioenergy, the most appropriate use of the scarce resource will be determined by various factors (e.g. demand from other sectors, source of bioenergy etc.). The CCC has developed its own assumptions and recommendations on future bioenergy use.
4 Results

4.1 Core assumptions

The results below must be considered in the context of the key modelling assumptions, summarised in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Summary of key modelling assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Assumption</strong></td>
</tr>
<tr>
<td><strong>Discount rate</strong></td>
</tr>
<tr>
<td><strong>Fuel costs</strong></td>
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<tr>
<td><strong>Technology costs</strong></td>
</tr>
<tr>
<td><strong>Suitability of buildings for renewable heat</strong></td>
</tr>
<tr>
<td><strong>Fuel carbon intensity</strong></td>
</tr>
</tbody>
</table>

Important note

The results below correspond to scenarios where the future mix of heating technologies has been set manually. No uptake model has been used in generating these results – i.e. there has been no representation of consumer decision-making or assessment of the policies required to realise such futures. The scenarios should not be interpreted as representative of our view of the future heating market in the UK.

4.2 Heat output and CO₂ emissions

With full exploitation of the technical potential of renewable heat, the policy extension and DH, constrained scenarios lead to a complete shift in the UK’s heating market by 2050. Similarly, gas and oil boilers are completely replaced by mainly heat pumps and direct electric heating under the electrification scenario, as shown below.

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10 This was not an aim of this study, rather the scenarios are defined to gain insights into potential costs and wider implications of alternative futures.
The overall heat delivered under each scenario reflects the total thermal demand of the building stock, which in turn is set by the energy efficiency scenario selected (Central under the baseline and High efficiency for the scenarios above).

Clearly, these scenarios (and even the baseline) represent a significant deviation from the current heating market in the UK (which is dominated by fossil fuels, predominately natural gas). This magnitude of change to the UK’s heating market is unlikely to come about without clear, long-term policies to direct the transformation. If successful, the Renewable Heat Incentive will initiate a market for renewable heating technologies, but previous analysis demonstrates that continued support for renewable heat is likely to be required into the next decade and beyond to bring about sustained uptake. Replacing all fossil fuel heating systems with renewable heat by 2050 is a stretching ambition that ultimately is likely to need “sticks” as well as “carrots”, i.e. the eventual phasing out of traditional fossil fuel boilers. The design of any such policy would have to consider a wide range of impacts, including fuel poverty, consequences for existing and developing supply chains, and practical issues relating to a wholesale shift in the heating market.

The consequent impact on CO₂ emissions has been calculated for the scenarios above and for context total remaining emissions are compared against estimated total emissions due to heating in 1990. Remaining emissions under each scenario (due to total fuel consumed) in 2050 are presented in the graph below.

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12 The tightening of Building Regulations (Part L) towards zero carbon buildings from the end of this decade will provide a strong incentive to specify renewable heating systems in new buildings (since it will become increasingly difficult to meet the regulations without doing so).
13 This was the selected reference year since long-term cross-sector UK CO₂ emission reduction targets are set relative to 1990 emissions (e.g. in the Climate Change Act).
Figure 6: CO₂ emissions from heating in 2050 under the baseline and a selection of low carbon scenarios

These results show that the baseline represents a two-thirds reduction in emissions from the heat sector relative to 1990 levels. Scenarios under which fossil fuel heating is almost completely phased out by 2050 could lead to a reduction in excess of 90% relative to 1990 emissions. This level of emission saving depends on:

- An order of magnitude drop in the carbon intensity of grid electricity (relative to today’s levels). The emissions presented above are calculated using an emission factor of just under 50gCO₂/kWh for grid electricity in 2050.
- Development and eventual complete dominance of a renewable heating market in the UK such that the use of fossil fuels is practically eliminated by 2050. This would have major implications for infrastructure such as the gas grid and power sector (we discuss this further in the full report).
- High levels of suitability for renewable heat in UK buildings (we test the impact of suitability assumptions in the sensitivity analysis below).

Note that emissions remain in 2050 even with a near total shift to renewable heating due to the existence of a significant thermal demand (and the fact that according to our assumptions, none of the fuels is zero carbon by 2050).

### 4.3 Economic impacts

We assess the costs of each scenario by calculating the resource cost, defined as the sum of the annualised capital costs of heating system installations together with annual fuel and maintenance costs. The total annualised resource costs (for all buildings) under the scenarios described above are presented below, split by capital costs (capex), maintenance (opex), and fuel costs.¹⁴

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¹⁴ Note that the costs of energy efficiency measures are not included in the resource costs presented here.
These results suggest that when evaluated at a social (i.e. low) discount rate, the total resource cost of the policy extension and DH, constrained scenarios is comparable to the baseline. Relative to the baseline, these scenarios represent a shift away from fossil fuel (mains gas) boilers, largely towards the installation of heat pumps (and additional deployment of district heating fed mainly by heat from power stations in the case of the DH, constrained scenario). Figure 7 demonstrates that these scenarios exhibit higher overall capital costs but lower maintenance and fuel costs, which is consistent with the characteristics of renewable heating systems. This result (of minimal additional resource cost relative to the baseline) depends on substantial cost reductions in installed cost of heat pumps (equivalent to nearly 40%) being realised by 2030. The results of a sensitivity test to this assumption are presented in the full report.

The electrification scenario leads to a significant cost increase relative to the baseline due to the high number of consumers switched to direct electric heating (and therefore exposed to high ongoing fuel costs). These results suggest that on the whole heat pumps are likely to be a more cost-effective solution to decarbonise heat (rather than direct electric heating) in a future with a plentiful supply of low carbon electricity.

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15 Note that the electrification scenario includes high uptake of solar thermal relative to the baseline (>15m installations by 2050), included for consistency with the high energy efficiency uptake assumed. This accounts for a large part of the increase in capital costs seen under this scenario.
5 Sensitivity analysis

5.1 Energy efficiency scenario and grid electricity carbon intensity

The results above suggest that deep cuts in emissions could be attained by shifting the UK’s heating market away from fossil fuels, and instead relying on low carbon electricity to meet thermal demands. We stress test the results by varying a number of key assumptions, as summarised in Table 3.

Table 3: Energy efficiency and electricity carbon intensity sensitivity analysis

<table>
<thead>
<tr>
<th>Input variable</th>
<th>Value in lead scenario</th>
<th>Variation analysis value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency (EE) scenario</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>CO₂ intensity of grid electricity</td>
<td>390gCO₂/kWh in 2030, falling to 49gCO₂/kWh in 2050</td>
<td>390gCO₂/kWh (constant over time)</td>
</tr>
</tbody>
</table>

The impact of these variation analyses are shown below for each of the three main scenarios.

Figure 8: CO₂ emissions from heating in 2050 – sensitivity analysis results, policy extension scenario

These results show that given an abundant supply of low carbon electricity, a reduced level of energy efficiency rollout has a relatively limited impact on emissions. In practice, energy efficiency rollout is expected to be important in ensuring widespread suitability of buildings for renewable heat; however limits on data availability mean that this effect cannot be captured in the modelling.

The high reliance on electricity makes CO₂ savings highly sensitive to grid carbon intensity. However, the rollout of heat pumps provides some level of insulation against this effect relative to direct electric heating, as demonstrated by the results below.
Figure 9: CO₂ emissions from heating in 2050 – sensitivity analysis results, electrification scenario

These results highlight the fact that meeting thermal demands via direct electric heating will only offer carbon savings (relative to gas) if the grid carbon intensity falls significantly from current values.  

The carbon intensity of heat from natural gas is around 200gCO₂/kWh. Grid carbon intensity would need to be below this level (from around 500gCO₂/kWh currently) for direct electric heating to provide a benefit in carbon terms. Heat pumps can provide savings even with relatively high carbon electricity due to the high efficiency values possible.
under the policy extension scenario). District heating could provide some hedging against failure to decarbonise electricity supply; the amount is clearly proportional to the overall level of DH uptake.

It is clear from the results above that failure to decarbonise electricity supply is a key risk to meeting emission reduction targets.

### 5.2 Discount rate

Resource costs are calculated using a social discount rate of 3.5% under the core scenario runs, and we investigate the impact of this metric through a sensitivity test using a rate of 7.5%.

**Figure 11: Resource cost in 2050 – sensitivity analysis results**

The impact of discount rate is clear from the results above, which demonstrate the higher sensitivity of more capital-intensive futures to discount rates. At commercial discount rates
(typically in excess of 10%), the costs of scenarios with high levels of renewable heating and / or district heating uptake relative to the baseline are higher still.

5.3 Suitability for renewable heat

5.3.1 Overview

Due to their different characteristics, renewable heating systems are not necessarily direct replacements for incumbent installations. For example, biomass boilers tend to be physically larger than fossil fuel equivalents and require additional space for fuel storage; low temperature heat distribution is required to maximise the efficiency of heat pumps etc. The proportion of the building stock that is technically suitable for renewable heating technologies is a necessary assumption derived from detailed analysis of the characteristics of the building stock, but also a relatively uncertain factor. The core scenario runs include optimistic assumptions in relation to suitability for renewable heat; hence we explore the impact of more conservative figures below.17

5.3.2 Suitability scenarios

Suitability factors (which account for factors such as physical space restrictions, grade of heat and environmental factors) were derived by AEA and are used within the model to distribute the renewable heating technologies in buildings. However, the overall penetration of renewable heat depends on the level of overlap of technically suitable buildings between the different technologies. For example, if ASHPs, GSHPs and biomass boilers are each considered suitable in 50% of suburban semi-detached houses the overall potential for renewable heat in houses of this type could be:

- 50% (half of houses could install any one of the three and half can install none, referred to as “perfect overlap”).
- 100% (this represents the other extreme, which we call “no overlap”).
- A proportion of houses between these two extremes.

The model includes functionality that allows the user to specify which of these three alternatives will be represented and this forms the basis of our sensitivity analysis.

Table 4: Suitability scenarios – overview

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core runs</td>
<td>Optimistic suitability assumptions, the “no overlap” scenario described</td>
</tr>
<tr>
<td></td>
<td>above.</td>
</tr>
<tr>
<td>Intermediate suitability</td>
<td>Overall technical potential for renewable heat set to an intermediate</td>
</tr>
<tr>
<td></td>
<td>value between the “no overlap” and “perfect overlap” cases.</td>
</tr>
<tr>
<td>Conservative suitability</td>
<td>Less optimistic suitability assumptions, corresponding to the “perfect</td>
</tr>
<tr>
<td></td>
<td>overlap” case outlined above.</td>
</tr>
</tbody>
</table>

17 Given their technical and economic characteristics, heat pumps are expected to be the primary building-scale renewable heating option in the medium to long term. In this study we estimate that heat pumps could supply low carbon heat to around 65%–85% of the building stock depending on assumptions regarding technology suitability and acceptability.
5.3.3 Results

We examine the impact of varying the suitability assumptions using the *policy extension* scenario as an example. The graph below shows heat served by technology for the core run, intermediate and conservative suitability scenarios.\(^\text{18}\)

![Heat output by technology in 2050 (all sectors)](image)

**Figure 12: Heat delivered by technology in 2050 – suitability sensitivity testing**

With optimistic suitability assumptions, heat pumps dominate the heating market in 2050 under the *policy extension* scenario, with less than 4% of heat demands being served by fossil fuel boilers. At the other extreme (in terms of suitability), fossil fuel boilers serve around a third of the total thermal demands in the *policy extension, conservative suitability* scenario, with a significant impact on CO\(_2\) emissions, as shown in Figure 13 below.

\(^{18}\) Note that with the exception of suitability assumptions, all inputs are constant between results for the *policy extension* scenarios.
Clearly, the suitability of the UK’s building stock for renewable heat is a very important (and relatively uncertain) parameter. Of particular concern (given the expected leading role of the technology) is the suitability of heat pumps in retrofit applications. The main issues include:

- Lack of space to install the equipment in some properties.
- The need for a hot water tank given the recent trend for removing hot water cylinders from homes (with the growing market share of combination boilers in recent years).19
- Questions regarding whether the technology can meet all of a building’s thermal demands whilst achieving the expected efficiency value.

The European Heat Pump Association notes that:

“While the market for heat pumps in new residential buildings has picked up momentum and is even self sustaining in some countries, their application in the retrofit segment as well as in commercial and industrial buildings is just starting.”20

Some empirical data on heat pump performance in the UK comes from the Energy Saving Trust field trials.21 While initial results showed disappointing heat pump performance22, the trial has continued, focusing on measures to improve the performance of the installations. Further results are expected by autumn 2012, which should provide valuable insights and lessons related to maximising heat pump performance.23

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19 This issue is discussed in further detail in the main (powerpoint) report.
22 The trial involved monitoring 83 heat pumps in locations throughout Britain. Many of the units were installed in 2008, before the introduction of the Microgeneration Certification Scheme. The disappointing performance figures were largely due to poor system design, installation and in some cases operation.
23 Personal communication with The Energy Saving Trust (February 2012).
The Renewable Heat Premium Payment Scheme will provide more recent data on the performance of heat pumps via the monitoring that is being undertaken. At the time of writing no data from this exercise have been published, however early indications are that efficiency values of the monitored systems are promising.\textsuperscript{24}

Current evidence suggests that there are fewer suitability constraints to retrofitting district heating in terms of technical performance and we reflect this in the modelling by not varying the level of DH deployment by suitability scenario. Emissions savings under the DH, constrained scenario are therefore less sensitive to suitability assumptions, as the graph below shows.

\textbf{Figure 14: CO\textsubscript{2} emissions from heating in 2050 – suitability sensitivity testing with the DH, constrained scenario}

So in addition to having whole life costs comparable with building scale renewable heating and reducing the exposure of emissions from the UK’s heat sector to grid electricity carbon intensity, the rollout of district heating could mitigate the concerns relating to suitability for building-scale renewable heat.

\textsuperscript{24} Source: personal communication.
6 Conclusions

6.1 Thermal demand in the UK over the period 2030–2050

- With continued growth in the UK’s building stock to 2050, the potential for reductions in overall thermal demand relative to today's is limited. Projected total UK building heat demands in 2050 range from 416TWh/yr (High efficiency scenario) to 532TWh/yr (Low efficiency scenario). For reference, the equivalent figure for 2011 is around 480TWh/yr.

- Even stabilising demands at current levels will be a significant challenge in a future with increasing population and building stock. This fact should not undermine demand reduction efforts; on the contrary, energy efficiency rollout and other measures (such as behaviour change) should continue to be promoted.

- The thermal demand projections imply that low carbon supply will be an essential element of meeting emission reduction targets.

6.2 Scenarios for low carbon heat supply to 2050

- This study’s results support an ambition for the UK’s heat sector at least in line with the overall 80% cut in emissions by 2050, provided that the power sector is largely decarbonised over the same period.

- There exist a limited number of pathways to achieving ambitions at or beyond this level. Features of all include:
  - A near complete shift in the heating market beyond 2030, i.e. the growth in market share of renewable heating technologies shown in previous CCC modelling to 2030 must continue over the following decades.
  - An order of magnitude drop in the carbon intensity of grid electricity relative to today’s values.
  - An abundant supply of ultra-low carbon electricity for heating.

- The suitability of the existing building stock for renewable heating technologies becomes an increasingly important factor in the longer term under futures with high levels of decarbonisation. Further empirical evidence is required on the performance of renewable heating technologies, particularly in retrofit applications, to validate modelling assumptions.\(^{25}\)

- The most robust low carbon heat supply pathways will involve a mix of technologies. While a high reliance on electrification of heating is expected to be needed (together with grid decarbonisation), district heating could have an important role in protecting against:
  - The risk of failing to decarbonise electricity supply.
  - The uncertainty regarding suitability of the existing building stock for building-scale renewable heating technologies.

\(^{25}\) Further performance data will become available from monitoring as part of the Renewable Heat Premium Payment Scheme; and from the Energy Saving Trust’s heat pump trials, which are ongoing and further results are expected to be available by autumn 2012.
6.3 The role of district heating in decarbonising heat supply

- District heating is likely to play a role in decarbonising heat supply in buildings in the UK. Employing a mix of technologies offers a number of advantages and this study's results suggest that DH could be cost-competitive with building-scale renewable heating technologies (when evaluated at a social discount rate) provided that deployment is focused in regions of highest heat density.

- In a biomass-constrained future the sources of low carbon heat supply for district heating may be limited, and in the long term the majority of heat supply to DH is likely to come from thermal power stations.

- The annual amount of heat which could in theory be extracted from current thermal power stations is similar in magnitude to the total annual thermal demand of all dwellings and service sector buildings in the UK. As shown in the main report, about 80% of thermal demand is technically suited to DH, the rest being in areas too sparsely populated and more suited to building scale heating systems.

- In theory power stations could therefore supply all buildings suitable for DH if very well insulated seasonal thermal storage with losses below 25% could be constructed. However, seasonal storage is very expensive due to the large volumes and high insulation requirements, so diurnal (daily) thermal storage is more likely to be used in the near future. With diurnal thermal storage, power stations could theoretically provide around 35% of annual demand. However, this is unlikely to be delivered in practice as thermal power station capacity and demands are geographically distributed very differently, meaning prohibitively long connections would be required. We estimate a maximum of 28% of thermal demand could be supplied by existing power stations within reasonable connection distances but note that this would require a high degree of co-ordination of DH development and clustering near existing thermal power stations.

- For the greatest penetration and / or most cost- and carbon-effective outcome, DH networks and thermal power station developments should be co-ordinated to maximise opportunities for DH supply from power station heat.

- In addition, within the anticipated availability constraints for heating purposes, a maximum of 9% of non industrial heating demand could be supplied by biomass boilers, less any used for thermal purposes in industry and individual building scale boilers, and around 3% of demand could be supplied by water source heat pumps.

- The numerous barriers associated with district heating rollout (identified in previous studies)27 will have to be overcome for its economic potential to be exploited, which could see it up to around a quarter of future heat demands being met by district heating.

- Biomass-fed district heating is unlikely to feature widely in the heat supply mix in 2050 (based on the findings of the CCC’s Bioenergy Review). However, large scale biomass boilers could be an important technology in the short to medium term to facilitate the development of local DH networks, and eventually clusters that can connect to power stations in the longer term.

26 Such storage would be needed to accumulate surplus heat generated in summer for use during winter.
27 For a concise overview of the barriers, and references to further relevant studies, see: Achieving deployment of renewable heat, Element Energy and NERA for the CCC, section 4.3.6, (April 2011).
6.4 Wider impacts of decarbonising heat supply

- In a future with limited supplies of sustainable bioenergy (e.g. consistent with the CCC’s Bioenergy Review), the high reliance on low carbon electricity to decarbonise heat will put upward pressure on electricity demands. For example, electricity demands for heating reach 100TWh/yr in 2050 under the policy extension scenario (over a quarter of the UK’s total electricity consumption in 2010).

- Shifting the majority of the UK’s heating systems from fossil fuel boilers to (largely) heat pumps will also increase peak demands on the electricity grid. Under the same scenario, peak electricity demands due to heating are estimated to be around 65GW (a figure similar to today’s total peak demands).

- This suggests a need for greatly increased peak generating capacity, combined with measures such as demand side response and thermal storage to reduce the impact.

- Impacts on local distribution networks are also likely to be significant (e.g. potential voltage drops, overloading transformers etc.) under a future with high electrification of heating. While the extent of grid upgrades required would vary by region, it is likely that significant investments would be needed.

6.5 Risks to decarbonising heat supply

- **Failure to decarbonise electricity supply** is a key risk to meeting emission reduction ambitions in the heat sector due to the important role of low carbon electricity in any decarbonised heat future.

- **Lack of suitability for renewable heat** (e.g. due to space restrictions or grade of heat required) is another significant risk. Although with very low carbon electricity available, direct electric heating could be used to meet high CO₂ reduction ambitions (albeit at significantly increased cost at the national level (relative to widespread heat pump uptake)). Increased district heating rollout offers a further means of mitigating this risk.

- Continued availability of relatively cheap gas and indifference towards carbon saving could restrict the uptake of renewable heating technologies. A complete switch to low carbon supply will require a sustained economic case for renewable heat and/or the mandatory rollout of low carbon technologies in the medium to long term.
Annex A District heating background and methodology

As part of this study AEA supplied district heating technical and cost data input assumptions to the main economic model. To produce data in the format required for the model AEA carried out a considerable amount of independent techno-economic modelling, using highly disaggregated sector and spatial thermal demand data along with technical and cost data for DH and heat plant collated from a variety of sources.

A.1 Introduction to DH

District Heating (DH), also known as Community Heating, refers to the provision of heat generated centrally and then distributed, using hot water or steam, to users through a network of pipes. For non industrial district heating, water is typically circulated at around 90–110°C (depending on the size of scheme) and feeds conventional central heating and hot water systems, either directly via a hydraulic board which reduces pressures and temperatures to those appropriate for the buildings, or via heat exchangers.

While DH has been used in the UK since the 1950s it currently only provides a small proportion (c. 2%) of total heat demand in the UK with many schemes abandoned in favour of individual heating systems. In contrast, countries such as Finland and Denmark with a long history of DH, have 49% and 60% respectively of their total heat demand provided by DH and in their urban areas in excess of 90% of all buildings are connected to DH networks.

Whilst DH penetration in Germany and France is considerably less mature, it is still higher than the UK with both countries having strategies to increase DH penetration so it is more appropriate to draw comparisons between the UK and these countries. DH currently serves around 14% of the heat demand in Germany and this is expected to rise to around 20% as a result of Government policy. In France the current DH penetration is around 5% with a target to increase the share of renewable fuel used for DH from around 30% to around 50% by 2020 (to help meet national targets of 23% for renewable fuel usage), doubling or tripling the number of households served.

Whilst DH is only a means for delivering heat to users (the carbon intensity of the heat it supplies is dictated by the heat generating technology and associated fuel sources that feed into it), it can facilitate carbon savings compared to on-site heat generation.

District Heating can:

- Supply a large number of small heat demands from a small number of large low carbon or energy efficient heat sources such as CHP, biomass boilers or other renewable heat sources. This is often more practical, cost effective and energy efficient than building scale low carbon heating.
- Utilise waste heat from industrial processes.

DH networks incur standing heat losses, particularly in summer when hot water is typically circulated via the same network to serve hot water loads and old DH schemes suffered from high heat losses because of poor insulation and water leaks. However modern systems are well insulated and continuously monitored and maintained to minimise leakage, with annual standing heat losses typically of the order of 2–5% in winter but proportionately higher in summer when the load served is considerably reduced. The benefits of using low carbon heat sources such as biomass boilers or CHP usually outweigh the standing losses where low carbon heat sources would be impractical and / or
less efficient at a building scale. In comparison, losses in the electricity distribution system would also be incurred in supplying individual building heat pumps. Currently transmission losses in the UK are around 7–8% between generation and consumers. Thus modern and well maintained DH connected to low carbon heat sources could play a large part in delivering the 2050 low carbon heat target.

The main hurdle for DH development is the high capital cost of laying DH networks and connecting to buildings. It is usually more capital intensive to install DH than conventional gas or electric heating systems and payback times can be considerable. Even if payback times are reasonable in theory, the capital investment poses various risks depending on the nature of the DH developer. For example, the capital may be unavailable for a local authority scheme, a private housing developer may not be able to recover the additional investment in housing sales and an Energy Supply Company may not make the required return on a scheme supplying existing buildings if occupants do not connect.

However building scale renewable heating systems are similarly much more costly than conventional systems so the difference in capital cost (between DH and building-scale renewable heat) is far more marginal. Additionally, DH pipework typically lasts twice as long as building scale or central renewable heating plant.

When costs are annualised to take DH and renewable heating plant life into account, this study shows that, on average, it may in fact be slightly cheaper (in capital terms alone) to install DH fed by a combination of biomass boilers, heat pumps and power station heat than installing a mix of individual renewable heating systems.

A.2 Additional benefits of DH

Additional benefits of DH are that:

- DH can distribute heat from processes that would be challenging or undesirable to implement at the individual scale (e.g. biomass, energy from waste etc.).

- It is technology neutral, allowing a variety of different types of heat sources to connect to the same system. This diversity enhances security of supply for end customers and facilitates “future-proofing” in that emerging low-carbon technologies can be retro-fitted to connect to the network once they become economically viable.

- It is more cost effective and practical to install thermal storage on a district heating scale than in individual buildings. Thermal storage (usually large hot water tanks) allows decoupling of heat generation from demand which increases security of supply and allows heating plant to be operated more efficiently. It also allows surplus heat to be generated from heat pumps or electrode boilers utilising low carbon electricity or extracted from power stations at times when electricity is cheaper and stored to meet thermal demand when electricity is dearer.

- As noted above, the presence of a district heating infrastructure opens opportunities to harvest low grade heat from commercial and industrial sources by using a heat pump to deliver heat to the DH return pipes. Possible sources could be the cooling of electronic equipment, air conditioners, building scale CHP and machinery.

- DH can reduce national fossil fuel consumption therefore increasing security of supply.
As heat from DH and low carbon technologies can be more cost effective, heat from DH can be sold to consumers more cheaply than they could generate it themselves, helping to alleviate fuel poverty.

A.3 Additional barriers and potential remedies

In addition to the high capital costs, a recent report ‘The Potential and Costs of District Heating Networks’, identifies a series of barriers to the deployment of DH in the UK. The report advises that barriers can grouped into three types: economic, institutional and carbon price, discussing these barriers in depth and making clear that the barriers are complex in nature and closely inter-related.

Based on the report, the principal barriers for DH can be summarised as follows:

- **Perceived Lack of DH development expertise in the UK.** The low level of DH penetration to date is expected to lead to higher development costs than in countries with high DH penetration as contractors are likely to incorporate higher contingency costs to cover construction risk. Furthermore, this perception may also lead to investors seeking higher returns in response to this apparent risk, thereby increasing the cost of capital. This barrier would be expected to diminish as DH penetration increases and experience grows.

- **Demand risk.** A DH network needs to achieve a certain level of initial demand (known as base load) at which revenues are sufficient to deliver a return on investment. Furthermore, investors will wish to see this demand is secure in the long-term. This base demand can be difficult to achieve if dependant on a large number of small demands connecting to the system and difficult to maintain where customers are not fixed into long-term contracts. This uncertainty over demand will result in a higher return being sought by investors.

- **Public Perception.** Successful deployment of DH will be dependent on convincing consumers to connect to the new system. However, DH does not have a strongly positive public image in the UK due to negative press in the past regarding inefficient operation of schemes and a lack of customer control. While modern systems have overcome these drawbacks, such opinions may still need to be addressed. This contrasts with the situation in other countries where DH is preferred due to its perceived reliability, availability and lower cost. Recent public attitudes research conducted by the UK Green Building Council and Zero Carbon Hub\(^{28}\) found a positive view of DH networks as a key component of community infrastructure.

- **Need for Co-ordinated Action between Multiple Parties.** The successful development of a DH network cannot be readily undertaken by any one party. Instead, development requires close co-operation between a range of groups including local authorities, developers, housing associations, businesses and contractors. Achieving this level of co-operation can often be difficult.

- **Concerns regarding DH becoming redundant in the future.** While gas CHP based DH can demonstrate carbon savings over current prevailing technologies (i.e. gas central heating and electric heating) there is concern that these savings would be diminished by future developments such as decarbonisation of grid electricity. However the existence of a distribution infrastructure would provide opportunities to move from gas to renewable fuels or recover waste heat from low carbon thermal power stations and industrial processes with the flexibility to exploit and utilise different sources and grades of thermal energy more practically and cheaply.

- **Need for Public-Sector Support.** Examples in the UK and other European Countries have shown that the development of large-scale DH networks generally require strong support / leadership from the public sector, particularly at the local government level. This provides the stable policy environment that private-sector investors require in

\(^{28}\) In support of their report *Sustainable Community Infrastructure.*
order to invest in a project. However, the support for such development can vary between Authorities due to the factors such as:

- Environmental/sustainability matters not being seen as a high priority issue in comparison to education, waste management etc.
- Individual authorities not possessing necessary expertise to lead such development. Authorities need to be informed about matters including heat mapping, incorporating DH into spatial planning policy and procurement options for DH.

**Current Policy Context.** Current policy sometimes places DH at a disadvantage against other technology options. Examples include:

- Current building regulations encourage developers to install electric heating in new buildings, rather than considering DH or CHP as alternatives.
- Application of planning policy guidance from CLG\(^29\) requiring LPAs to apply target percentage of the energy to be used in new developments to come from decentralised and renewable/low-carbon energy sources, has been applied in an inconsistent manner between local authorities. For example, some local permitting authorities (LPAs) permit only renewable energy technologies to contribute to this target – therefore deterring developers from considering DH utilising fossil-fuel heat sources.
- Social landlords are restricted by Housing Corporation regulation from increasing rents to cover investment in energy efficiency measures even though these will result in lower fuel bills for tenants.

**Carbon Price.** Low/zero carbon technologies are disadvantaged by the fact that costs for conventional technologies do not reflect the cost of carbon. As investors are not provided with a firm “carbon price” signal, it does not allow for carbon savings to be recognised financially, although this situation is changing.

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\(^{29}\) Department for Communities and Local Government.
A.4 Heat sources suitable for district heating

A strength of DH is that it is technology neutral, permitting heat from a variety of heat sources to be transported to heat users.

Figure A1 above provides a summary of the types of heat source that can potentially connect to DH systems. Indeed, as the distribution infrastructure can be expected to have a longer lifespan (c. 40 years) to that of most heat sources (c. 15–25 years) it is conceivable that a DH network will be served by a varying profile of heat sources over its lifetime. This in turn presents the opportunity for the carbon intensity of heat to be decreased in a staged manner over the lifetime of the network in response to market conditions. DH schemes will typically incorporate thermal storage, facilitating load shifting. This increases operating plant efficiency and security of supply and allows power station heat extraction (with consequent power loss) or heat pumps or electrode boilers to generate the daily heat requirement at times when electricity costs are low.

Whilst all of the above sources have the potential to connect to a DH network, the ease with which this can be achieved can vary:

- **Natural Gas CHP.** Natural gas based heat generation for DH can deliver very good reliability and availability. It can be deployed in a variety of forms and sizes from standalone boilers through to CHP schemes to large-scale power stations where heat is extracted so the plant operates as CHP.

  Large standalone gas boilers for DH are little or no more efficient than individual condensing boilers in buildings and when DH standing losses are considered there is typically no energy saving so such boilers are likely to be used for standby purposes alongside other low carbon technologies.

  Due to its flexibility, cost effectiveness and maturity, gas-fired CHP plant is well-placed to serve as one of the foundations for developing DH networks in the short and medium term. Gas CHP currently saves carbon compared to conventional gas boilers and power generation. However this benefit can be expected to diminish in the long term if electricity generation decarbonises as anticipated and as more renewables are
used in heat generation. With the current targets for decarbonisation of heat and power, gas-fired CHP would cease to be a carbon saving technology by the 2030s.

Beyond this point, DH fed by heat extracted from large-scale CCGT equipped with CCS is expected to be the main source of low carbon heat originating with natural gas. Currently most large-scale capacity is located away from centres of population thereby presenting high connection costs but these can still be cost effective as shown in this study. Future redistribution of capacity closer to centres of population would improve cost effectiveness further.

- **Biomass** can deliver good reliability and availability. It can be deployed either as heat-only boilers or as CHP. Siting can be constrained by factors such as site access, air quality limits and (particularly for CHP) available space. Heat produced will contribute to renewables and carbon reduction targets.

However the anticipated availability of biomass for heating is estimated as 50TWh/Yr due to much UK resource earmarked for power generation with CCS and high temperature industrial processes. On this basis, biomass could only deliver a maximum of around 9% of the current UK heat demand and some of this will be used in individual building scale boilers and therefore be unavailable to DH. Where biomass is used for CHP rather than heat only boilers, this constraint will be compounded as CHP uses more biomass to generate a given amount of heat due to generating electricity also. Using biomass in CHP is more energy efficient than using it in separate biomass boilers and power generation where no heat is recovered from the latter but it is usually at a scale unsuited to carbon capture and in fact if the grid decarbonises at target levels, it is possible that small scale biomass CHP without CCS may save little or no carbon in the long term compared to separate power generation with CCS and biomass boilers. The lowest carbon solution overall is to reserve biomass for large scale power generation with carbon capture feeding DH and for small rural biomass boiler schemes which are unsuited to power station connection

- **Thermal Power stations.** The future potential deployment of CCS for coal and natural gas-fired generation presents an opportunity for DH in that this will create a substantial source of surplus and low-carbon heat that could be supplied to DH networks. The majority of power stations generate power in Steam Turbines or Combined Cycle Gas Turbines (CCGT) with multiple steam turbine stages. In highly efficient power generation, the steam exits at near vacuum pressure (approximately 0.1 bara or less) to maximise power generation before being condensed in cooling towers using external cooling water (e.g. from rivers) to enable it to be pumped back to the power station boilers. Under such conditions the exhaust steam is around 45-50°C. Traditional UK heating systems comprise radiators designed for input (flow) temperatures of 82°C and output (return) temperatures of 71°C. DH flow water therefore needs to be well above 81°C and returns to the central heating plant at about 60-70°C. Hot tap water is typically heated to 60°C so similar flow and return temperatures would be required whether the DH feeds traditional hot water cylinders or replaces combi systems providing hot water instantaneously via heat exchangers.

- The temperature of the low pressure exhaust steam of efficient condensing steam turbines is therefore insufficient to supply a DH scheme. A steam turbine suitable for DH will either be a back-pressure turbine, where steam is exhausted at the higher pressure corresponding to the temperature requirement, or a pass-out condensing turbine where some auxiliary medium pressure steam is bled off prior to the final turbine stage to heat the DH temperature to the required level. The heat led back-pressure turbines are more energy efficient overall and commonly employed in DH applications where their power capacity is a relatively small proportion of a country’s total generation capacity but pass-out turbines are more suitable for large scale power generators so we assume these would be employed in our analysis.

Extracting medium pressure steam in this way leads to a reduction in power generated by the turbine stages downstream so there is a trade-off between heat and electricity. The ratio of heat extracted to power reduction is known as the Z ratio. Providing the
boosting steam is extracted as late as possible in the process, for example prior to the final turbine stage at around 2–3 Bar, this loss is minimised.

The Z ratio for DH applications is directly comparable with the Coefficient of Performance of a Heat Pump as both require additional power to be generated to deliver a heat load. The Z ratio is typically around 8 which is much higher than the coefficient of performance which could be achieved by a heat pump. It is reasonable to conclude that heat extracted from power stations has a lower carbon intensity than that from heat pumps.

We estimate the total amount of heat available from extracting heat from thermal power stations is significantly higher than that available from the other principal low carbon DH options, biomass boilers and large heat pumps, due to the constraints on their availability. Waste heat recovery from thermal power stations therefore represents the most significant source of low carbon heat for DH.

Additional opportunities for capturing more of the waste heat from power stations with reduced need for bleed steam may become available in future, for example from heat rejected from the carbon capture process or by installing under-floor heating in buildings which will require lower DH temperatures. However these benefits are difficult to predict and quantify so we have taken the conservative approach of ignoring these in the modelling.

Nuclear power stations use steam cycles and can therefore provide heat to DH in the same way and with similar efficiency as other current thermal power stations although the added future possibility of heat recovery from carbon capture would not exist. As their output cannot be easily modulated, they have a very high load factor, and can therefore deliver heat with very good reliability and availability. However most existing capacity is located away from centres of population, thereby presenting higher connection costs than most other thermal generators. Future opportunities for linking nuclear power stations to DH would benefit from new stations being constructed closer to population centres but public opposition and safety considerations are a likely barrier.

- **Energy from waste (EfW)** boilers or CHP can deliver good reliability and availability. It can also provide other benefits such as reduction of residual waste going to landfill. Siting of facilities can be constrained by factors such as site access, air quality limits and available space but waste management authorities will typically seek to locate facilities relatively close to large centres of population where most waste is generated making them a particularly attractive opportunity for DH.

Heat availability from current EfW stations is a very small proportion of the total generation mix (around 2%) so the contribution from existing facilities would be relatively small compared to power stations. However this may increase in future. Any increase in future capacity would merely decrease the requirement from power stations so our ‘unconstrained’ power station scenario effectively incorporates this opportunity.

Emerging technologies such as gasification and pyrolysis of waste may present future opportunities by allowing smaller EfW facilities to be developed, overcoming the location constraints identified above. Supply of heat to the surrounding community will contribute to meeting environmental permitting requirements and may have positive impact on public opinion of such developments. Biomass element of wastes will contribute to renewables and carbon reduction targets. In particular the use of biogas derived from food waste in CHP could also make a useful contribution given the location of waste arising close to population centres.

- **Water source heat pumps.** Large standalone heat pumps are another potential source of low carbon heat to DH. Ground Source Heat Pumps (GSHPs) tend to be modular and therefore do not tend to benefit from economies of scale in terms of required land area or cost. Installing DH scale GSHPs heat pumps will require large areas of public land to be available as they don’t use the land available from private gardens. The overall benefits of using large GSHPs with DH as opposed to individual
building scale heat pumps are therefore not obvious. We thus assume the use of heat pumps for DH will be limited to water source heat pumps at lakesides or coastal areas. On this basis, we have estimated the overall potential in the UK to be considerably lower than the potential for biomass boilers.

In a highly decarbonised electricity future, heat pumps with DH have the added advantage of being able to utilise excess renewable electricity, for example when high winds occur at night when excess electricity would be sold cheaply to DH operators to top up DH thermal storage thus reducing electricity costs and helping manage low carbon energy supply.  

- **Electrode Boilers.** Direct electric boilers in a highly decarbonised electricity future, could, in the same way as heat pumps, provide some low carbon heat at times where there is excess renewable electricity. They are clearly less efficient than heat pumps but do not need a large heat source as heat pumps do and have much lower capital costs. These are currently used in Denmark where there is a high penetration of wind energy. They are only used to contribute a small proportion alongside the main heating plant and not as the main heating plant as it would be very costly and inefficient to provide direct electric heating to a DH network on a continuous basis.

- **Surplus Heat** from industrial processes (e.g. power generation, oil refining, bulk chemicals etc.) will contribute to carbon reduction targets due primary energy savings delivered by displacing heat from conventional sources. However, sources may be intermittent in nature and heat generated may also be of a low grade (e.g. low temperature water) preventing the heat from being injected into the DH system. While this may be overcome by incorporating a “boost” source (e.g. heat pump or boiler) to achieve DH system conditions this may diminish carbon savings.

- **Solar Thermal** will contribute to carbon reduction and renewables targets but most of the heat is generated in summer and therefore most of the contribution is to heating hot water with a little space heating possible in spring and autumn. The technology requires large available area – can be deployed where space already in use (e.g. roof tops)- but is better suited to open plots.

- **Biogas** is generated by the anaerobic digestion of wastes. Location of facilities can be constrained by factors such as site access and space requirements. Siting of facilities will also be influenced by the type of waste being received. Potential for biogas from sewage treatment works is good as these will tend to be located near to centres of population but facilities handling agricultural/food wastes may not be within economic range. Heat sources using biogas may also experience competing demands for biogas to be injected into the natural gas network.

- **Geothermal** sources, which include the use of heat pumps, can deliver heat with reasonable reliability and good availability. Where the earth’s crust is thin, usually in areas of high volcanic activity, high temperature heat is available in the ground for direct use. A prime example of this is Iceland where heat has been extracted for district heating for decades. However this is not common and the only such scheme in the UK is in Southampton. However, the earth or large bodies of water are still an

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Heat Pumps and Electrode boilers used in conjunction with district heating and thermal storage offer the opportunity to use low cost surplus renewable electricity for heat. Using large heat pumps in this way uses the electricity more efficiently albeit at a much higher capital cost. This concept is used in countries with a large share of renewable energy, for example hydropower in Sweden where spring melt and autumn precipitation create surplus power which is sold cheaply and used for heating and energy storage in hot water tanks etc. To achieve temperatures suitable for DH, a large multi MW scale heat pump is required such as the one employed at Värtan Ropsten in Sweden which has a 180MW capacity. (See [http://www.friotherm.com/downloads/vaertan_e008_uk.pdf](http://www.friotherm.com/downloads/vaertan_e008_uk.pdf)). Electrode boilers are used in Denmark which has a high amount of surplus wind power. A similar situation could occur in the UK following large scale deployment of large intermittent sources such as offshore wind farms in periods of low electricity demand and high wind supply.
effective store of heat gained in summer for use in winter and this low grade heat can be efficiently extracted using a heat pump. Siting of facilities will be constrained by the availability of a suitably large heat source (e.g. aquifer or lake). Such facilities may be constrained by available space but would not have as demanding requirements for site access as other options such as biomass. Heat produced would contribute to renewables and carbon reduction targets. Heat generated tends to be low/medium grade, which may be incompatible with DH systems conveying high-grade heat. This may be overcome by incorporating a “boost” source to achieve system conditions however this may diminish carbon savings.

A.5 DH applications in domestic and service sector buildings

Boilers typically generate hot water at around 80°C and circulate this to radiators or air handling units in dwellings, commercial and public buildings. Some hospital DH schemes are steam based as steam is required for medical equipment but many old schemes are converting their systems to hot water and generating steam for medical equipment locally which is more energy efficient.

DH can link buildings low carbon heating sources, including buildings which are not suited to individual renewable heating options (e.g. urban flats) thus increasing the efficiency and penetration potential of low carbon heat. This is usually based around larger anchor buildings such as hospitals or swimming pools which have high and relatively constant heat loads and are therefore more suited to individual low carbon heating technologies but benefit from increased and diversified heat loads by connecting to other buildings.

Where the extracted heat can be put to useful purposes, the supply of heat from centralised generation can even compete with alternative supply options such as heat pumps. The challenge, therefore, is developing arrangements whereby heat that can be extracted can also be put to some use.

A.6 DH penetration scenarios

In considering the development of large-scale DH networks there are two principal penetration scenarios:

1. Organic Development Scenario. As illustrated in figure A2 below, the DH network is initially developed as a series of small energy clusters serving a geographically small area centred upon one or more “anchor” loads and served by a single small heat source (e.g. natural-gas CHP). As the clusters become more established, they can expand to take on more loads as they become economically viable. This expansion will normally require an increase in the supply capacity of a network by the expansion of the existing heat sources. As these clusters grow they may then merge with each other to share heat sources and ultimately connect to a large source of low carbon heat such as a power station. The scope for growth will depend ultimately on how built up the area is with large urban areas most likely to merge and connect to power stations.

This approach requires lower upfront capital and risk at each phase due to its limited initial coverage. Demand risk can be managed by sizing the scheme such that the majority of each cluster’s capacity is met by the anchor load. However our model anticipates that DH schemes will tend to form in town and city centres first and avoid neighbouring suburbs so DH could be scattered geographically for a considerable time. This is illustrated in Figure A3 which shows how our economic DH model anticipates the geographical progression of DH scheme development where the economics of each local development is considered in isolation with no thought for how these might later be interconnected and fed from power stations. There is a risk that by 2030, when the grid is scheduled to be decarbonised to the extent that gas CHP will no longer be a carbon saving technology and biomass demand for heating is
likely to approach the allocated resource of 50TWh/Yr, DH may not have clustered in a way that is conducive to power station linking. At this point further low carbon DH penetration may be constrained. With current power station locations and capacities this is likely to be the case.

2. **Coordinated Power Station DH Development Scenario.** Here the final potential for large DH schemes in large urban and surrounding suburban areas and their proximity to power stations are considered from the outset and the best opportunities selected and developed as single networks and connected to power stations from project inception skipping phases 1 and 2 of the cluster network scenario. Biomass use in DH is reserved for more remote schemes less well suited to power station linking.

Figure A4 illustrates what our model predicts as the maximum potential for power station linking with current power capacity distribution. Figure A5 illustrates a theoretical scenario where power station capacity is significantly expanded and redistributed to such an extent that it could serve 80% of all UK heat (the reasonable limit on individual DH cost effectiveness). By comparing with Figure A3 (which also covers 80% of heat load) the increased co-ordination of DH clustering can be seen.

This extreme scenario is unlikely to occur as the electrical demand is unlikely to expand to such levels, despite electrification of transport, as the remaining demand for electric heating amongst the remaining 20% of load not served by DH would be little higher than current levels. However it serves as an extreme scenario of the difference between independent organic DH development and coordinated power station and DH planning.

In the long term, this approach is likely to offer the highest long term low carbon DH penetration in the cheapest way. However up front capital costs and risks are high and this ideal scenario is therefore unlikely to occur without strong Government support.

Current Government initiatives mentioned below are designed to encourage a compromise between these scenarios prior to 2030 whereby DH schemes will be installed in the most cost effective areas fuelled mainly by gas CHP or biomass but with consideration to planning power station siting to best facilitate later connection to DH. It is important that the geographical progression of DH be monitored and policy coordinated to ensure the transition from local networks fed by gas CHP and bio-fuels to being fed by power station heat can be made when the time comes.
### Organic and Coordinated Development Scenarios

| Stage 1 – Initial Development  
(Organic Development Scenario only) | Stage 2 – DH Scheme Addition and Expansion  
(Organic Development Scenario only) | Stage 3 – Regeneration |
|-----------------------------------|------------------------------------------|-----------------------|
| Independent DH networks developed  
based around key “anchor” loads (e.g.  
social housing, hospitals, universities  
etc.) and other loads in the vicinity. Each  
scheme served by a single, small heat  
source (e.g. biomass boilers or large e.g.  
biomass CHP depending on the size of  
scheme). | New DH Schemes Established and existing DH schemes expand to connect additional loads that have become economically viable. Individual heat sources grow in capacity to meet demand. Adjacent networks grow closer together forming DH clusters. | Adjacent DH schemes (clusters) are inter-connected and connected to a large heat source which may include surplus heat from power stations. This may be carried over long distances using high capacity “transmission” mains. Some of the original heat sources will be near the end of their lives making this transition more cost effective and where this is not the case the original DH heat sources can provide security of supply. In the Coordinated Power Station Development Scenario, the whole network is developed and transmission mains laid at once. |

### Key

- Heat Load
- Anchor Heat Load
- Distribution Pipeline
- Transmission Pipeline
- Heat Source (small)
- Heat Source (large)
- Power Station or other surplus heat
A.7 DH economics and key influencing factors

The main elements of a district heating system are:-

1. Central Heat Generating Plant

2. The DH network comprising:
   a) Transmission mains which link power stations to distribution networks where applicable.
   b) Interlinking mains linking adjacent DH schemes together to form clusters for power station linking.
   c) Distribution mains which radiate from central heating plant, typically running along roads in urban areas.
   d) Branch mains which run from distribution mains to individual buildings.
   e) Building connections (heat exchangers or hydraulic boards regulating pressures in the case of direct connections).
   f) Heat meters installed in each building.

A.7.1 Capital cost per unit heat

As the cost savings of a DH scheme tend to be proportional to the amount of heat served, generally speaking the lower the capital cost per MWh, the more cost effective the DH scheme. As the capital costs are generally dominated by DH network costs, generally the lower the capital DHN costs per MWh, the more cost effective the DH scheme.

A.7.2 Linear and area heat density

For DH schemes not fed by power stations but by relatively local heating plant, as in phases 1 and 2 above, on average, approximately 40% of the cost is in the distribution mains and the remaining 60% is in the branch connections, building connections and heat meters. The capital cost of transmission mains is approximately proportional to the total length of distribution mains and the remaining DH costs are roughly proportional to the number of buildings. Of course the total heat load served and size of buildings can vary the pipe sizes and therefore linear cost and the branch, connection and meter costs per building but these rules broadly apply, particularly where the total demand is dominated by dwellings which have less variability than non domestic buildings. Where domestic demand dominates, the total heat demand on a DN network is approximately proportional to the number of dwellings. Therefore the branch, connection and meter costs are approximately proportional to heat demand. So generally speaking, the cost per MWh contains a variable element proportional to the total distribution length and a fixed element relating to building connection costs. Therefore the larger the linear heat density (demand per metre of distribution pipework), the lower the overall cost per unit of heat served. Therefore a key factor in the cost effectiveness of an area is the linear heat density.

Broadly speaking areas with higher linear heat density will tend to have higher area heat density so as a rough guide, areas with higher area heat density will be more cost effective for district heating. However this does not always hold true. In some cases small village networks with a low area heat density can be more cost effective than suburban areas because they consist of relatively poorly insulated dwellings with large areas of land attached whereas a modern suburban area with small gardens may have a larger area density but similar linear spacing along a street and lower individual heat demands and therefore lower linear heat density. In addition the overall demand of the suburban schemes will be higher and therefore the average pipe size larger. In this case the village
network may be more cost effective so the rough rule of high area heat density being most cost effective may not hold true, linear heat density is likely to be a better indicator.

A.8 Power station fed schemes

DH schemes fed by power stations have the additional cost of long and large transmission pipes. At the same time, pipework to interlink DH schemes to form clusters will be required to minimise the number of transmission pipes required. The closer these networks are, the less interlinking pipework needed. Minimising the overall capital cost per MWh served will be a balance of maximising the linear heat density in the distribution networks served and maximising the ratio of total heat served to the cost of transmission and interlinking pipework. This may mean the most cost effective schemes overall will include areas with a lower linear heat density which would be less attractive as individual gas CHP/biomass boiler fed schemes but are necessary to contribute to a higher overall return on a power station fed scheme. The most cost effective schemes will generally occur where power stations are sited near large urban areas which generally have high linear heat density and high overall demand located relatively nearby.

Currently nuclear power stations are, on average, sited further from population centres than coal and CCGT stations and therefore the economic viability of connecting them is generally worse. However it is not possible to numerically generalise the relationship between a nuclear power station’s distance from surrounding heat loads and the economic viability of supplying heat to these as the relative location of other major power stations is also a factor. For example the closest centre of population to Torness nuclear power station is Edinburgh but the Cockenzie coal power station is much closer and therefore a more suitable heat supplier to an Edinburgh district heating scheme. The remaining opportunities for Torness to supply DH would be to relatively small and/or distant DH networks which do not have a closer power station. The overall economics of these connections would be poor. On the other hand, Hunterston Nuclear Power Station is a similar distance from Glasgow but being the nearest major power station to many areas on the west side of Glasgow, the potential for supplying DH is large. Therefore, the economics of DH from Hunterston are much better than those presented to the Torness station despite both stations being similar distance from major population centres.

The following maps illustrate the results of our DH rollout scenario modelling. Details of key technical and cost assumptions and numerical outputs of the DH modelling, which were used by Element Energy in the main economic modelling, can be found in the main report.
This shows how DH is likely to progress following the organic development scenario. The areas shown in red will develop first and the yellow ones latest. The maximum feasible penetration is 80% above which costs escalate steeply so this represents the upper limit on DH penetration. However with the current heat availability from power stations, constrained biomass availability and limited sites for water source heat pumps, a maximum of around 40% is more realistic from these low carbon sources and the remaining 40% would require the use of fossil fuels. However without a coordinated policy of siting power stations close to urban centres even this may be unlikely to occur as such heat clustering may not be conducive to power station linking.
This shows how current power stations could be linked to DH assuming the coordinated power station DH development approach. Notably the penetration in large urban areas such as London would be low due to insufficient heat capacity from power stations in London or major power stations outside London such as those in the Thames Estuary and Didcot which would be fully deployed more locally. Meanwhile some other power stations, for example Drax, the UK’s largest thermal power station, would be underutilised serving only York and a few surrounding settlements but not Leeds, the nearest major conurbation, which would be served by Ferrybridge and Castleford as these are much closer.
This shows how DH could be met by power stations following the coordinated power station DH development approach in a scenario with a large expansion of power generating capacity which could meet 80% of UK heat demand. Generating capacity is still located at existing sites but distributed in proportion to heat load. The pipe connections are omitted for clarity. It can be seen that clustering of areas of similar penetration timing are more pronounced in this scenario than in the organic development scenario and so power station linking is likely to be more cost effective.