



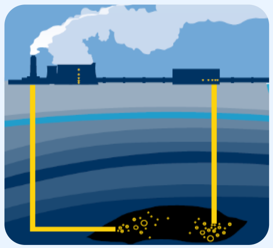



Research on district heating and local approaches to heat decarbonisation

A study for the

Committee on Climate Change

Main Report

20th November 2015

Element Energy Ltd

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Introduction

The Committee on Climate Change (CCC) have commissioned a consortium led by Element Energy, and including Frontier Economic and Imperial College London, to carry out research on **District heating and local approaches to heat decarbonisation**. The resulting analysis will be used to refresh the CCC's scenarios on low carbon heat from district heating and inform the CCC's advice to government regarding the 5th Carbon Budget.

- **Specific aims** of the project are to:
  1. *Review evidence on district heating and cooling and the potential benefits of decentralised approaches*
  2. *Develop heat load projections and district heating scenarios*
  3. *Characterise the current and near-term market for heat networks in the UK*

- The project entitled "Research on district heating and local approaches to heat decarbonisation"
- This report is the **Main report**, which summarises the research we have undertaken in relation to items 1-3.
- An Annex to the main report**: "Overcoming barriers to district heating"**, described the research we have performed in relation to item 3 in detail. While we include in this report the high-level policy recommendations resulting from this research, the reader is referred to the Annex for further information.

Acknowledgements

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Contents

District heating and local approaches to heat decarbonisation:
Key findings of study

➢ ***We have developed three core scenarios for deployment of district heating (DH) to 2050***

The three scenarios reflect different levels of policy intervention to incentivise and assist the roll-out of district heating in the UK. For each scenario, we have presented the **range of heat sources** likely to be employed, the associated **carbon emissions abatement** and the **abatement cost**.

➢ ***Our Central scenario leads to a deployment of 42 TWh/yr of DH in 2030 and 81 TWh/yr in 2050***

The heat is supplied by a range of sources, many of which are highly localised, **including waste heat from industry and power stations**, **water sources** and **sewage**, as well as **energy-from-waste** and **biomass**. The displacement of the mainly gas-based counterfactual with these low carbon sources leads to a carbon **emissions abatement of more than 15 $MtCO_2$/yr in 2050**, at an **average cost of £108/tCO_2**.

➢ ***Achieving the level of deployment in the Central scenario will require concerted policy action***

Policy intervention is required to overcome the existing barriers to uptake of DH, including **externalities, natural monopoly characteristics, demand uncertainty, barriers associated with policy, consumer barriers and institutional** issues**.** Our key policy recommendations to address these barriers include:

1. **A financial incentive** to address the externality in the market related to carbon emissions;
2. **Competition policy** to ensure fair outcomes for consumers;
3. **Dedicated local heat zones** within which various policies, including public body connection to DH networks, planning policy to encourage the use of local heat sources and the removal of incentives for competing heating technologies, are applied.

➢ ***Two further scenarios, Barriers and High, explore the impact of lower and higher levels of policy action respectively***

We represent a range of levels of policy action through variation in model assumptions on carbon value, consumer connection fraction, availability of waste heat and biomass, and others. We find that a failure (or choice) not to address all the above barriers will limit the deployment of DH to 25 TWh/yr in 2030 and **39 TWh/yr** in 2050. A greater level of policy action, meanwhile, could lead to a 'maximum' DH deployment of around 54 TWh/yr in 2030 and **111 TWh/yr** in 2050.

➢ ***Analysis of the maximum roll-out rate of DH suggests that the recommended policies should be implemented without delay***

Assessment of the maximum practical roll-out rate for DH – identified from an analysis of historic uptake in non-UK markets as around 20% annual growth in an 'emerging' phase, falling to around 6% in a 'mature' market – suggests that achieving a high level of deployment to 2050 will **require significant progress** in implementing the recommended policies **by 2020**.

Purpose and structure of this report

This report summarises the findings and methodology of our research

- The purpose of this document is to summarise the findings and methodology of our research, including our key recommendations to policymakers on how to incentivise and assist the development of a mature and effective market for district heating in the UK.
- The reader is also referred to the Annex to this report entitled “Overcoming barriers to district heating”, in which our work to identify the barriers to DH deployment in the UK, and the potential policy solutions, is described in more detail.

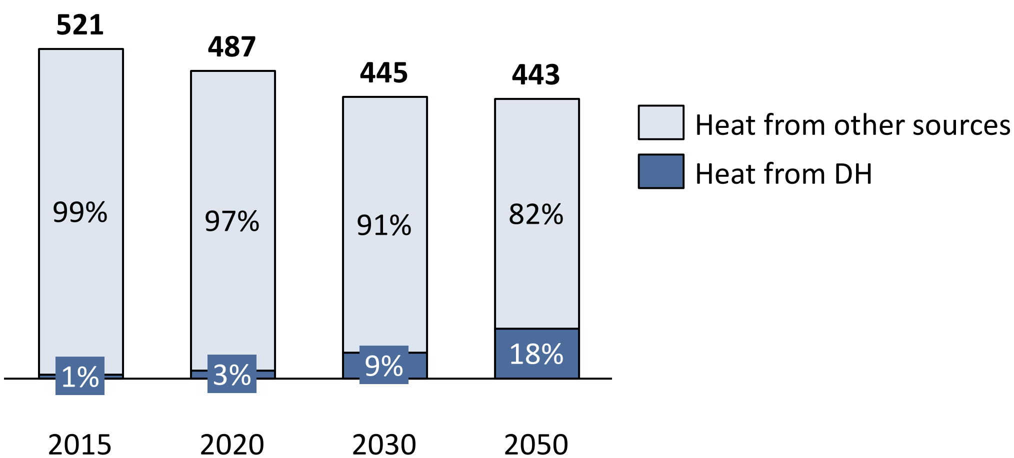
The **structure of this report** is as follows:

- Section 1 (this section) is the Executive Summary.
- Section 2 presents a review of the evidence on district heating (DH) and cooling, as background and context for this work.
- Section 3 describes the methodological approach taken in this study, and summarises the key assumptions used in the modelling.
- Section 4 presents the derived levelised costs of energy from DH for various heat supply options, across different demand-side groups and for different time horizons, and compares those with the cost of the counterfactual heating options.
- Section 5 presents a number of deployment scenarios for district heating to 2050 under different levels of policy intervention, along with a number of key sensitivities.
- Section 6 draws out the key findings of the work, and summarises the insights for policymakers.

Our Central scenario, describing a case where policy has overcome key barriers to DH, finds a potential deployment of 81 TWh by 2050

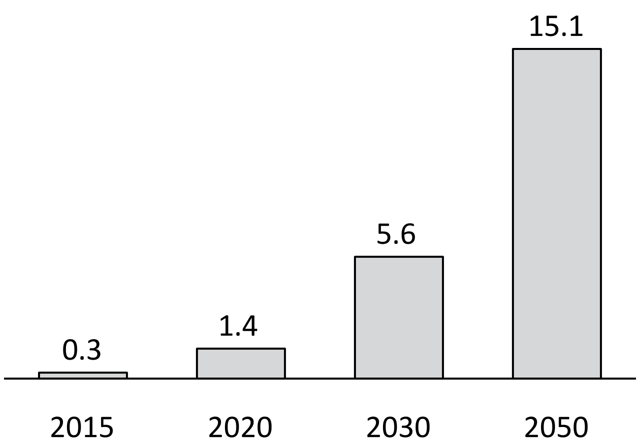
District heating deployment in the Central scenario

Heat supply in the domestic and non-domestic sectors* (TWh)



Associated CO_2 abatement

CO_2 emissions abatement from DH ($MtCO_2$)

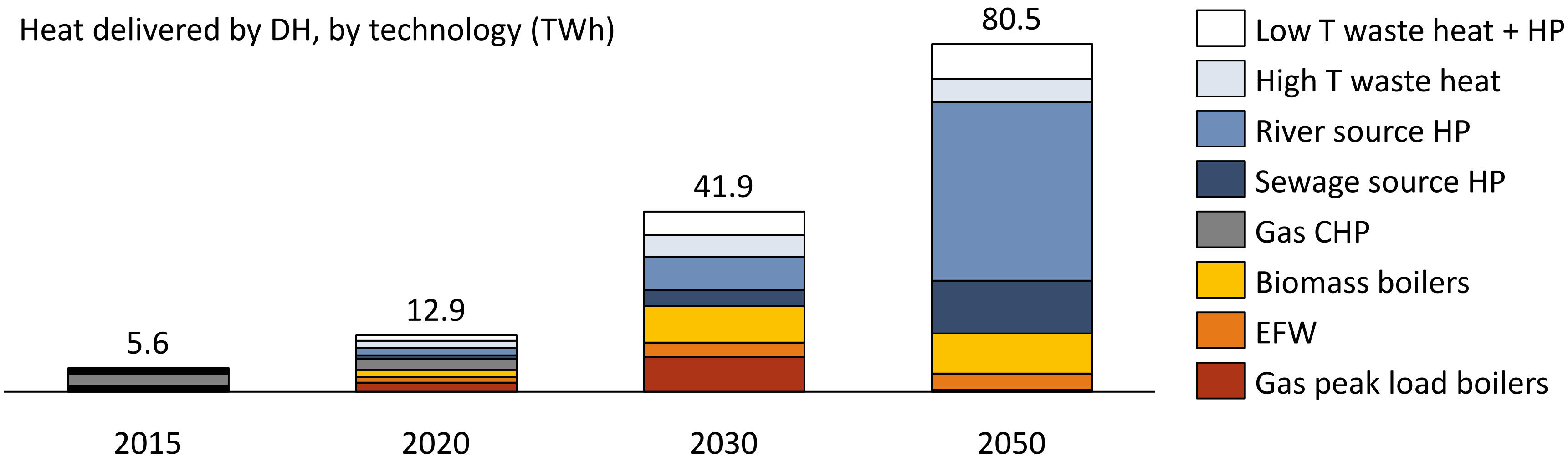


- **Our Central scenario** represents a case where the **existing barriers to district heating**, including market and policy failures, a lack of consumer interest and trust, uncertainty of demand, high technology cost and institutional issues such as skills and knowledge, **have been overcome**. The detailed assumptions in the Central scenario are described in Section 5.
- **Key policy recommendations** to overcome these barriers include: (i) a **financial incentive** for DH, (ii) robust **competition policy** to ensure fair outcomes for the consumer, and (iii) the provision of dedicated **local heat zones** where a policy of connection of public buildings to DH is adopted and financial incentives for non-DH heating options are removed.
- Under the successful implementation of these policies, we find that **42 TWh of DH could be deployed by 2030** (corresponding to 9% of total UK heat demand), and that **81 TWh could be deployed by 2050** (18% of total heat demand).
- The **number of 1 km^2 zones** in which DH is deployed by 2050 is found to be **less than 2,500** of the nearly 20,000 such zones which cover 90% of the UK heat demand.

*Excluding process heat in industry

A wide range of heat sources is likely to be used, according to local availability

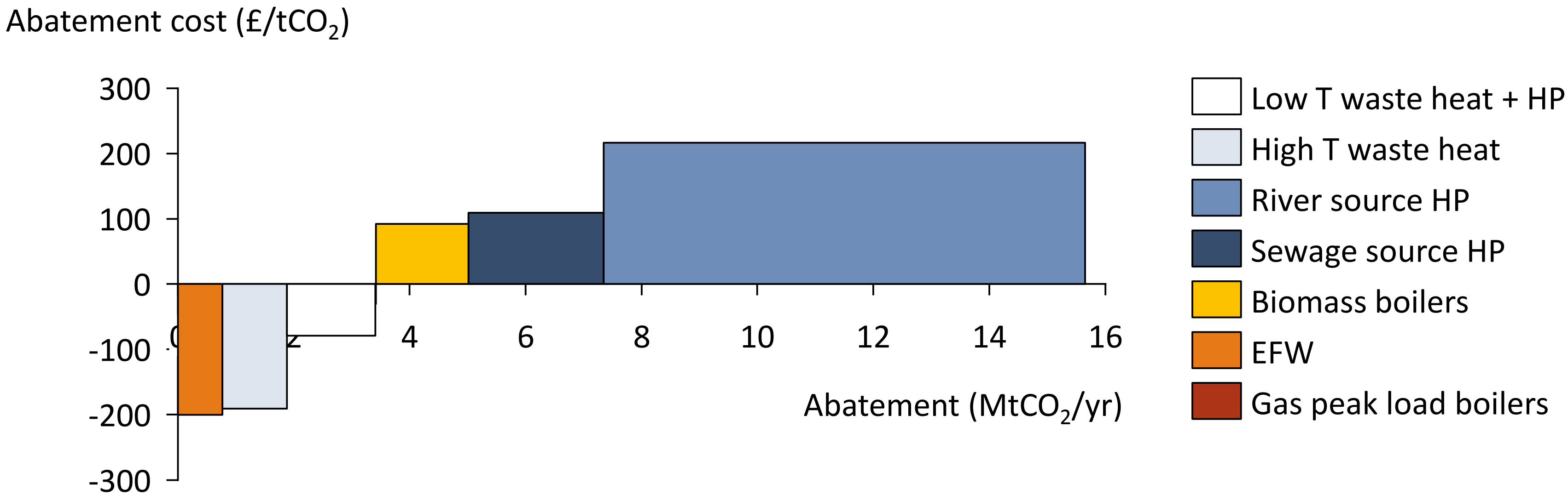
Technology mix in the Central scenario



- A wide range of heat supply technologies will contribute, reflecting the **variety in locally-available secondary heat sources**.
- While the majority of schemes in the UK are currently based on **Gas CHP**, we find a very limited role for Gas CHP in the longer term in the low-carbon heating scenarios modelled here. This is explored further in Section 3.
- We forecast an early role for **waste heat from industry and power stations** located near centres of heat demand, with 11 TWh by 2030. High temperature waste heat will feed networks directly, where low temperature waste heat will need first to be upgraded by heat pumps. **Energy-from-waste (EFW)** plants are also likely to play an early role, contributing 4 TWh by 2030.
- The UK has a vast heat resource in the form of **water sources**, and we find that an extensive deployment of DH of the kind in the Central scenario is likely to require significant use of this resource. DH based on water sources reaches 41 TWh by 2050. **Sewage** presents a somewhat higher grade source of heat located near demand centres, and could contribute 12 TWh by 2050.
- **Biomass-**based DH is also expected to play a key role in a low-carbon DH sector, particularly where local secondary heat sources are not available. Based on an estimate of the biomass resource available to DH, we find that it could contribute 10 TWh by 2050.

We find that waste heat and EFW are the most cost-effective heat supply options, with water-source heat pumps the most costly

Average abatement cost in 2050 by technology in the Central scenario

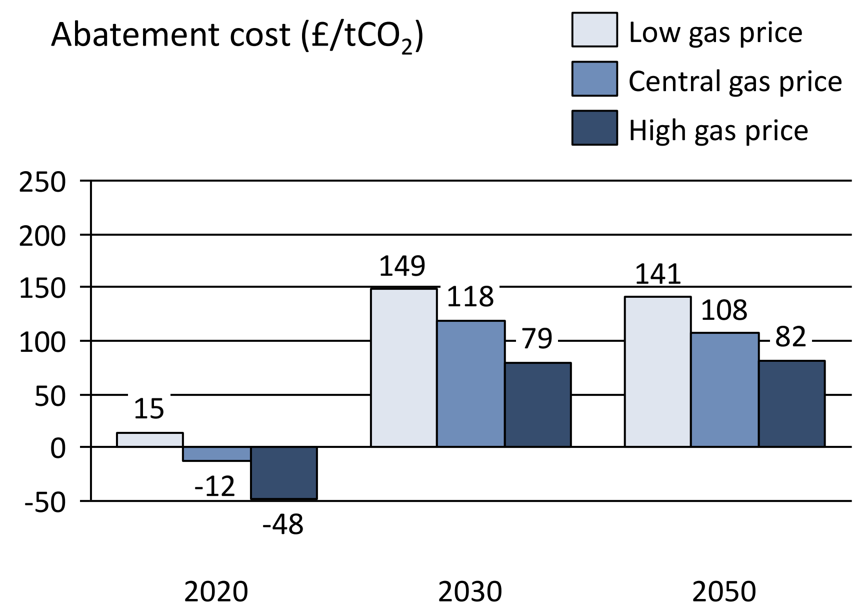


- Total **carbon emissions savings** in 2050 in the Central scenario are more than 15 $MtCO_2$/yr.
- In the model, the financial incentive for low-carbon DH is represented through a carbon value. As described in Section 3, DH schemes are built where they are more cost-effective than the mainly gas-based counterfactual, accounting for the carbon value. In the Central case, the carbon value reaches £78/tCO_2 in 2030 and £333/tCO_2 in 2050[1].
- The associated abatement cost varies strongly with heat supply technology. **Waste heat from power stations and industry** and **EFW heat** are typically the **most cost-effective options**, with negative average abatement costs in the range -£79/tCO_2 to -£200/tCO_2. We therefore expect these options to be taken up earlier wherever such sources are located near heat demand centres.
- Lower-grade heat sources, including **water-source heat** and **sewage-source heat**, are less cost-effective with average abatement costs of £109/tCO_2 and £216/tCO_2 respectively, but offer significant carbon abatement potential of more than 10 $MtCO_2$.
- **Biomass**-based DH is also reasonably costly, but under the assumptions made in the Central scenario is found to be more cost-effective than the water-source heat pumps, with an average abatement cost of £92/tCO_2.

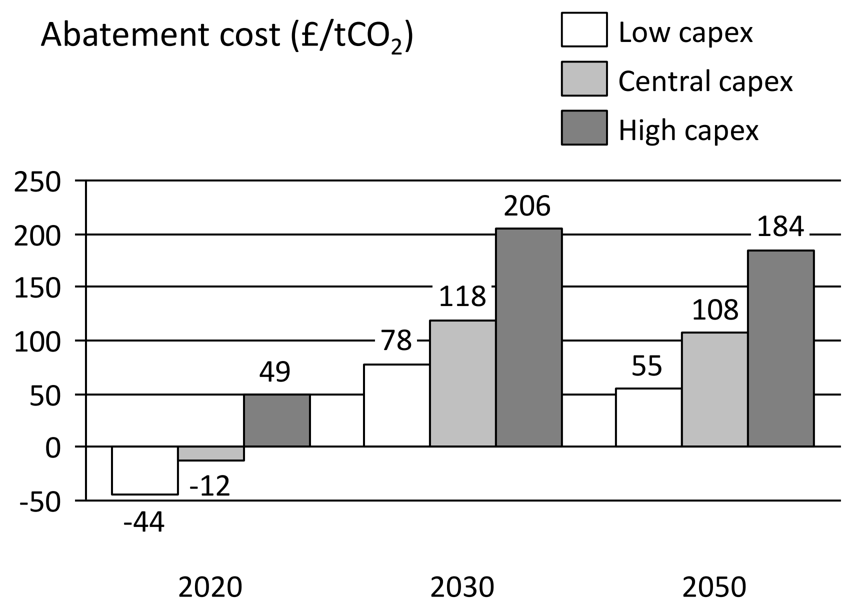
1. See CCC technical report, Buildings chapter

Average abatement cost is dependent on the future gas price, and carries some uncertainty relating to the cost of relatively immature technologies

Gas price sensitivity to abatement cost



Capital cost sensitivity to abatement cost



- In the Central scenario, the **average abatement cost is negative in 2020** at -£12/tCO_2 (reflecting the fact that the most cost-effective schemes tend to be implemented earliest), **rising to £118/tCO_2 in 2030** and £108/tCO_2 in 2050.
- We have performed a **sensitivity analysis** on the abatement cost using the CCC's Low and High **Gas price scenarios*** (see Appendix), and our own Low and High **Capital cost scenarios** (applied to water-source and sewage-source HPs, biomass boilers, thermal storage, DH pipework and heat interface units). Note that, for the analysis shown, we have fixed the deployment of DH.
- **Higher Gas prices reduce the average abatement cost**, since the counterfactual (mainly gas boilers) is more strongly affected than the DH schemes based on a fuel mix of electricity (for HPs), gas (for peaking plant), biomass or no fuel (for High T waste heat). In 2050, the High Gas price leads to a 24% reduction in abatement cost to £82/tCO_2; the Low Gas price an increase of 31%.
- **High Capital costs impact only the DH scheme cost**, and not the counterfactual cost, and hence have a significant effect on the abatement cost. In 2050, the High Capital costs lead to a 70% increase in abatement cost; the Low Capital costs a 49% decrease.

*We note that the gas price affects the electricity price to the extent that gas power stations contribute to the electricity generation mix; Low and High Gas price cases lead to associated Low and High Electricity price cases respectively.

The level of district heating deployment seen in the Central scenario will require concerted policy action

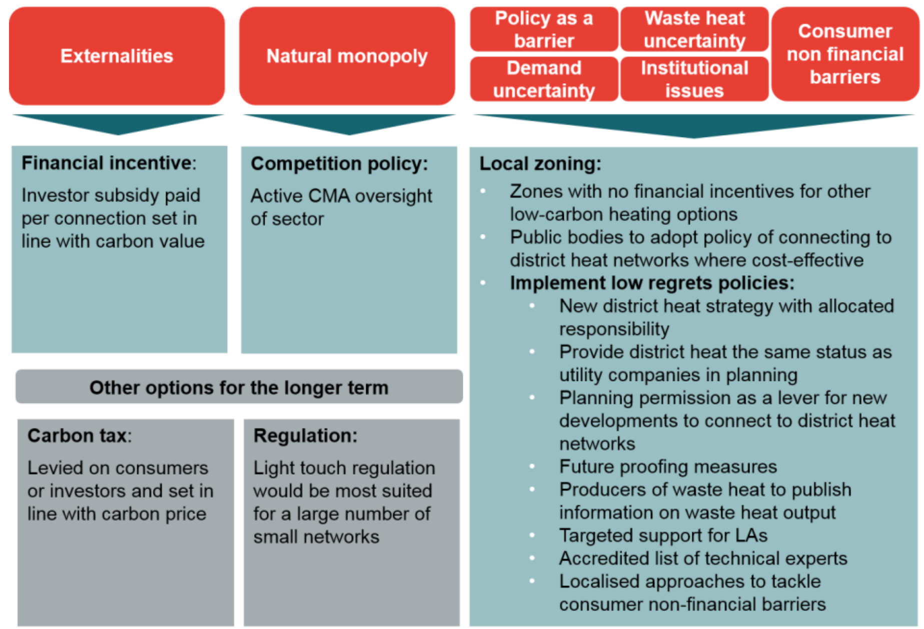
Shortlisted policies to meet Central scenario

- The Central scenario represents a case where the **existing barriers to district heating have been overcome.**
- A detailed assessment of the barriers for heat networks in the UK, and potential policy solutions, are presented in the accompanying Annex "*Overcoming barriers to district heating*".
- Key barriers identified include **externalities, natural monopoly characteristics, demand uncertainty, barriers associated with policy, consumer barriers and institutional issues**.
- We have assessed a wide range of policy measures to overcome these barriers for their suitability to the UK case.

- Our **key policy recommendations** include:

1. **A financial incentive** paid to investors that aims to address the externality in the market related to carbon emissions.
2. **Competition policy**, in the form of CMA oversight, to address natural monopoly concerns and help to ensure fair outcomes for consumers to preserve the reputation of the sector.
3. **The provision of dedicated local heat zones** within which DH is deemed cost-effective. Within these zones relevant local policies can be applied in a targeted way, including a **public body policy of connecting to DH networks** where cost-effective, the **removal of financial incentives for other heating technologies**, and a number of other options as set out in the figure on the right.

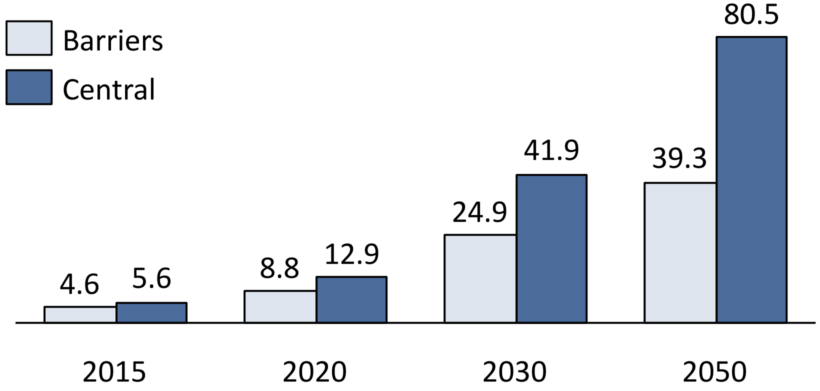
Graphical summary of policy recommendations



In the Barriers scenario, where a number of key barriers to DH are not overcome, deployment remains below 40 TWh to 2050

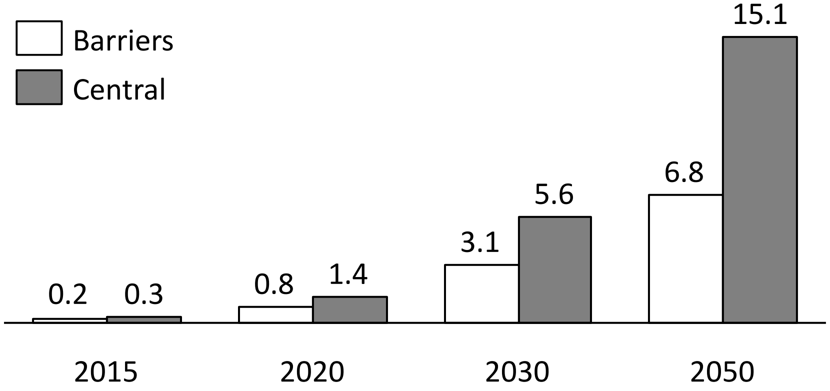
DH deployment in the Barriers scenario

Heat delivered by DH* (TWh)



CO_2 abatement in the Barriers scenario

Carbon emissions abatement ($MtCO_2$/yr)

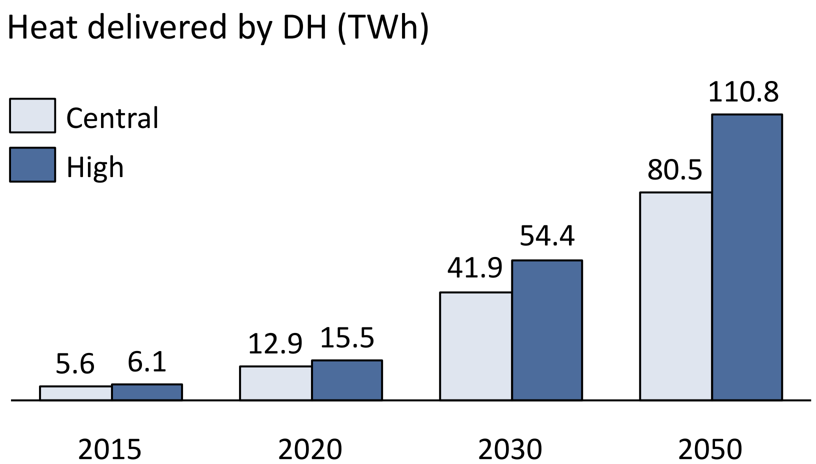


- Through the **Barriers scenario**, we have represented a case where a number of the key barriers to DH identified are not overcome – either through a choice of not to implement policies to address them, or a failure of those policies.
- In the modelling, this is represented by a significantly **lower connection fraction** to DH schemes than in the Central scenario (at 50% as compared with 90% - see sections 3 and 4 for more details). A lower connection fraction within an area suitable for DH is likely to result from a **lower level of consumer trust and engagement**, a **lower level of adoption of the public body policy of connecting to DH**, and from **competition with other incentivised low carbon heating** technologies.
- We note that in the Barriers scenario shown here, the financial incentive for low carbon DH is still applied in the form of the same carbon value as used in the Central scenario.
- The impact of the lower connection fraction is that the deployment of DH falls by 41% in 2030 to 25 TWh, and by 51% in 2050 to 39 TWh. This leads to a **55% drop in carbon emissions savings** in 2050 to 6.8 $MtCO_2$/yr.

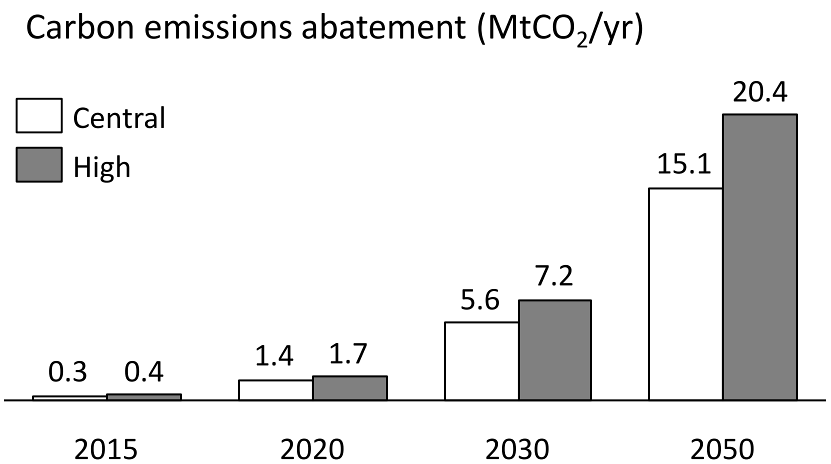
*Note that the deployment of DH in 2015 differs between scenarios as the first new schemes in the model are built in 2015.

High scenario represents an effective ‘maximum’ level of DH deployment, which we find to be in the region of 110 TWh per year

DH deployment in the High scenario



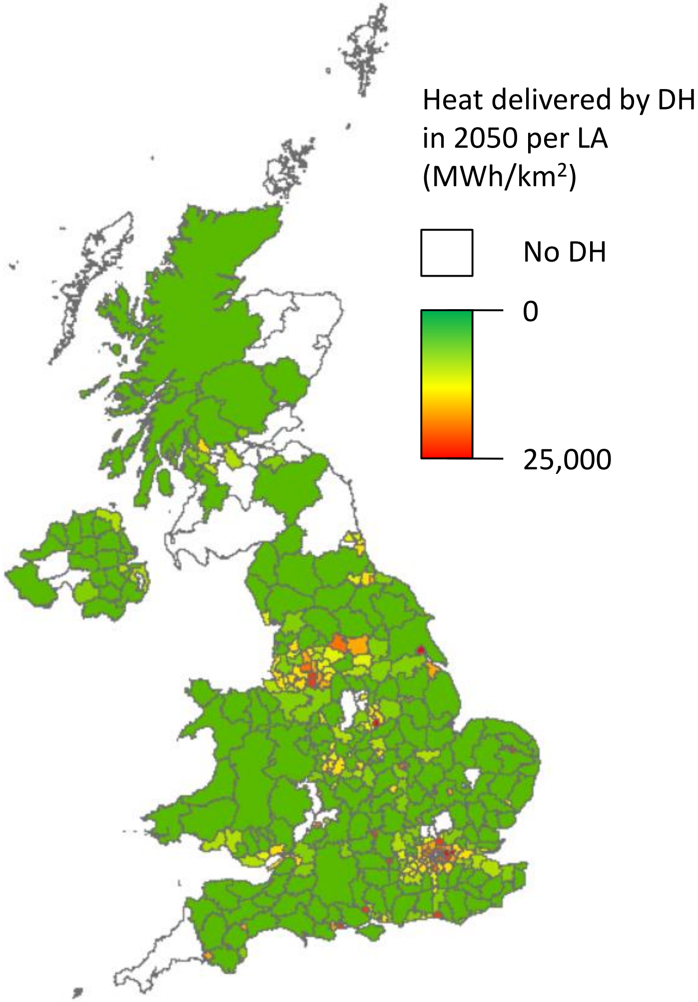
CO_2 abatement in the High scenario



- The High scenario reflects an estimate of the **‘maximum’ level of DH deployment in the case of a very strong policy push**, including:
  - **higher incentives** for low-carbon DH;
  - **very strong local heat zoning policy** to ensure almost full connection in areas suitable for DH and to influence the siting of new industry and power stations and the grade of heat captured from the plant;
  - **greater allocation of biomass** to DH networks.
- The higher incentive for low-carbon DH is represented in the modelling through the use of a higher carbon value reaching £116/tCO_2 in 2030 and £555/tCO_2 in 2050, and a connection fraction of 100% is used. We also represent the refurbishment over time of power stations to allow the capture of high T waste heat and, to represent the siting of new plant near demand centres, reduce the distance between plant and the network to a lower limit of 1 km.
- Deployment of DH in the High scenario is around 38% higher than in the Central scenario, and the **carbon emissions savings around 35% higher than in the Central scenario, at more than 20 MtCO_2/yr**.

Heat networks will be concentrated in urban areas with access to waste heat, water-source heat or biomass

Deployment occurs where high heat demand density coincides with local heat or fuel resource



- Heat networks are suitable for **areas of high heat demand density**, where the high capital cost of the required infrastructure can be justified by the high utilization factor (and high value of heat sales)
- Accordingly, as shown on the map on the left, uptake of DH in the Central scenario is **concentrated in urban areas** and isolated sites of high density development outside urban centres
- However, the **local availability of heat sources** – particularly waste heat sources and water sources – also **plays a very important role** in determining the location of viable DH schemes
- This is particularly the case in the scenarios we present here, given the constraints placed on the deployment of Gas CHP to 2050*
- We also present in the table below the uptake of DH in the Devolved Administrations; we find that, where policy is aligned across all regions, **nearly 15% of the DH is deployed outside England**

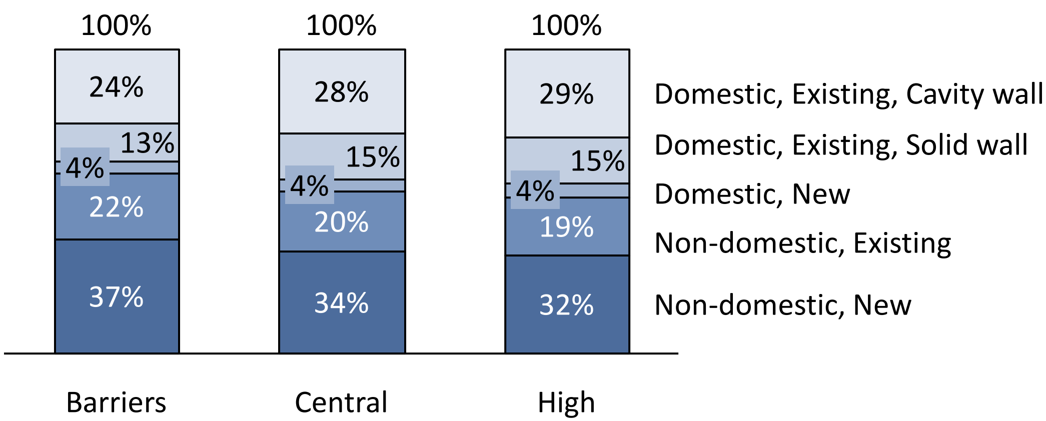
	Heat delivered by DH (MWh/km^2)	Fraction of total (%)
England	69.6	87%
Scotland	3.7	5%
Wales	4.0	5%
Northern Ireland	3.0	4%
Total	**80.3**	**100%**

*As described in Section 3

District heating is likely to be deployed more widely in the non-domestic sector

Sectoral breakdown of heat delivered by DH in 2050

Heat delivered by DH in 2050, by sector
(% of total heat delivered by DH)



	Share of total heat delivered by DH (2050)		Share of UK heat demand in sector (2050)	
	Domestic	Non-domestic	Domestic	Non-domestic
Barriers	41%	59%		
Central	47%	53%	72%	28%
High	48%	52%		

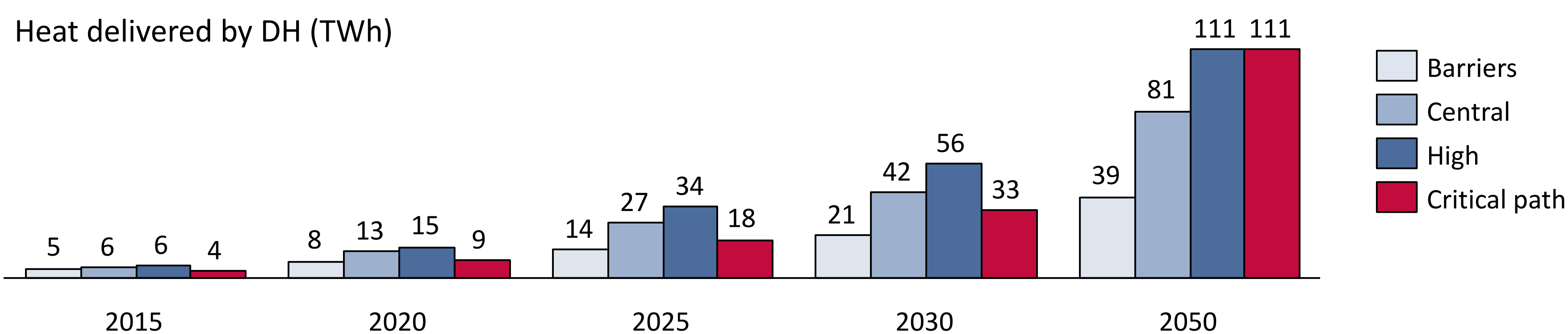
- Our bottom-up modelling has found that the deployment of district heating is likely to be significantly greater in the non-domestic sector than in the domestic sector.
- In the Central scenario, **53% of the heat delivered by district heating in 2050 is associated with the non-domestic sector**, despite the non-domestic sector representing only 28% of UK heat demand in that year.
- Whereas around **34% of non-domestic heat demand is served by DH in 2050** in the Central scenario, that fraction is only around **12% for the domestic sector**.
- This result reflects the fact that **non-domestic buildings tend to be concentrated** in areas with a higher building density and therefore heat density, such as **town and city centres**.
- Another important contributing factor is that non-domestic buildings are on average larger than domestic buildings, and act as better '**anchor loads**' for DH schemes, leading to lower connection costs per kWh of heat delivered.

An analysis of the maximum roll-out rate of district heating suggests that the recommended policies should be implemented without delay

Critical path analysis suggests that progress to 2020 is key to achieving wide deployment by 2050

- We have developed a ‘Critical path’ scenario for DH. The **Critical path describes a level of deployment at each year up to 2030 which leaves open the option to deploy district heating at ‘large scale’ in 2050,** accounting for the finite rate at which heat network infrastructure can be rolled out in practice.
- ‘Large–scale’ is here defined as the level of deployment in the High scenario – that is, **111 TWh in 2050**. In other words, therefore, the Critical path is the minimum level of deployment that needs to be in place in each year to 2030 for a 2050 deployment of 111 TWh still to be achievable.
- The Critical path has been **developed using historic data** on the maximum achievable growth in DH in **markets outside the UK**.
- We identify a growth rate limit of around 20% per year* in an ‘emerging’ market phase, falling to around 6% in a ‘mature’ market.
- We find that the **Central scenario meets the Critical path to 2030** – that is, at any year to 2030, the growth rate which would be required beyond that year to reach 112 TWh of deployment in 2050 is not greater than the growth rate limit identified.
- However, the **Barriers scenario has already fallen behind the Critical path by 2020**. Since the Barriers scenario reflects the case where not all existing barriers to the rollout of DH have not yet been overcome – although a carbon value is applied – this suggests that the **recommended policy measures should be implemented without delay** to enable wide deployment to 2050.

Comparison of the Central, Barriers and High scenarios with the Critical path to 2030



*In terms of national heat demand supplied by district heating.

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A range of previous scenarios for district heating penetration in 2050 are underpinned by different assumptions

TWh/yr delivered heat by DH in 2050	Scenario name/origin	Key assumptions/narrative
285	Element/AEA ‘unconstrained’	DH is incentivised; heat is mostly sourced from new thermal power stations which are collocated with heat demand
148	Element/AEA ‘constrained’	DH is incentivised; heat is mostly sourced from thermal power plants in their current locations
35-83	Poyry ‘scenario 9’ (highest scenario)	Low discount rate (3.5%), carbon value rising to £60/tonne by 2050
60	Redpoint ‘Core scenario’	Based on an energy system cost optimisation methodology
46	Element/AEA ‘baseline’	No financial incentives for DH; competition with building-scale heating technologies
18	Poyry ‘scenario 5’	Policy environment based on 2009 (e.g. carbon value based on EU ETS); 20% capex reduction on DH technologies
<=3	Poyry other scenarios	Policy environment based on 2009 (e.g. carbon value based on EU ETS)

- In the most optimistic scenario, the energy system is designed around district heating (cogeneration)
- The others are either ‘uptake’ models in which DH is chosen at the point at which it becomes cost effective, optimisation models, or ‘what-if’ scenarios investigating the effect of different policies.

The Potential and Costs of District Heating Networks, Poyry, 2009
2050 options for decarbonising heat in buildings, Element Energy/AEA, 2012

Typical DH network temperatures have decreased over time, enabling increasing integration of low grade, locally available heat sources

Heat sources can be classified by temperature

- 'Low' temperature heat sources generally require a heat pump to upgrade the heat to a higher temperature before it is delivered to the network

Low temperature heat source
- Water (river, lake, sea, aquifer, mine)
- Sewage networks and water treatment works
- Ground
- Air

Low or high temperature heat source
- Solar thermal
- Geothermal
- Waste heat from industrial processes and power generation

High temperature heat source
- Purpose-built CHP, including Energy From Waste
- Boilers (gas, oil, biomass)

DH networks can be classified by temperature

- 1st generation (1880s-1930s): steam based, with network supply temperature > 120°C
- 2nd generation (1930s-1970s): hot water based, with network supply temperature > 100°C
- 3rd generation (1970-present): network supply temperature between 80°C and 100°C
- 4th generation (currently in development): network supply temperature <= 60°C[1]
- An alternative approach is to use ambient (or close to ambient) temperature in the network and use building-scale heat pumps to further increase the temperature

1. See for example http://www.4dh.dk/

Heat recovery from industry and power stations for DH networks has been investigated by previous studies

Industrial processes often result in significant amounts of waste heat

- A number of energy-intensive industries provide potential for recoverable heat: refineries, iron & steel, ceramics, glass, cement, chemicals, food & drink, paper & pulp.
- Recent research exploring the largest UK sites in the EU ETS identified the recoverable potential as around 30 TWh/yr (resource based on analysis of the top 72 sites)
- Some of this could be available at low cost, although not free[1]. For example, around 4TWh/yr of recovered heat can be made available for DH at less than £30/MWh, then a further 24 TWh/yr would be available at around £90 /MWh.
- However, it is not currently clear how much of the waste heat is used on-site and how much would be available to DH networks. This is the subject of ongoing research.

Heat recovery from power stations is possible at several points in the power generation process

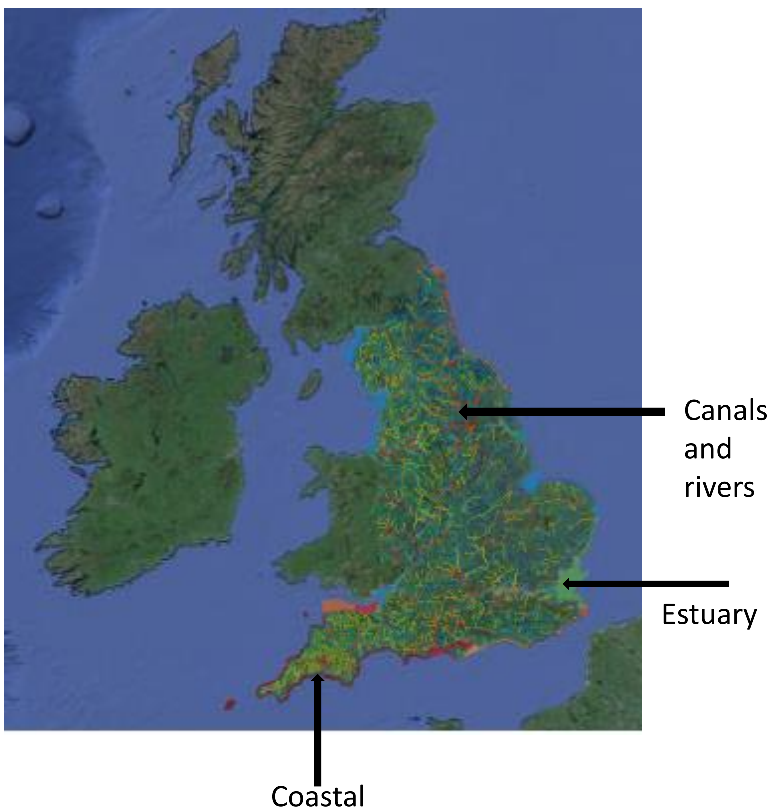
- High temperature heat can in theory be recovered from steam turbines.
- Recent work with stakeholders has shown that the cost involved in retrofitting current power stations for this purpose is equivalent to fitting a new turbine – up to 1/3 of the cost of the power station. However new-build power stations provide a less costly opportunity to incorporate this type of heat recovery.
- Low temperature heat is available from cooling water; this typically has a temperature of 30-40°C and must therefore be upgraded using a heat pump. Element Energy et al (2014) identified 58 TWh of low temperature cooling water heat available at a production cost around £30/MWh.
- Nuclear DH, although not currently carried out in the UK, takes place in Switzerland[2]. In these plants, heat is normally extracted from the steam cycle.

1. *The potential for recovering and using surplus heat from industry*, Element Energy et al (2014)
2. See for example *Utilising Nuclear Energy for Low Carbon Heating Services in the UK*, Jones (2013)

New evidence on water source potential has mapped supply to heat demand

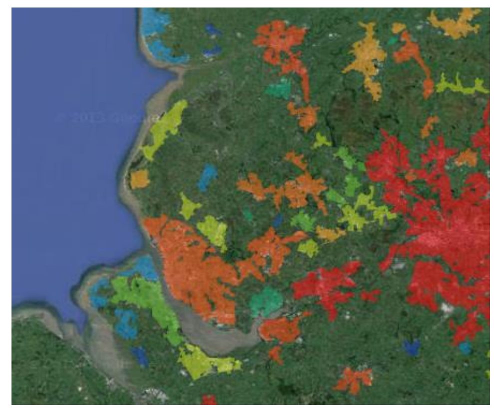
National Heat Map

The incorporation of the Water Source layers in the DECC National Heat Map (NHM) has allowed estimation of the potential for use of various water bodies in heat networks (in England only) after the application of certain environmental constraints.



Settlements and usable resource

A further layer was developed for the NHM giving the river source potential within 1km of all ‘settlements’ (areas of urban development of area >= 3.3 hectares) in England[1].



Technical potential from Settlement layer

The summed potential over England is 232 TWh/yr.

This does not take into account the viability of heat networks, it is simply the heat available from the warm side of heat pumps using rivers as their source, given certain environmental and spatial constraints.

Images: http://tools.decc.gov.uk/nationalheatmap/

1. *National Heat Map: Water Source Heat Map Layer*, Atkins (for DECC) (2015)

Other ‘free’ heat sources include sewage-source heat, geothermal heat and ground-source and air-source heat

Sewage source and sewage treatment plant heat recovery

- The use of sewage, typically around 14-22°C[1] , is novel and is not currently implemented in the UK.
- Can be used in a high temperature network with central heat pump (e.g. Helsinki) or a very low temperature network with heat pumps at the building scale (e.g. North Saanich, Canada)
- Using trunk sewers as the heat source entails colocation of demand and supply, which is not necessarily the case with water treatment works

Image: Sinclair Knight Merz

Geothermal district heating in the UK is an area in which more research is needed[2]

- A number of areas have been identified in which the geology could be suitable for extraction of heat; this is often for the purposes of electricity generation but sometimes for heat only[3]
- The only current operational scheme used to heat buildings is in Southampton; there are a small number of experimental and planned schemes
- Temperatures vary from around 30°C (experimental boreholes in Eastgate, Durham) to 100°C (Redruth)

Ground and air source

- It is not common to find ground and air source heat pumps in large scale heat networks; these sources tend to serve smaller networks such as one or several blocks of flats (for example, the 65-flat communal ground source heat pump installation at Austin House in Walsall)

Combinations of free heat sources

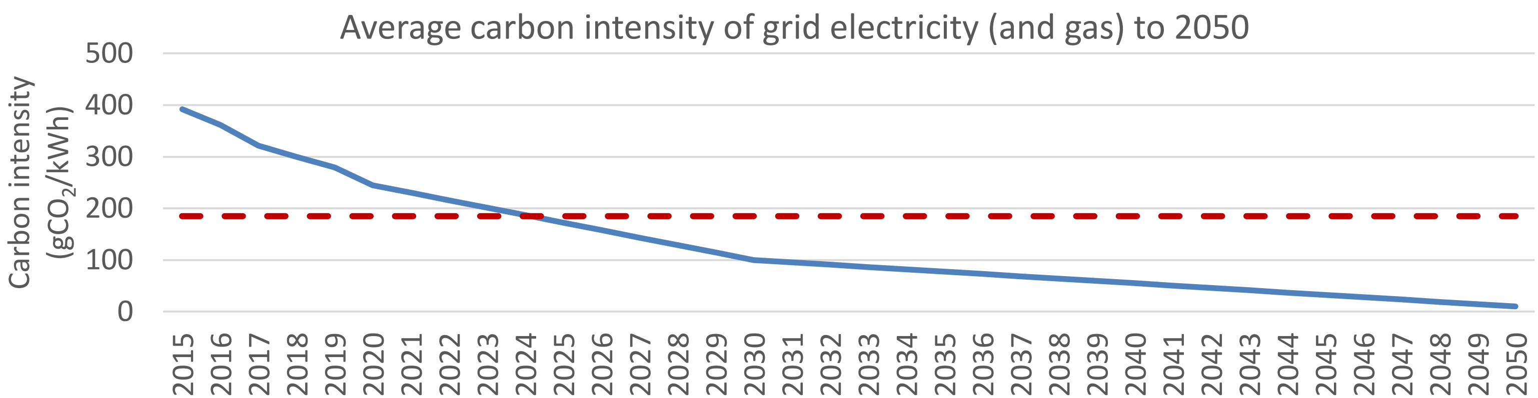
- It is sometimes more efficient to use different heat sources at different times of year within the same heat network. For example the Helsinki DH network uses seawater in summer and sewage water in winter as heat sources.

1. *London’s Zero Carbon Energy Resource: Secondary Heat Report Phase 1,* Greater London Authority et al (2013); 2. This statement is made by DECC in *2050 Pathways Analysis*, DECC (2010); 3. *Geothermal energy potential: Great Britain and Northern Ireland,* Sinclair Knight Merz (2012)

The role of gas/oil boilers and CHP will become limited as the electricity grid decarbonises

Conventional DH networks typically use gas CHP/boilers for baseload and gas/oil boilers for peak load

- Projections for the CO_2 intensity of grid electricity show a rapid decrease over the next 10 years until it falls below that of gas[1]. This suggests that from the mid-2020s, generating electricity from gas CHP results in higher CO_2 emissions than importing it from the grid.
- However, assuming that generation from gas CHP offsets the marginal grid generation plant, the CO_2 displaced will be significantly higher than the grid average. Modelling of the appropriate marginal emissions factors for electricity displaced by CHP[3], which is largely gas CCGT generation, suggests that gas CHP could continue to save CO_2 into the early 2030s.
- It should be noted that both the grid average and marginal plant CO_2 intensities are subject to some uncertainty.



Biomass could play a role in replacing some gas CHP and boilers for baseload and peak load

- However, only a small portion of anticipated biomass resource is allocated for DH (see right).
- This is because much of the anticipated resource will be used primarily in combination with CCS, high temperature industrial processes and replacing steel and concrete in construction[4].
- Using biomass for peak load is also expensive, given the low utilisation factor for capital-intensive plant.

Scenario	2050 biomass resource for DH, TWh
Central	10
High	50

1.Data source for grid CO_2 intensity: CCC analysis; 2. See 5th Carbon Budget Analysis, CCC (2015); 3. Modelling the impacts of additional gas CHP in the GB electricity market, LCP (2014); 4. Bioenergy review, CCC (2011).

There is potential for improved cost and performance of district heating infrastructure in UK networks (1)

Key options for cost reduction and performance improvement to 2050

1. Reduce oversizing

- Stakeholders highlighted that both building-scale plant and central infrastructure tend to be significantly oversized in the UK, leading to higher capital costs than necessary.
- It is likely that increased experience of district heating in the UK may lead to learning on this issue, resulting in lower network costs.

Oversizing: one example given by a stakeholder

Peak demand of individual dwelling of 150 m²	Service pipe capacity in Denmark	Service pipe capacity in UK
18 kW	32 kW	60-75 kW

2. Reduce network flow and return temperatures

- The advantages of low flow and return temperatures are lower network thermal losses and increased efficiency of heat pumps if low grade heat is used as a source.
- Further advantages of low return temperatures specifically include improved CHP and boiler performance and – assuming a fixed flow temperature, such that the temperature difference between flow and return is maximised – reduced diameter distribution pipes and a reduced volume of thermal storage for a fixed amount of stored heat.
- Experience has shown that it is possible to connect existing buildings to a network of 60°C flow and 30°C return temperature, if insulation is upgraded, new larger radiators are fitted* and there is no single glazing. However, this is problematic for certain areas in the UK where replacing windows with double glazing is difficult from a planning permission perspective.
- Very low temperature networks (10-20°C) used in conjunction with building scale heat pumps have been demonstrated in several residential environments although this is not a widespread approach. It can have the advantage of providing cooling from the same network, and if heating and cooling loads are balanced, it is an efficient means of heat and coolth recovery.

*Stakeholders generally commented that customers were unlikely to switch to DH if this involved buying new radiators. Some but not all stakeholders felt that most radiators are already oversized to a great enough extent to be used with lower flow temperatures.

There is potential for improved cost and performance of district heating infrastructure in UK networks (2)

Key options for cost reduction and performance improvement to 2050

3. Reduce network thermal losses

- Recent research[1] collecting detailed information on a small number of UK DH schemes found distribution thermal losses up to 11% (of heat generated) in bulk schemes and 43% in non bulk schemes. Bulk schemes are defined as those in which the main scheme operators deliver heat in bulk to major distribution points but do not have responsibility for final delivery to the end customers; non-bulk schemes are those in which the scheme operator or manager is responsible for delivering heat to individual customers.
- The same research suggested that high losses can be experienced through internal distribution pipework within buildings, which are not always insulated to the same standards as buried heat network pipes; this effect has not yet been quantified.
- This is also known to contribute to overheating in buildings during summer months.
- Electrical losses (parasitic electricity demand for pumping and controls) was found by the same research to equate to 1-4% of annual heat demand.

1. *Assessment of the Costs, Performance, and Characteristics of UK Heat Networks*, AECOM (for DECC) (2015)

Thermal storage can perform multiple functions within heat networks

Thermal storage is commonly incorporated with DH networks to perform the following functions

- Reducing both the size of peak load heating plant and its operation (and thus CO_2 emissions, since peak load plant is often highly carbon intensive).
- Allowing heat to be utilised even if the times it is available (e.g. solar thermal) or cost-effective to run plant (e.g. CHP, heat pump) do not coincide with the times it is demanded.
- Related to the above, where there is co-production of electricity and heat, storage allows electricity generation at times when there is no demand for heat, without resorting to heat rejection.
- Managing the network return temperature.
- Providing interim resilience if heat supply is interrupted

Thermal storage can be classified by its thermodynamic mechanism and by its application

		Application	
		Short term buffer	Interseasonal
Mechanism	Sensible heat storage	Tank (water) High temperature molten salt	Aquifer (water) Borehole (rocks) Pit (rocks and water) Tank (water)
	Latent heat storage	Phase change materials	Ice
	Thermochemical heat storage	A number of chemicals and reaction types (e.g. redox, hydration & dehydration)	

Thermal storage for district heating usually consists of sensible tank-based systems

Thermal storage current deployment in UK

- Just over 7% of the operational DH schemes in the UK are known to operate with a thermal store; however this is expected to increase[1]. The majority of these are short term tank storage systems, with capacity ranging from a few hours to a few days.

Thermal storage potential in UK DH networks – how much and which technologies?

- An ideal thermal store for a DH network would have the following characteristics
  - High energy density, therefore using as little space as possible
  - Optimal operation at the temperatures typically used in DH networks (30-100°C)
  - Low capital and maintenance cost
  - Low power requirement
  - Sufficient charge and discharge speed
  - High utilisation over a year
- Currently, sensible storage (usually tank-based) is the least expensive and has the advantage of indifference to network operating temperatures
- However, tank sensible storage has relatively low energy density and the size of installations is therefore often restricted by available space. This is particularly a concern for DH networks which tend to be most economically viable in areas of high heat demand and by consequence high building density and high land value. The issue of limited space is one of the major drivers towards more novel storage technologies.
- In the context of DH networks, interseasonal storage can be very expensive compared to its low utilisation unless it is naturally available (e.g. presence of an aquifer), and is not generally assumed to be an important aspect of UK DH networks in the coming decades.

1. *The potential for thermal storage to reduce the overall carbon emissions from district heating systems*, Tyndall Working Paper 157, Martin & Thornley (2013)

Systemic benefits of heat networks and the integration of heat with the wider energy system

Role of heat networks in a more integrated energy system

- During the past decade there has been increasing interest in the potential economic, environmental and energy security benefits of energy system integration.
- Of the various energy vectors, engineering and interfaces involved in integration, the energy system components related to heat have emerged as a key area where the concept may be most effective.
- This is because heat cuts across sectors and technologies, and because it is cheap to store (for short periods).
- Previously, heat has usually been considered in isolation (e.g. heat in buildings, or heat in industry), and has often been considered a less important energy vector.
- The primary emerging area of interest is arbitrage between heat, electricity and gas vectors, including all the sectors, infrastructure, technologies and interfaces that could be involved. Heat networks would clearly be an integral part of such an energy system.
- Heat integration is a highly active area of research in Europe, with emerging methodologies and findings. It is expected that knowledge and demonstration in the area will yield further insights in coming years.

Modelling of systemic benefits

- An additional Scenario to those undertaken in the main part of the report, entitled the 'Integrated Scenario', attempts to capture the effects described above. It can be found in the Appendix.

References for further reading

- A list of references for further reading on this topic is included in an Appendix.

Contents

UK cooling demand projections give a large range of possible trajectories

A scenario based approach to future cooling demand

- In 2010, DECC published 4 scenarios for the evolution of cooling demand to 2050[1], as the UK climate warms.
- In the plots below, moving from Level 1-4 entails higher energy efficiency and more demand reduction, as well as a lower percentage of the building stock with air conditioning installed. It can be seen that these scenarios vary widely, to the extent that in non-domestic buildings cooling demand can either decrease or significantly increase.

Figure D4: Trajectories for total domestic cooling demand under four levels of change

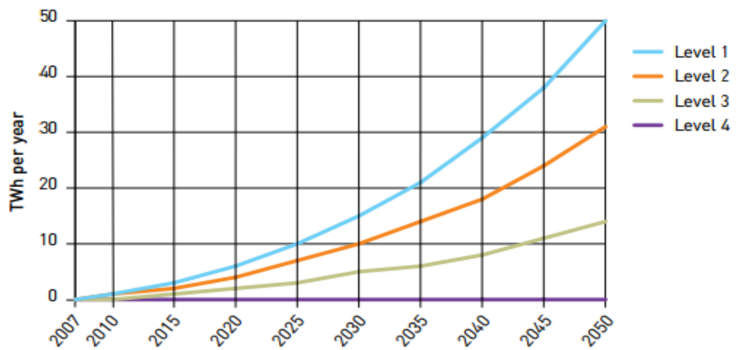
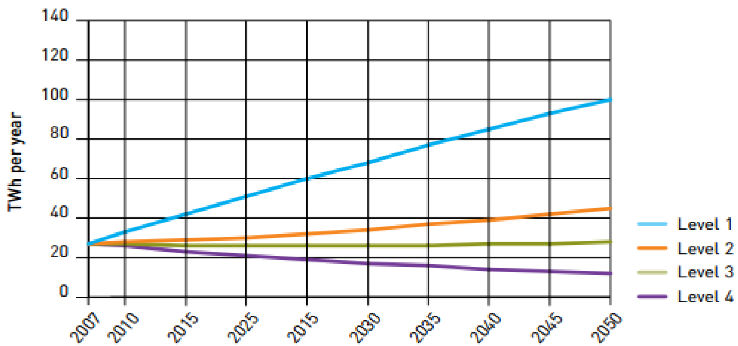


Figure D6: Trajectories for total non-domestic cooling demand under four levels of change



The role of district cooling in supplying the demand in the DECC pathways

- DECC again used a scenario approach to associate a mix of cooling technologies with each demand level. These scenarios were based on a range of assumed fuel mixes. According to the approach, district cooling is only possible where there is heat available from a non-electric fuel type (power station heat off-take, geothermal district heating). Therefore these scenarios are not based on demand or potential for district cooling per se, but on the evolution of heat supply to 2050.
- Over the next few slides we examine the potential for district cooling from a different perspective: stakeholder option and applicability to a UK context.

1. 2050 Pathways Analysis, DECC (2010). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42562/216-2050-pathways-analysis-report.pdf

District cooling is generally more costly and less efficient than district heating

Cooling networks will be introduced here by comparing them to heating networks

- Analogous to heat networks, cooling networks transport ‘coolth’ from a source through pipes, and transfer the coolth to the distribution circuit of buildings in which there is coolth demand.
- The flow pipe is usually around 5°C and the return around 15°C, and as such the temperature difference in cooling networks is approximately 10°C, compared to a delta T of 20-40 degrees in heat networks.
- For this reason, cooling network pipes are larger in diameter to those in heating networks: for example the inner diameter of the Helsinki cooling network is 400-800mm[1]. The increased space and higher losses associated with larger pipes lead to DC being less efficient at transporting coolth over large distances than DH.
- Also similar to heat networks, DC can be retrofitted into buildings with existing building scale cooling equipment.

Current status of cooling networks in the UK

- District cooling is not widespread in the UK. There are examples of cooling networks retrofitted into existing district heating schemes (e.g. in Southampton city centre) and new-build district heating and cooling (DHC) schemes (e.g. London Olympic Park, Salford Media City, London Citigen).
- Most new-build UK schemes are based on trigeneration; see next slide.

1. *Cooling More With Less*, Euroheat & Power (2006)

A range of coolth sources and technical configurations can be used for district cooling

Coolth sources

- Coolth is generally produced using compressor chillers, absorption chillers or water-source heat pumps .
- The economics of coolth production can be made more favourable if there are locally available coolth sources, such as a lake or aquifer. Absorption chillers can be driven by the heat output of CHP; this is known as CCHP (Combined Cooling, Heating and Power) or trigeneration.

Cooling networks

- Conventional cooling networks use gas or electricity-consuming plant to produce a flow temperature of around 4°C.
- Conventional networks can also incorporate free cooling if there is a nearby source, or coolth sources at a higher temperature than the network using heat pumps/chillers.
- A novel approach to district cooling is using an ice-water slurry as the working fluid (at around -1°C). This has a high transport energy density and uses both sensible and latent energy transfer; however the hydraulics of the network can be more complex than in conventional cooling networks.[1]

Using district heating and cooling together to increase efficiency: three ways

- A centralised heat pump can simultaneously provide heat to a heating network and coolth to a cooling network using its hot side and cold side;
- Trigeneration can be used to vary the ratio of heat to coolth provided, according to demand for each, whilst always allowing electricity to be produced. This is particularly advantageous in situations where a city's electricity is produced from CHP, since high electrical output can be maintained in both summer and winter.
- Very low temperature networks used with reversible building-scale heat pumps can allow both heat and coolth to be drawn from and rejected to the network, reducing the amount of central heating and cooling plant required.

Storing coolth

- Coolth can be stored as either chilled water or ice, and therefore work on sensible or latent storage mechanisms.
- For example, the Paris district cooling network incorporates ice storage (using 4 ice storage tanks of 200 m^3, with a total cooling capacity of 30 MWh).

http://www.districtenergy.org/assets/CDEA/Best-Practice/IEA-District-Heating-and-Cooling-Connection-Handbook.pdf

Demand for district cooling in the UK is considered to be low by key stakeholders

Stakeholders highlighted a number of barriers to uptake of district cooling in the UK

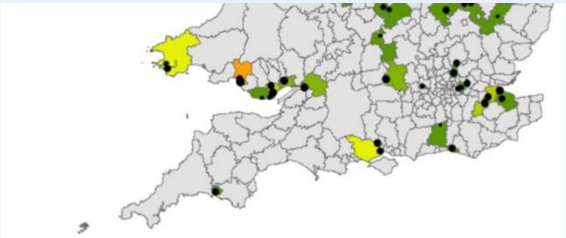
- The economics of district cooling are rendered less favourable than those for district heating by the larger pipes required (and therefore higher capital and installation costs).
- In conventional heating networks using CHP, the time at which it is economically advantageous to run the plant is the same as the time of high heat demand (i.e. during the day). Electrical chillers do not have this coincidence, therefore absorption chillers making use of CHP are currently more popular in the UK
- However, as the CO_2 benefits of CHP decrease over time (as explained earlier), absorption chillers are less favourable, so electric chillers would start to be used. **Large, centralised electric chillers do not give a significant efficiency gain over building-scale chillers**, therefore the economic case for district cooling is difficult to make as we progress towards 2050.
- District cooling is not currently popular in the UK due to a distrust that it is advantageous over building-scale cooling, and relatively low cooling demand. (In the USA, however, DC is much more popular and is marketed as more convenient and requiring less space - not necessarily as saving money or energy)
- Cost savings from installing district cooling at the same time as district heating are not necessarily a given, since often the two networks are not routed through the same areas of a development.

Contents

The model includes a wide range of key local factors influencing the viability of district heating

Local factor influencing DH viability	How is this included in the model?
• **Heat density** • **Building mix** (domestic/non-domestic) • **Number of buildings/connections** (presence of large 'anchor' loads) • **Future thermal efficiency of buildings** (Domestic solid/cavity wall mix)	**'Zone archetypes'** describing these properties at a local level (1km scale)
• **Availability of waste heat sources** from industry and power • **Availability of water sources** • **Availability of fuel sources** (biomass, energy from waste, etc.)	**'Availability/suitability'** of these factors at Local Authority level





Waste heat sources – as point sources and by LA (illustrative)

The key building blocks of the modelling approach are zone archetypes, heat supply options and heat sources

Definition of key modelling terms

Term	Description
Zone	A real region of area 1 km^2
Zone archetype	A fictitious region of area 1 km^2 with a set of properties representing the characteristics of zones which impact strongly on the viability of district heating, used to represent the heat demand characteristics of zones in the modelling
Heat supply option	A simple combination of technologies which could be used to provide heat to a district heating network, consisting of up to two baseload technologies (such as Gas CHP or water-source heat pumps) and one or both of peaking plant and thermal storage
Heat source	A heat source is a source of secondary heat which could be used by a heat supply option to serve a district heating network, such as water-source heat, industrial waste heat or sewage

- In the following sections, further details each of these modelling concepts are given.

Overview of core modelling approach

High-level overview of DH uptake modelling approach

MODEL STEPS

1. **1. Calculate LCOE** of all possible supply options for every 'zone archetype'
2. **2. Simulate uptake** of district heating across all modelled 'zones'
3. **3. Calculate key output metrics** based on the uptake

INPUT DATA

Inputs to step 1:

- **Heat demand** of zone archetypes
- Local **heat sources** database
- **Heat supply** technologies data

Inputs to step 2:

- **Cost threshold** for uptake
- District heating **growth constraints**
- **Real zones** matched to zone archetypes

Contents

Zone archetypes have been constructed to describe the characteristics of real zones influencing the viability of district heating

Summary of variables used to define zone archetypes and data sources used

Variable	Reason included	Source(s)
Heat demand (including domestic/non-domestic split)	• Viability of district heating as a cost-competitive alternative to individual building-level heating systems is strongly dependent on the heat density of the zone in question • Zone archetypes have been constructed to capture the wide range of heat densities occurring across real 1km^2 zones	• DECC heat map (England) • Scottish heat map (Scotland) • DECC Sub-national electricity and gas consumption data (Wales and Northern Ireland) • ECUK data (calibration to overall UK heat demand)
Number of connections (domestic and non-domestic)	• Number of connections within the zone in question determines the connection cost incurred • A small number of non-domestic connections will entail a lower overall connection cost than a large number of domestic connections, where the heat demand may be similar	• DECC heat map (England) • Scottish heat map (Scotland) • DECC Sub-national electricity and gas consumption data (Wales and Northern Ireland)
Solid/cavity wall split	• Heat demand of the existing building stock is likely to reduce over time as energy efficiency measures are installed, influencing the cost-effectiveness of district heating • The level of heat demand reduction achieved will be dependent on the remaining potential for insulation and the level of thermal efficiency that can be reached • A useful indicator for the heat demand reduction potential is the wall construction type of the building	• English Housing Survey (England) • Scottish Housing Condition Survey (Scotland) • Living in Wales Survey (Wales) • Data not available for Northern Ireland
Network length	• The length of the network required to serve all buildings within a zone strongly influences the network cost and the overall cost-effectiveness of district heating	• Road length data from Ordnance Survey MasterMap

Heat demand across the UK is based on heat map data and other sources

Description of sources

Region	Sources used to determine heat demand	Description
England and Scotland	• DECC heat map (England) • Scottish heat map (Scotland) • Energy Consumption in the UK (ECUK)	• Heat map data was obtained, estimating the heat demand from domestic and non-domestic buildings in all 1 km^2 zones in England and Scotland • Total heat demand across the UK was calibrated to ECUK data
Wales and Northern Ireland	• DECC Sub-national electricity and gas consumption data (Wales and Northern Ireland) • Energy Consumption in the UK (ECUK)	• Heat map data for Wales and Northern Ireland was not available • DECC Sub-national electricity and gas consumption statistics were used to match local authorities in those areas to the closest corresponding areas in England and Scotland; heat demand of zones in Wales and Northern Ireland was estimated by assigning zone archetypes to those areas based on this matching process • Total heat demand across the UK was calibrated to ECUK data

Heat demand has been estimated for all 1 km^2 zones across UK

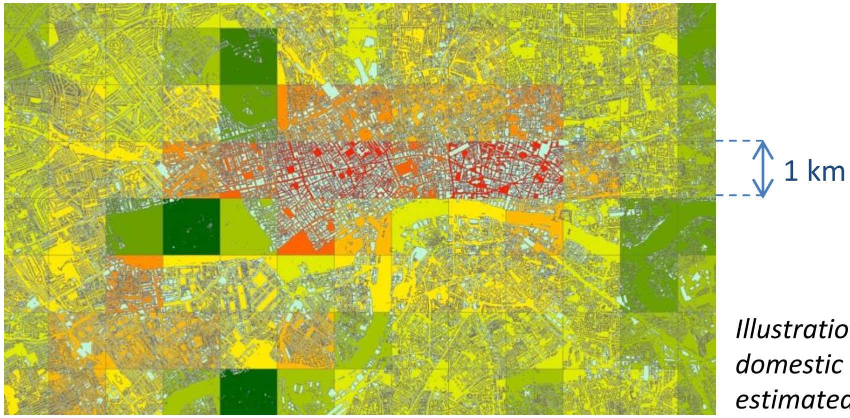
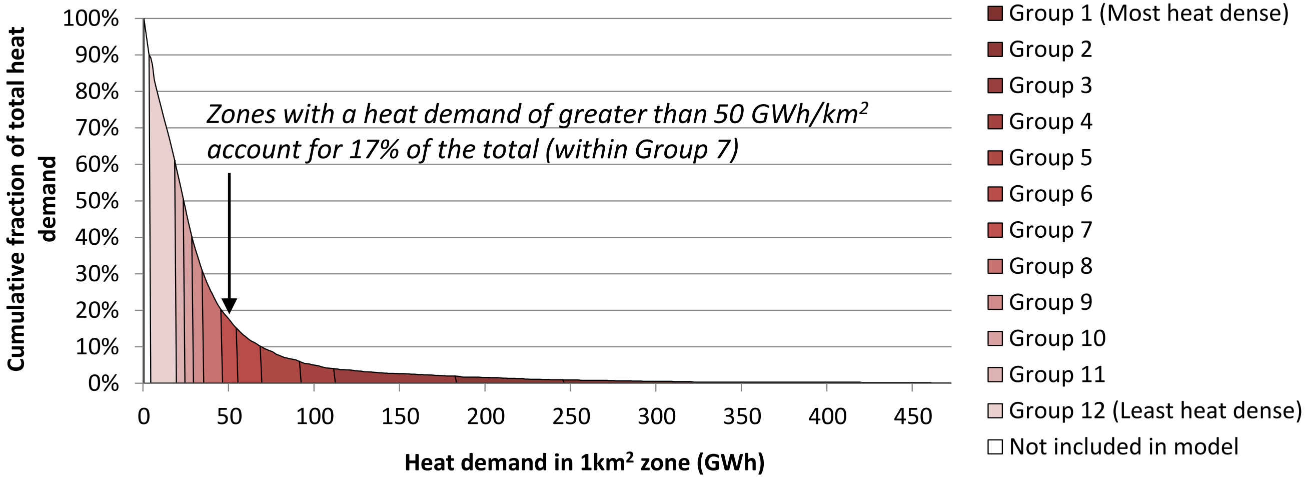
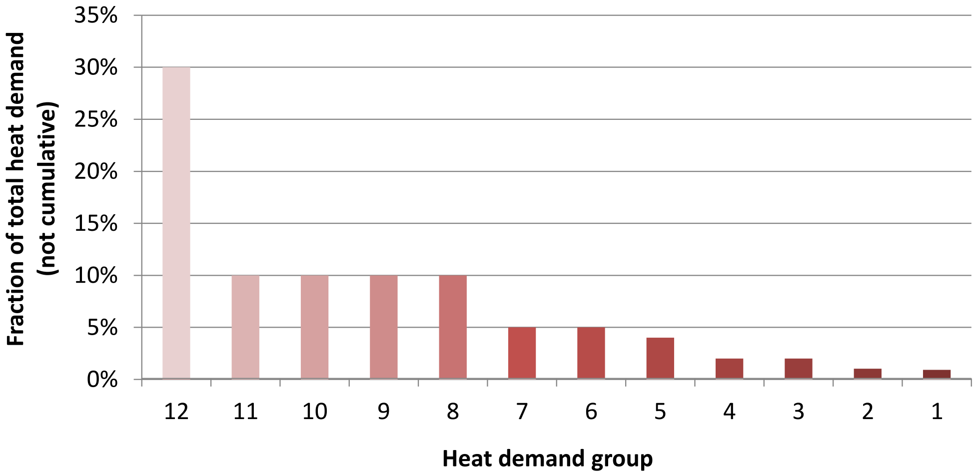


Illustration of heat map data for an area of London: domestic and non-domestic heat demand has been estimated for each 1 km^2 in the UK

Zone archetype definition includes 12 heat demand density groups

Heat demand density groups used in zone archetype definition





- **Zones are assigned to one of 12 groups** according to their heat demand
- Heat demand density groups are defined to provide **higher resolution at the more heat dense end**, to ensure more heat dense zones are not 'diluted' by less heat dense zones
- 'Top 90%' (most heat dense) heat demand is included in the definition of ZAs – the 'bottom 10%' is not included as deemed technically unsuitable
- Heat demand of each zone archetype is then derived as an average across all zones associated with that archetype

*Zone archetype definitions were formed from analysis of English and Scottish heat map data since this was available at 1km^2 resolution

The ‘top 10%’ of total heat demand is concentrated in less than 300 zones

Frequency of heat demand density groups in the model of UK heat demand

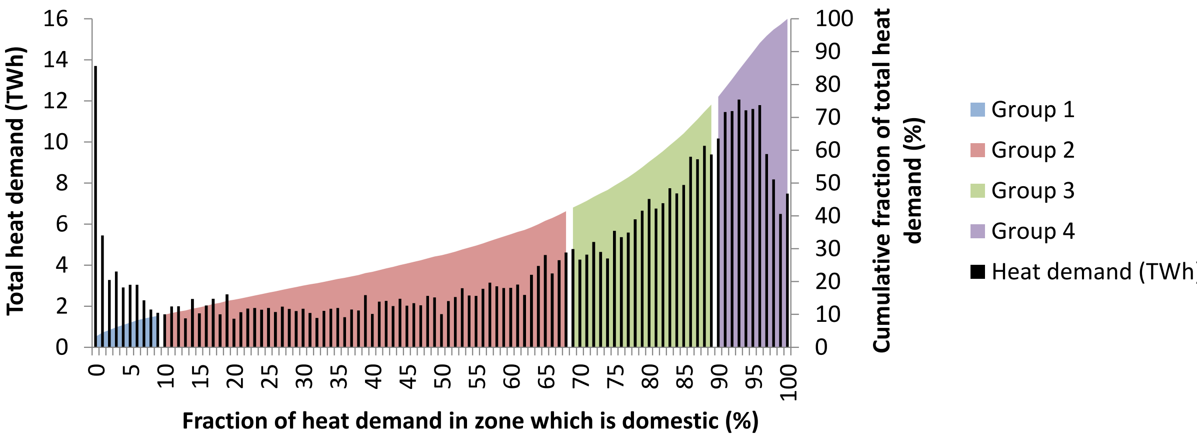
Heat demand group	Fraction of total heat demand* in group	Fraction of total heat demand (cumulative)	Number of 1km^2 zones in this group
1	1%	1%	14
2	1%	2%	24
3	2%	4%	77
4	2%	6%	105
5	4%	10%	256
6	5%	15%	408
7	5%	20%	499
8	10%	30%	1,272
9	10%	40%	1,572
10	10%	50%	1,916
11	10%	60%	2,405
12	30%	90%	18,264

- **Heat demand is very unevenly distributed** across the approximately 250,000 zones of 1 km^2 across the UK
- Analysis of English and Scottish heat map data showed that **90% of the total heat demand is located in the most heat dense 27,000 of the 120,000** zones in England and Scotland.;
- Only the 6,000 most heat dense zones are required to capture the ‘top 50%’ of the total heat demand; **the ‘top 10%’ of heat demand is located in fewer than 500 zones**
- As may be expected, this suggests that only a **relatively small number of district heating zones may be required to achieve** a high coverage of total heat demand and, in the case of low carbon district heating schemes, **significant carbon emissions reductions**
- On the basis of heat demand (before considering the location of favourable heat sources), we might expect the several tens of zones in the top heat demand groups to be the first to take up district heating

*Zone archetype definitions were formed from analysis of English and Scottish heat map data since this was available at 1km^2 resolution. ‘Total heat demand’ here refers to the sum of English and Scottish heat demand

Zone archetypes also describe the building sectoral mix

Domestic/non-domestic split groups used in zone archetype definition

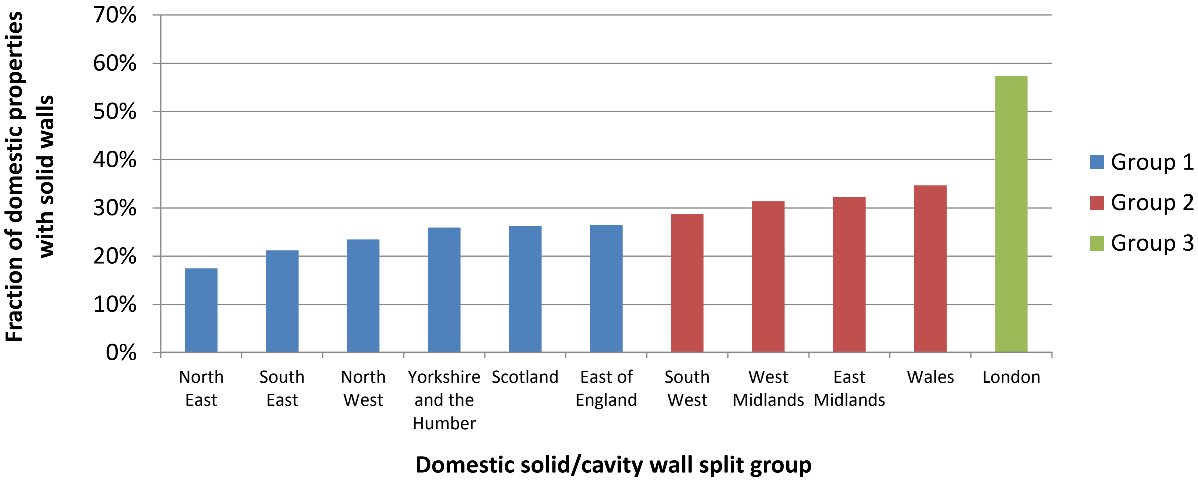


Domestic/ Non-domestic split group	Proportion of zone heat demand which is domestic
Group 1	0-10%
Group 2	10-65%
Group 3	75-90%
Group 4	90-100%

- **DECC and Scottish heat map data** contain the domestic and non-domestic heat demand separately.
- **Zones are assigned to one of 4 ‘Domestic/Non-domestic split’ groups** according to the fraction of their demand which is associated with domestic buildings.
- Domestic/non-domestic mix impacts the **number of connections** and the **future thermal efficiency trajectory:**
    - Non-domestic buildings are typically larger and require a smaller number of connections per MWh heating served, leading to lower costs;
    - Energy efficiency improvements proceed at a different rate for domestic and non-domestic buildings.
- Groups were chosen to capture those zones which are predominantly non-domestic and predominantly domestic (Groups 1 and 4 respectively), which make up more than 30% of the total heat demand; the number of groups was limited to 4 to ensure a tractable number of zone archetypes.

Zone archetypes also describe the wall construction type for domestic buildings

Solid/cavity wall split groups used in zone archetype definition



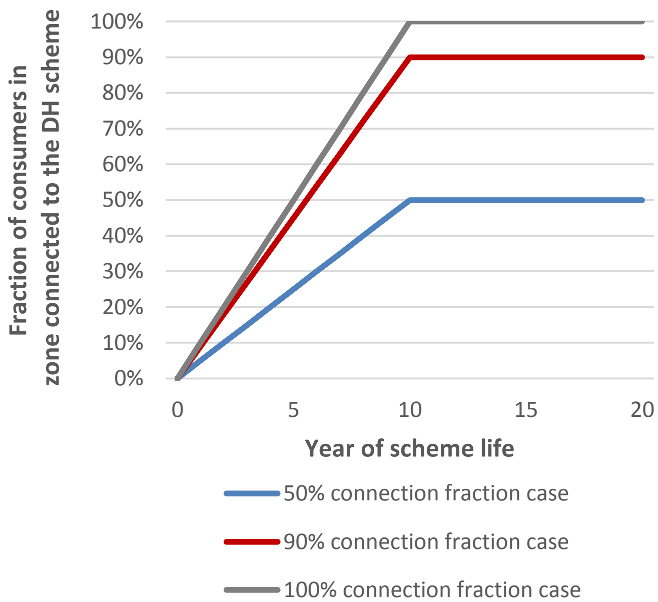
- Wall type (solid or cavity wall) **influences the future thermal efficiency trajectory** of the zone.
- Cavity wall dwellings are projected to be insulated more rapidly and in a larger section of the stock than solid wall dwellings. In the Central heat demand scenario, 83% (4.5 million dwellings) of 2013 remaining potential for cavity wall insulation is achieved by 2030, with 49% (3.5 million dwellings) of the 2013 remaining potential for solid wall insulation achieved by the same date. Therefore, solid wall properties are expected to have a higher average heat demand.
- Available data on this property is relatively limited – it is determined here **at Government Office Region level**, based on national housing survey data.
- **Zones are assigned to one of 3 groups** according to the fraction of domestic properties which are solid walls.
- The number of different wall types is limited to 3 to ensure a tractable number of zone archetypes.

‘Connection fraction’ is a key assumption in determining the heat demand in a given zone and hence the cost of district heating in the zone

Description of connection fraction

- ‘Connection fraction’ is the **fraction of consumers within a zone connected to a DH scheme** (we define it as the fraction of the heat demand connected to DH)
- While the cost of required heating plant and the revenue generated from heat sales are strongly dependent on the connection fraction, **the cost of the distribution pipework is largely independent of the connection fraction[1]**
- **LCOE of DH** is therefore rather strongly dependent on the connection fraction
- Three connection fraction cases are used in the core scenarios (as shown on the right)
- **90% and 100% connection fraction case** represents cases where most or all barriers to consumer connection have been overcome through various policies and initiatives, as outlined in a later section and described in detail in the accompanying Annex “Overcoming barriers to district heating”
- **50% connection fraction case** represents a more conservative case where barriers to consumer connection remain
- We emphasise that using a non-zero connection fraction to derive the LCOE of the (hypothetical) scheme does not imply that a scheme is necessarily built in the model – the scheme will only actually be built if it is cheaper than the counterfactual (see later)

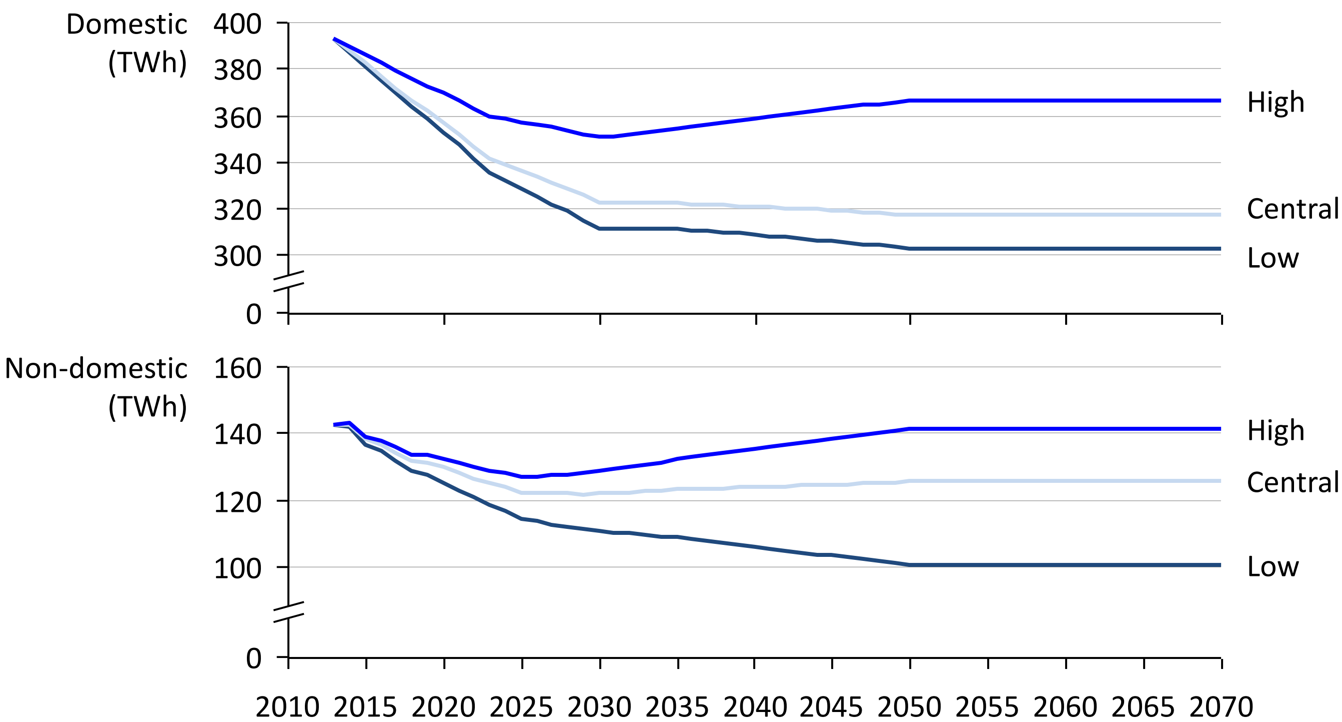
Connection fraction cases



[1]Under the simplifying assumption that connected customers are distributed uniformly.

Heat demand projections to 2070 have been developed and applied to the zone archetypes

Heat demand[1] projections to 2070



- Element Energy's mature **domestic and non-domestic bottom-up building energy models** were used to develop heat demand projections to 2070
- Heat demand in 2013 was **calibrated using ECUK** Table 3.05 for Domestic and Tables 4.05[2] and 5.14 for Non-domestic

Sector	Heat demand in 2050 (TWh)		
	Low	Central	High
Domestic	303	317	367
Non-dom	101	126	142
Total	**404**	**443**	**508**

- A range of **scenarios for heat demand to 2050** have been developed for the domestic and non-domestic sectors
- The scenarios include the **growth in number of domestic buildings and in the floorspace of non-domestic buildings**
- In the Central scenario, the total heat demand falls 15% from 521 TWh in 2015 to 443 TWh in 2050 due to energy efficiency improvements, despite a growth in the building stock from 27 to 34 million domestic dwellings and from 1.2 to 1.5 billion m^2 of non-domestic floorspace
- These projections are applied to zone archetypes to capture the impact on the cost-effectiveness of district heating, including the likely **differences in future thermal efficiency of domestic vs non-domestic** buildings and **cavity vs solid wall** properties

(1) Values are for heat demand, not for final energy of fuel for heating; (2) Non-domestic includes industry 'Space Heating'.

Contents

We have included a wide range of heat supply options, with a focus on localised heat sources

Summary of supply option components

- We term a package of technologies supplying heat to a district heating scheme a ‘supply option’
- Supply options are constructed from up to 4 components:
  - **Baseload component 1:** this is provided by a ‘local’ heat source such as waste heat from a power station.
  - **Baseload component 2:** there can also be a second component of the baseload, such as biomass boilers or gas CHP. This is firstly because the local heat source may not be large enough to supply a heat-dense zone, and secondly to ensure that heat demand can be met when the output of a power station is reduced. However, rules have been imposed limiting the use of gas CHP in this modelling, to avoid lock-in of schemes with high CO_2 intensity. Gas CHP is only allowed with power station waste heat, and only if there exist other options which could replace it later. The rationale for limiting the use of gas CHP is explained in a later slide.
  - **Peaking plant and thermal storage:** peak demand is catered for using these. There are two options: ‘basic storage’ which still requires peak load plant, and ‘additional storage’ which eliminates the need for peak load plant but also requires additional baseload plant.
  - **Network temperature**: ‘Conventional’ or ‘Lower’ temperature.

Supply options included in the model

Baseload component 1 – local heat source	Baseload component 2	Peaking plant and thermal storage case	Network temperature case
• River source heat + heat pump (HP) • Industrial waste heat (low T) + HP • Industrial waste heat (high T) • Power station waste heat (low T) + HP • Power station waste heat (high T) • Sewage source heat + HP • Energy from waste (EFW) source heat	• Gas CHP • Biomass boiler	• Storage + gas boiler peak plant • Additional storage and baseload (no peaking plant required)	• Conventional T (80°C network flow T) • Lower T (60°C network flow T)
• 0%, 25%, 50%, 100% of baseload	• Remainder of baseload		

Further components of heat supply options in the model

Storage and peaking options

- The fraction of annual heat demand met by the baseload and peak plant is dependent on the thermal storage option.
- In real schemes, one advantage of using thermal storage is that it increases the potential for off-peak electricity to be used to run heat pumps.
- A second advantage can involve reduction in use of peak load plant, which is often fossil-fuel fired.
- These attributes of storage are represented in three ‘storage options’ in the model, which use different proportions of baseload plant, storage and peak load plant.
- “Additional storage” and “Additional baseload and storage” contain enough storage that the electricity purchased price is consider to be the off-peak price.

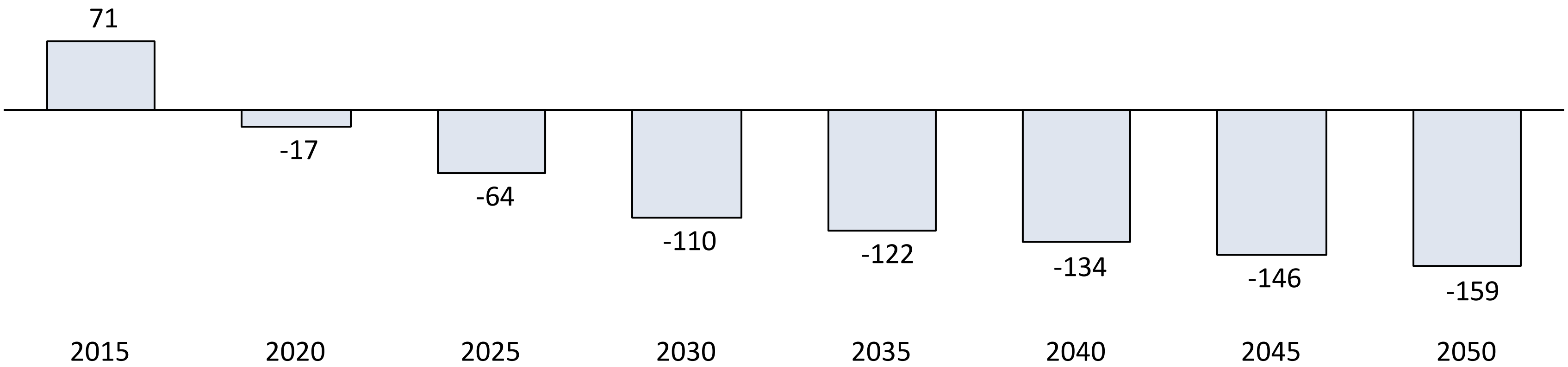
Thermal storage option	Thermal storage capacity (units of hours of average hourly heat demand)	Fraction of annual demand met by baseload plant (%)	Fraction of annual demand met by peaking plant (%)
Standard baseload and storage	2	65%	35%
Additional storage	12	65%	35%
Additional baseload and storage	9	100%	0%

Three example supply options

Baseload component 1 – local heat source (% of baseload)	Baseload component 2 (% of baseload)	Thermal storage option, and peak load plant if needed	Network temperature case
River-source heat + HP (50%)	Biomass boiler (50%)	Additional storage + Gas boiler peaking	Lower T
Power station waste heat + HP (75%)	Gas CHP (25%)	Additional storage + Gas boiler peaking	Conventional T
None	Biomass boiler (100%)	Additional baseload and storage	Conventional T

Gas CHP in district heating should be limited to sites where lower carbon options are available from around 2030

Emissions savings of Gas CHP versus counterfactual per kWh heat delivered (gCO_2/kWh)



- The debate around the extent to which the use of gas CHP will decrease or increase CO2 emissions was introduced on page 24.
- The CO_2 abatement performance of gas CHP depends on the marginal plant that is displaced by CHP generation, likely to be largely gas CCGT at least through the 2020s. However, once the penetration of low carbon generators reaches the point that they become the marginal plant at certain times of the year, expected to occur from around 2030, the carbon benefit of gas CHP is eliminated.
- The rationale for installing gas CHP in district heating also depends on whether there are other, lower carbon heat sources locally available to replace the gas CHP once it reaches the end of its life. If not, it will either be replaced with new gas CHP (resulting in lock-in of high carbon heat supply) or it may lead to stranded assets (a network but no heat source to enable its use).
- The implication of this is that the siting of new gas CHP must be chosen carefully where there exists another, lower carbon heat source, which could be incorporated into the DH network after the lifetime of the gas CHP is over.
- In the modelling in the next section, we have limited the role of Gas CHP: we only allow gas CHP as 25% of the baseload combined with power station waste heat.
- Gas CHP is deemed necessary here in order to ensure that heat demand can be supplied during times of non-availability of those sources (for example, fossil fuel-based power stations may in future experience significantly reduced load factors due to the deployment of intermittent renewables).
- However, we also present a sensitivity on the Central Scenario in which the use of gas CHP is not limited before 2030, to observe the effect on uptake of low carbon sources.

Contents

Heat sources in the model include power station and industry waste heat, water-source heat and sewage-source heat (1)

Summary of heat sources included in model and data sources

Heat source	Data source(s) used	Total annual resource input	Description
Industrial process waste heat	Element Energy modelled data on top 70 EU ETS sources in UK	31 TWh	• We use data on the available heat, the temperature of the heat (categorised as High T if ≥90ºC, and Low T otherwise) and the location of the source. • Waste heat sources are assigned to a local authority, any zone within which may make use of the heat source, providing it is of a suitable temperature and has not been depleted by another scheme. • High T sources are assumed to be ≥90ºC in the model, and Low T sources assumed to be 40ºC. The latter require use of a heat pump to upgrade them to the network temperature. • We reduce the available heat resource by 19% to account for the use of waste heat being used on-site, based on consultation with DECC.
Thermal power station waste heat	Element Energy modelled data on top 70 EU ETS sources in UK	38 TWh	• We use data on the available heat and the location of the source. Sources are assigned to local authorities. • The temperature of the heat source is 40ºC, representing cooling water from the end of the power generation process. Therefore a heat pump is required to upgrade the heat to network temperature. • In the 'Max' scenario (see later), an assumption is made that as power stations are refurbished, they are retrofitted to enable capture of high temperature waste heat, at a cost of £96/kW_e. • As the grid decarbonises in the coming decades, thermal power station generation output is expected to decrease, potentially reducing the available waste heat from power stations for use in heat networks. However, the extent to which this will occur is uncertain. In DECC's 2014 power sector model Reference scenario, however, the total non-nuclear thermal electricity generation decreases by around 20% only to 161 TWh/yr, with Gas-CCS providing the majority of this. Given that our analysis includes a relatively conservative 38 TWh of power station waste heat in 2015 – a fraction of the total thermal power generation, from the top 70 EU ETS sources only – we model a fixed available resource of 38 TWh to 2050.

Heat sources in the model include power station and industry waste heat, water-source heat and sewage-source heat (2)

Summary of heat sources included in model and data sources (continued)

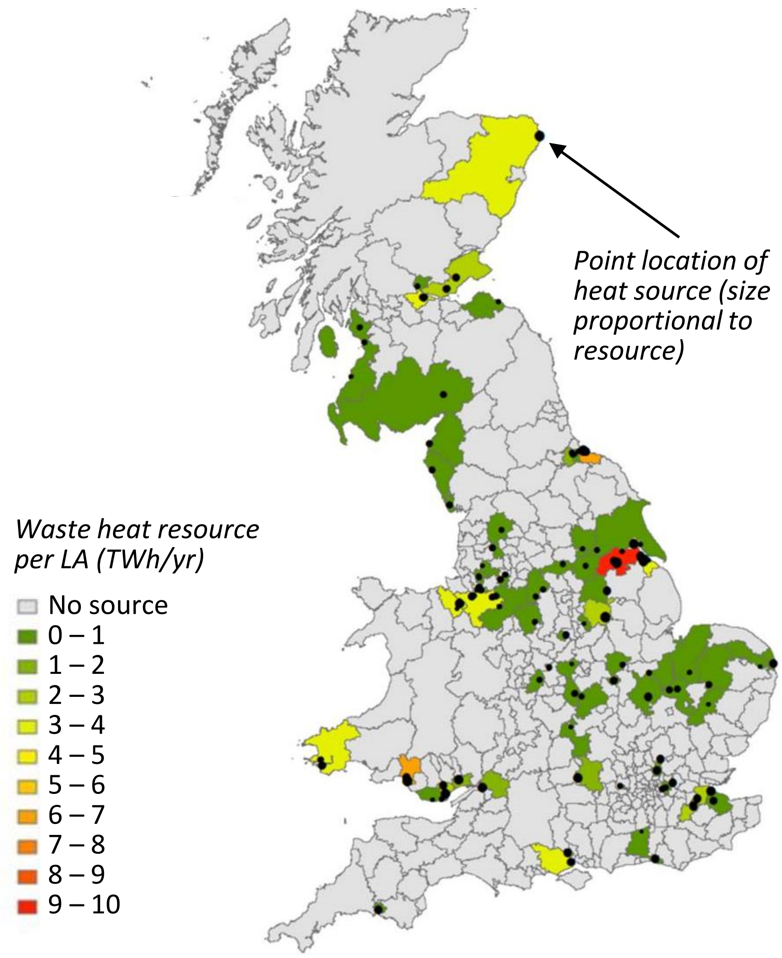
Heat source	Data source(s) used	Total annual resource input	Description
Water-source heat	• DECC water-source heat map	232 TWh	• We use the 'settlements' layer of the water-source heat map, which provides the amount of heat (in TWh) available from water sources within 1 km of heat demand centres • Water-source heat is allocated to local authorities based on location • The temperature of the water source heat is assumed in the model to be 10ºC
Sewage-source heat	• Element Energy analysis based on population at local authority level	18 TWh	• We derive an estimate of the sewage-source heat resource per person, and allocate resource to each local authority based on population • We assume 135 litres of sewage per person per day, with a temperature of 17ºC • Note that sewage source heat pumps for DH are still a novel technology and that real installations are rare.
Energy From Waste (EFW)	• WRAP database of existing EFW plants[1] • DEFRA projections of EFW increase to 2020[2]	3 TWh	• Existing sites in the WRAP database were allocated to the LAs they are located in • Since the actual thermal output or potential of many of these sites is unknown, the same thermal output was assigned to each site • DEFRA projections of increasing EFW resource were implemented by allocating the extra resource to random LAs which do not currently have EFW plants

Note: waste heat from nuclear power generation is not included in this study, due to uncertainty regarding public acceptance. Including this would increase the power station waste heat resource at either high or low temperatures depending on the heat extraction point. For more information on recovering heat from nuclear power please see ETI (2015).[3]

1. http://www.wrap.org.uk/content/list-energy-waste-sites; 2. DEFRA (2014). Energy from waste: a guide to the debate;
3. Energy Technologies Institute (2015). The role for nuclear within a low carbon energy system.

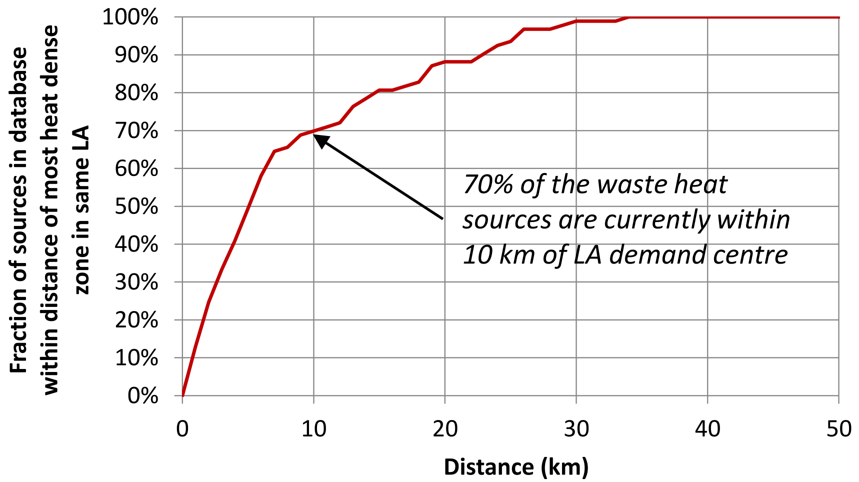
Visualisation of the amount and location of waste heat from industrial facilities and power stations included in the model

Waste heat sources included in the model



Connecting waste heat sources to zones

- To capture the distribution of distances between waste heat sources and areas of heat demand we have derived for each source the distance to the most heat dense zone in the same LA
- Cost of the associated transmission pipe is included in the model



Visualisation of water heat sources included in the model

DECC water source “settlements” layer

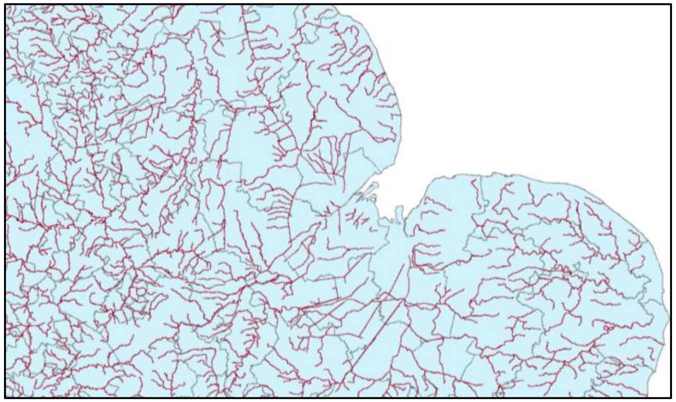


Illustration of basic DECC water source layer

Match with demand

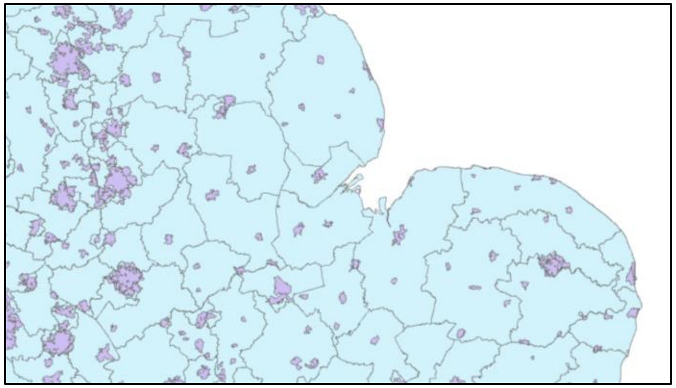


Illustration of DECC water source “settlements” layer

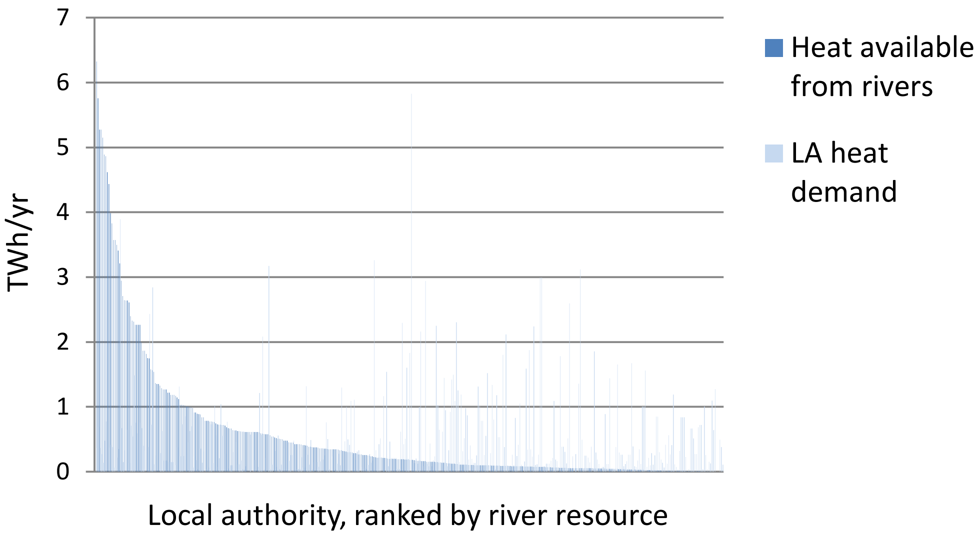
Description of data and processing

- Availability of water sources is based on the **DECC water source “settlements” layer**
- In this basic water source layer, the heat resource of all major rivers is included
- In the “settlements” layer, this **potential ‘supply’ of water source heat is matched with settlements within 1km** of the river[1]
- **We further processed this** by using a GIS layer describing the LA boundaries **to allocate each LA a resource for water source heat**
- Where a settlement crossed LA boundaries, the share of the area of the settlement within each LA was used to estimate the share of the water source heat resource to be allocated to each LA
- In the model, schemes based on water-source heat include the cost of **1km of additional transmission pipe** to connect the network to the water source

1. Settlement layer does not include canals or estuaries

Heat resource from rivers, although large in technical potential, is subject to a number of barriers

Spatial mismatch of heat supply and demand



- This graph illustrates that resource from a particular heat source, such as rivers, is unevenly distributed across LAs.
- The LAs with the highest river resource do not necessarily have the highest heat demand.
- Since we assume river-source heat cannot be used in LAs other than the LA where the river is located (indeed, we only allow water-source heat be transmitted 1 km), a significant proportion of river source heat is not useful.
- A comparison of the conincidence of heat demand and river-source heat at LA level suggests that the total useful resource is no greater than 73 TWh, much less than the 232 TWh of 'technical potential' within 1 km of demand centres.

Note on other barriers to access to water-source heat

- Although the river heat resource in DECC's settlement layer is technically usable (that is, from a high level analysis the change in temperature does not exceed 3°C, that recommended by the Water Framework Directive[1]), the resource does not consider practical constraints such as difficulty of installing heat pumps at multiple sites along a river or all other site-specific environmental constraints.
- Feasibility constraints also apply to sewage source heat pumps, where heat extraction is likely to be even more difficult from the practical perspective of access to the sewage.
- These additional barriers are not accounted for in the modelling.

1. For more information see Atkins (2014), National Heat Map: Water source heat map layer. The authors recommed that a site-specific suitability analysis should be carried out in addition to their high level analysis

Contents

Data on heat demand, heat supply options and heat sources are combined to derive the levelised cost of energy (LCOE) for DH

Cost components

Capital costs
- Heating plant and thermal storage
- Network-level and building-level infrastructure

Operating costs
- Heating plant and thermal storage
- Network-level and building-level infrastructure
- Fuel costs

Revenue
- Electricity generation (CHP)

Levers/Sensitivities

Delivered heat
- Fraction of consumers connected to scheme
- Heat demand projection scenario
- Lifetime heat delivered

Net present cost calculation
- Scheme lifetime
- Cost of capital
- Discount rate

Carbon value
- Cost of carbon emitted (including all carbon emissions)

Levelised cost of energy (£/MWh)

General approach to calculation of Annualised Capital cost, Total Annual cost and Levelised cost of energy (LCOE)

Annualised Capital cost

$$Annualised\ Capital\ cost = \frac{c}{1 - \frac{1}{(1+c)^n}} \times Present\ value\ of\ Capital\ cost$$

n = Lifetime of scheme (in years)*

c = Cost of capital (taken as 7.5% in all scenarios)

Total Annual cost

$$Total\ Annual\ cost = Annualised\ Capital\ costs + Annual\ Operating\ costs\ - Annual\ Revenue$$

(Note: Operating costs and Revenue for a scheme change over time with fuel and carbon value)

Levelised cost of energy (LCOE)

$$LCOE = \frac{\sum_{t=0}^{n} \frac{1}{(1+i)^t} \times (Total\ Annual\ cost\ in\ year\ t)}{(Total\ lifetime\ heat\ delivered)}$$

i = Discount rate (taken as 3.5% or 7.5%, varying by scenario)

*An economic lifetime of 20 years is assumed. All Capital costs are assumed to be met once only in the economic lifetime.

Additional notes on cost calculation methodology

Cost data

- Fuel price, carbon value, capex and opex assumptions are provided in the Appendix.

Network and plant sizing

- The network, heating plant and building-integrated plant such as heat interface units and heat meters) have been sized according to an analysis of the peak heat load in the scheme. In the case of the network and network-level heating plant, the heat load has been diversified according to standard design procedures.
- Network pipe diameters are sized in order to deliver the required peak load using a temperature difference between network flow and return temperature (a 'ΔT') of 20ºC for both High T and Low T networks.

Thermal and pumping losses

- Thermal losses are estimated based on the network temperature and typical ground and ambient temperatures, applying the 'Series 2' standards* for insulation thickness. Dependent upon the pipe diameter, the resulting specific thermal loss factors are in the range 0.1-0.3 $Wm^{-1}K^{-1}$.
- Pumping losses are based on typical industry figures, and are a function of the pipe diameter. The resulting pumping losses per unit of network length are in the range 10-100 Wm^{-1}.

Approach for Energy-from-waste supply option

- In the model, the 'Energy-from-waste (EFW)' supply option is treated as a source of (high temperature) heat.
- We do not consider the full business model for the EFW plant operator including the gate fee and the cost of generating electricity, etc. Instead we attach a cost to the heat only, using a 'Z-factor' (describing the electricity generation foregone through the capture of the heat and associated reduction in plant electrical efficiency) of 10. This factor is applied to the (variable) export price of electricity as given in the Appendix, to derive a minimum value for the cost of heat. This minimum cost is the price paid by the DH scheme operator within the model.

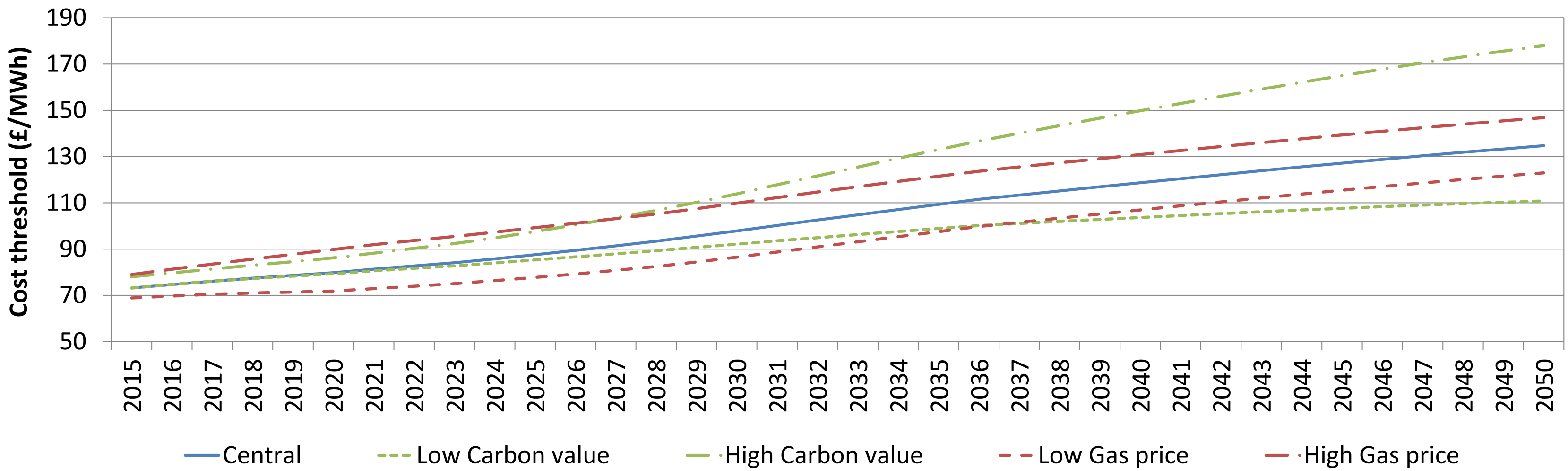
*Standard EN253 – see CIBSE/CHPA, Heat Networks: Code of Practice for the UK (2014).

Contents

Uptake of DH is determined by a comparison of the LCOE of the available DH options with a high-level counterfactual 'cost threshold'

Description of the 'cost threshold'

- The cost threshold represents the **aggregate levelised cost (in £/MWh) of the main counterfactual heating options** at building-level, including Gas boilers, Electric heating, ASHPs and GSHPs
- It is **calculated at a national level**, and is not intended to reflect detailed competition at the local level
- The **'market share'** of the counterfactual heating options is specified separately for Domestic and Non-domestic buildings, assuming a like-for-like replacement with existing heating systems
- The levelised cost for the counterfactual heating options is calculated using a 15 year lifetime, and includes **capex, opex, fuel cost** and the **cost of carbon emissions** using the carbon value scenarios provided by the CCC
- Cost threshold trajectories are **calculated for all scenarios used in the core model** (including fuel price, carbon value, discount rate and cost of capital)



District heating uptake module compares LCOEs in each zone and LA with the cost threshold to determine whether a heat network is built

Key aspects of the uptake model approach

- Within each LA, zones are ordered in terms of cost-effectiveness (LCOE) for DH, and zones are added in turn until the **aggregate LCOE of all zones taking up DH in the LA** is no longer below the cost threshold.
- The fact that the aggregate LCOE of the zones is the basis for comparison with the cost threshold – rather than the LCOE of individual zones – means that there is an effective 'cross-subsidisation' of individual zones below the cost threshold by individual zones above the cost threshold.
- This reflects a strategy of **maximising uptake of DH within each LA** (rather than minimising overall cost).
- This also **captures certain economies of scale**. For example, extra transmission pipe is added when a supply options involving connection to waste heat sources is selected, but the cost of the transmission pipe will be spread over any zones within the LA drawing from that heat source.

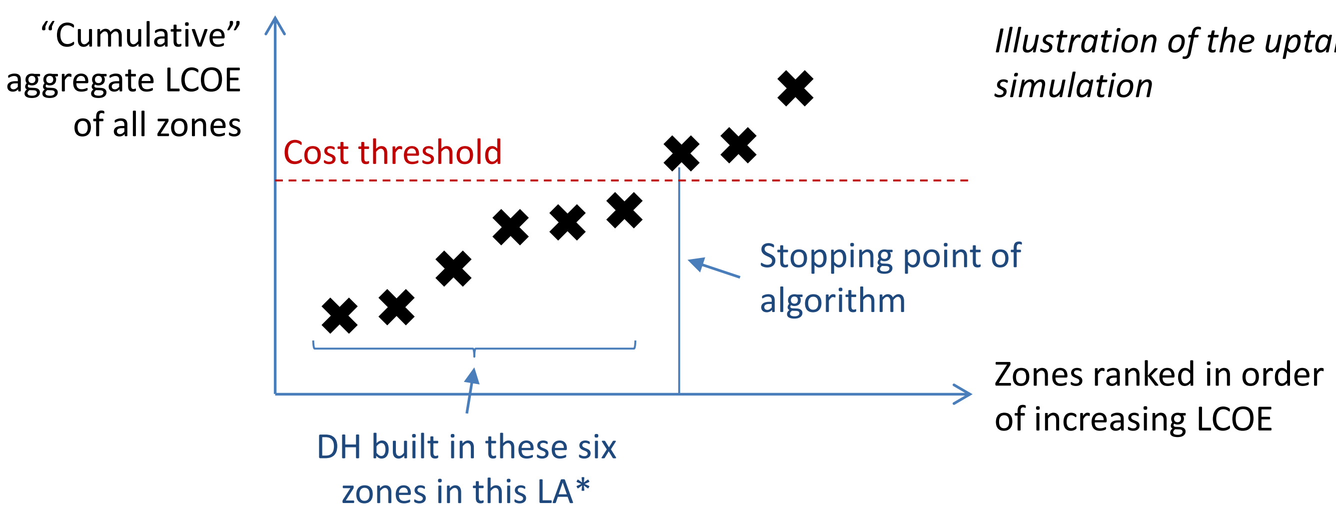


Illustration of the uptake simulation

*if growth/supply side constraints not exceeded

Further details on the uptake model

Decision points within the uptake model

- A ‘build decision’ is made every 5 years for every zone.
- At each decision point:
  - Zones without a DH network either remain without a DH network, or have a DH network built;
  - Zones with a DH network for which the end of the heating plant life has been reached will have their plant replaced by the most cost-effective supply option (which may involve a transition from a high T network to a low T network, at the cost of the new low T network);
  - Zones with a DH network for which the end of the heating plant life has not been reached are unaffected.

Replacement schemes and the economic and technical lifetime of the network

- In the model, the cost of the network is spread over an economic lifetime of 20 years. The useful lifetime of the network infrastructure is, however, likely to be much longer than this (perhaps 40-60 years). A result of this is that ‘replacement schemes’, which do not incur an additional network cost, are significantly more cost-effective than new build schemes.
- Where the network cost could be spread over a longer economic lifetime, this could increase the uptake of new build schemes.

Resource depletion

- The availability of finite resources, including waste heat, water-source heat and biomass, is re-calculated after each build decision.
- A zone may only make use of resource allocated to the LA in which the zone lies.
- With each LA, finite resource is depleted by the first schemes built, which ‘ring-fence’ the resource for their own use over the 20 year lifetime of the scheme.

Supply-side constraints

- Supply-side constraints are imposed to limit the growth rate of district heating networks at an LA level.

*if growth/supply side constraints not exceeded

Contents

Critical path scenario describes the minimum level of uptake of DH required over time consistent with widespread deployment in 2050

Description of the Critical path scenario

- The **Critical path describes a level of deployment at each year up to 2030 which leaves open the option to deploy district heating at 'large scale' in 2050,** accounting for the finite rate at which heat networks can be rolled out.
- 'Large–scale' is here defined as the level of deployment in the High scenario – that is, **111 TWh in 2050**.
- In other words, the Critical path is the minimum level of deployment that needs to be in place in each year to 2030 for a 2050 deployment of 111 TWh still to be achievable.
- The Critical path is not the result of a run of the core model. Rather, it has been **developed using historic data on the maximum achievable growth** in the deployment of district heating.

Data on maximum achievable growth in the deployment of district heating

- In the case of district heating, the key limit to the potential rate of deployment is the **maximum rollout rate of the network infrastructure**, which is **costly, disruptive** and **organisationally complex**.
- As well as requiring a lengthy period of feasibility assessment, local authority planning and raising of investment, a long-term strategy for the rapid deployment of heat networks requires a period of capacity building, training and skills within the local supply chain.
- We have examined the **historic rate of deployment of district heating in countries with more mature district heating markets** to understand the typical (and limiting) growth constraints which are likely to apply to the UK case given its current relative immaturity.
- The historic data collected is presented on the following slide.
- We have used the data to construct Low, Central and High growth rates for three 'growth phases', namely: **'Emerging', 'Growth'** and **'Mature'**, according to the maturity of the market in which the growth rate was observed.

Summary of data sources used to construct the Critical path scenario

Case*	Time period	Unit given	Range over period	Annual growth rate over first 5 years in period	Maximum Annual growth rate over any following 5 year period	Minimum Annual growth rate over any following 5 year period	Average annual growth rate over whole period	Qualitative market phase (approximate)
Germany	1960-1995	PJ/yr of district heating sales	30 to 200 PJ/yr	**17%**	**13%**	**0.40%**	**6%**	Growth and Mature
Copenhagen	1970-2005	% connection to scheme	30% to 98%	**3%**	**7%**	**1%**	**3%**	Growth and Mature
Gothenberg	1953-2009	km of DH pipework	0 to 1,100 km	**57%**	**10%**	**4%**	-	Emerging, Growth and Mature
Chinese cities	1990-2008	million m^2 heated floor area	200 to 3,475 million m^2	**44%**	**34%**	**14%**	**17%**	Growth and Mature
Frankfurt	1991-2006	Capacity of CHP	0 to 25 MW	**546%**	**213%**	**2%**	-	Emerging, Growth and Mature
Austria	1992-2003	PJ/yr of district heating sales	29 to 54 PJ/yr	-	-	-	**6%**	Mature
Belgium	1992-2003	PJ/yr of district heating sales	10 to 21 PJ/yr	-	-	-	**8%**	Growth
Finland	1992-2003	PJ/yr of district heating sales	85 to 159 PJ/yr	-	-	-	**6%**	Mature
Italy	1992-2003	PJ/yr of district heating sales	7 to 17 PJ/yr	-	-	-	**8%**	Growth
Netherlands	1992-2003	PJ/yr of district heating sales	19 to 98 PJ/yr	-	-	-	**16%**	Emerging
Portugal	1992-2003	PJ/yr of district heating sales	1 to 9 PJ/yr	-	-	-	**20%**	Emerging
Norway	1992-2003	PJ/yr of district heating sales	4 to 8 PJ/yr	-	-	-	**7%**	Growth
Denmark	1992-2003	PJ/yr of district heating sales	84 to 103 PJ	-	-	-	**2%**	Mature
Sweden	1992-2003	PJ/yr of district heating sales	135 to 170 PJ	-	-	-	**2%**	Mature
China	2000-2005	PJ/yr of district heating sales	871 to 2010 PJ/yr	-	-	-	**18%**	Growth and Mature

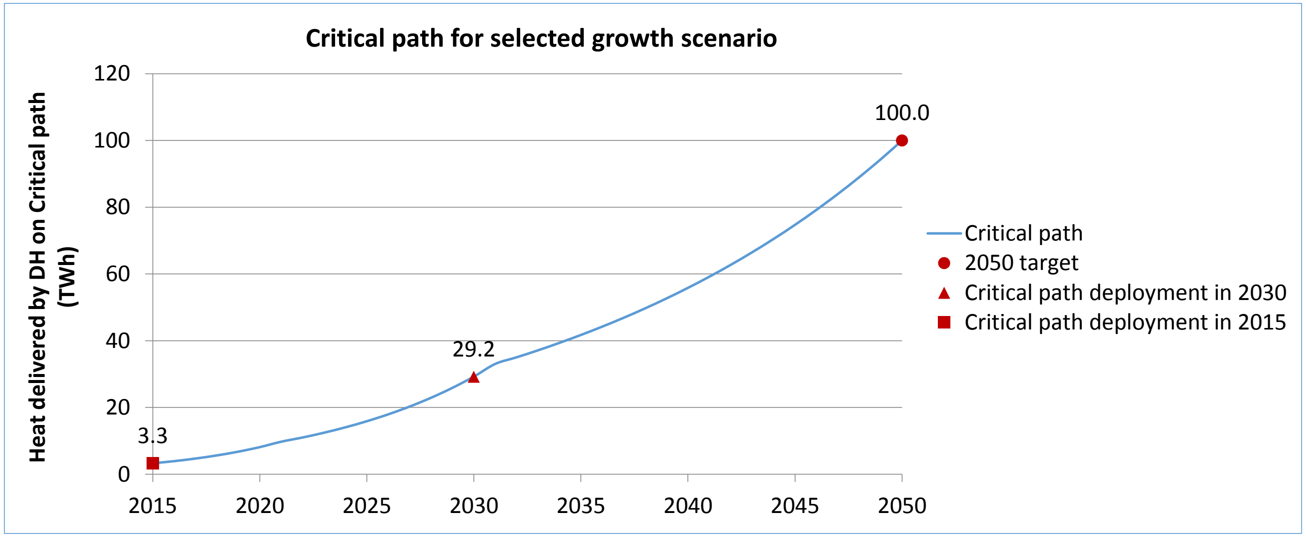
*Sources for all data points are provided in the Appendix.

Literature data has been used to develop Low, Central and High maximum growth rate assumptions

Summary of maximum DH deployment growth rate assumptions for Critical path scenario

Growth phase	Maximum annual growth in heat delivered by DH		
	Low	Central	High
Emerging	15%	20%	25%
Growth	8%	13%	18%
Mature	4%	6%	10%

- The data shown in the previous slide was used to derive the maximum growth rate assumptions for the three growth phases
- Using these growth rate constraints, the Critical path towards any given ‘target’ 2050 deployment can be derived
- The graph below shows an illustration of the Critical path scenario based on a hypothetical target of 100 TWh deployment in 2050
- The Critical path scenario based on the High scenario is presented later, in the results section

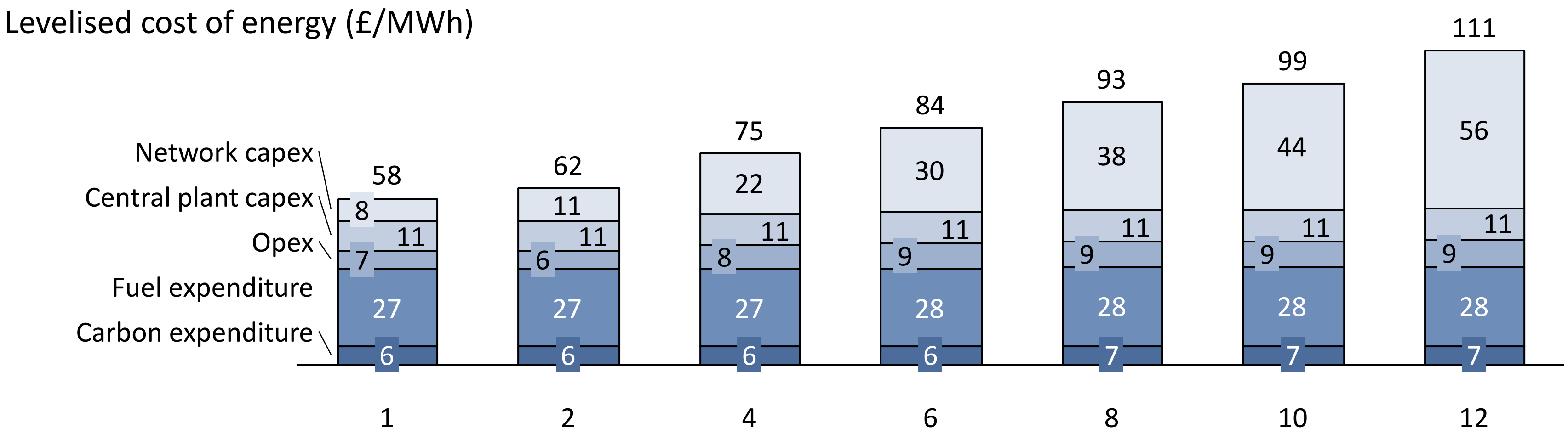


Example Critical path trajectory for a hypothetical target deployment of 100 TWh in 2050, using the ‘Central’ maximum growth rate assumptions, an ‘Emerging’ period of 2015-2020, a ‘Growth’ period of 2021-2030 and a ‘Mature’ period of 2031-2050. The finite growth rate assumptions mean that to achieve 100 TWh deployment in 2050, at least 29 TWh must have been deployed by 2030.

Contents

Levelised cost of energy for district heating is strongly dependent on the heat density of the zone

LCOE values for DH using Biomass in 2020 – Comparison of heat demand groups



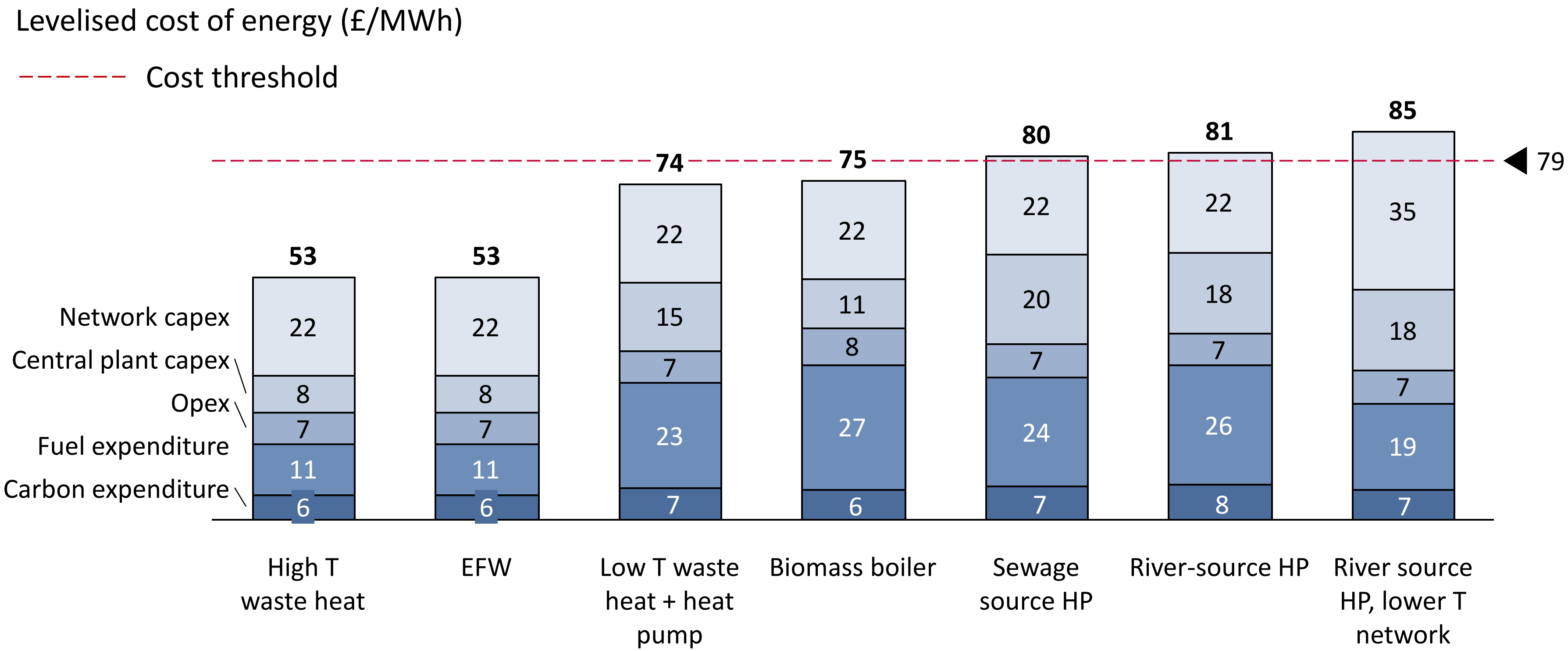
Heat demand group	**1**	**2**	**4**	**6**	**8**	**10**	**12**
Max heat density (GWh/km^2)	472	245	182	112	45	28	19
Fraction of UK heat demand (cumulative)	1%	2%	6%	15%	30%	50%	90%

- LCOE values for **biomass-based DH in 2020** are found to be in the range **£58-111/MWh** across the zone archetypes
- LCOE **increases strongly with decreasing heat demand**, due predominantly to an increasing contribution from the network resulting from the fact that the cost of the transmission and distribution pipe are much less strongly dependent on heat density of the zone than the cost of the CHP plant and the fuel spend
- Increasing heat density also leads to economies of scale for the heating plant, but this effect is small in comparison

LCOE values shown here correspond to ZAs with Fraction domestic group = 2, Fraction solid wall group = 2.
LCOE values shown correspond to the Central scenario assumptions (see later slide).

Cost-effectiveness of supply options

LCOE values for DH – Comparison of heat supply options (for build year 2020)



- The above chart shows a comparison of the LCOE in 2020 of a number of heat supply options serving the same zone archetype (in heat demand density group 4*)
- It should be noted that the LCOE for waste heat and EFW does not include the cost of the transmission pipe between the waste heat source and the network; this cost is added in the uptake stage of the model on a location-specific (LA-specific) basis
- The results are discussed on the following slide

*LCOE values shown here correspond to ZA with Heat demand group = 4, Fraction domestic group = 2, Fraction solid wall group = 2. LCOE values shown correspond to the Central scenario assumptions (see later slide).

High temperature waste heat and EFW are the most cost-effective options

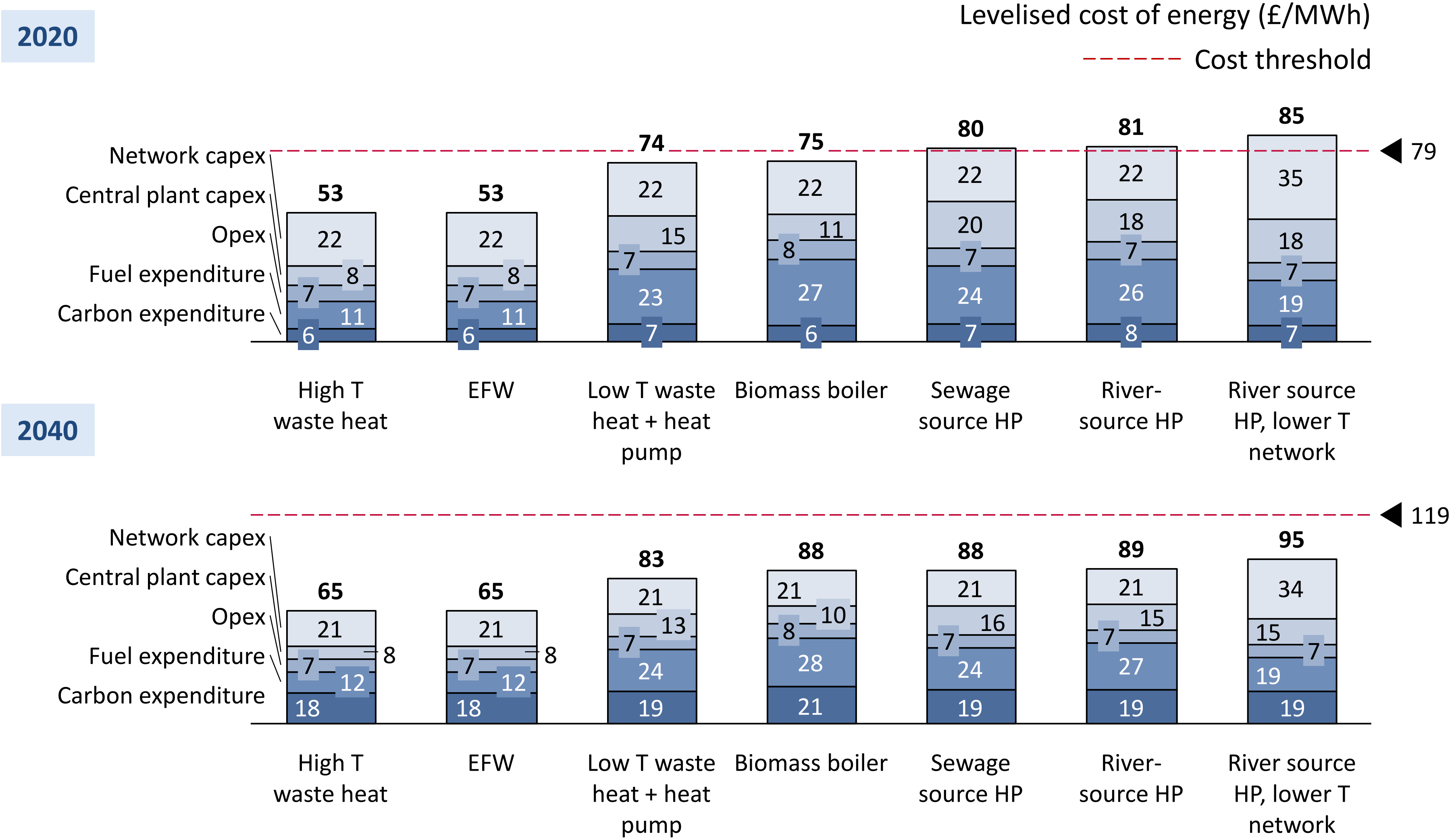
LCOE comparison of heat supply options (see chart on previous slide)

- **High T waste heat and EFW are the most cost-effective options*** at £53/MWh as they benefit from a small capex of central plant (peaking plant and thermal storage are still purchased) and low fuel spend (non-zero also because of peaking gas consumption)
- **Low T waste heat + HP** is the most cost-effective option in locations where High T waste heat and EFW are not available, at £74/MWh; a HP is required to increase the temperature of the waste heat (40ºC) to the network temperature (80ºC), but the fuel spend remains low as the HP operates with a high efficiency between these temperatures
- **Biomass boiler** has an LCOE of £75/MWh
- River and sewage source heat pumps have similar LCOEs. The heat pumps are more expensive for extracting heat from sewage but it is extracted at a higher temperature than that from rivers so the fuel expenditure is less.
- The cost of the network is the same for all supply options, except for the River-source HP with a Lower T network, as the lower temperature network requires larger diameter pipes at additional cost
- **River-source HP with a Lower T network** benefits from lower fuel spend than the River-source HP with a conventional temperature network, as the HP operates at a higher average efficiency; however, this is not enough to compensate for the higher network cost
- All of the above supply options use the 'standard' storage and peak load plant option, which involves providing 35% of annual heat demand from gas peak load plant; this incurs a carbon cost.
- The LCOEs shown here do not include the cost of the additional transmission pipe connecting the waste heat source to the network, since this depends on the distance of a specific waste heat source to a specific zone (and is therefore LA-specific, unlike the previous LCOE analysis). However, this cost adds between £1-20/MWh to the LCOE of a supply option in an LA where it is taken up; the higher end of the range applies to heat sources up to 30km from zones; the lower end applies to the 'high' scenario presented later in which the pipe length is limited to 1km implying colocation of heat sources and zones using DH[1].

1. The levelised cost of the transmission pipe also depends on the heat demand of the zone.

Comparison of LCOE of heat supply options in 2020 and 2040

LCOE values for DH – Comparison of heat supply options in 2020 and 2040, Heat demand group 4

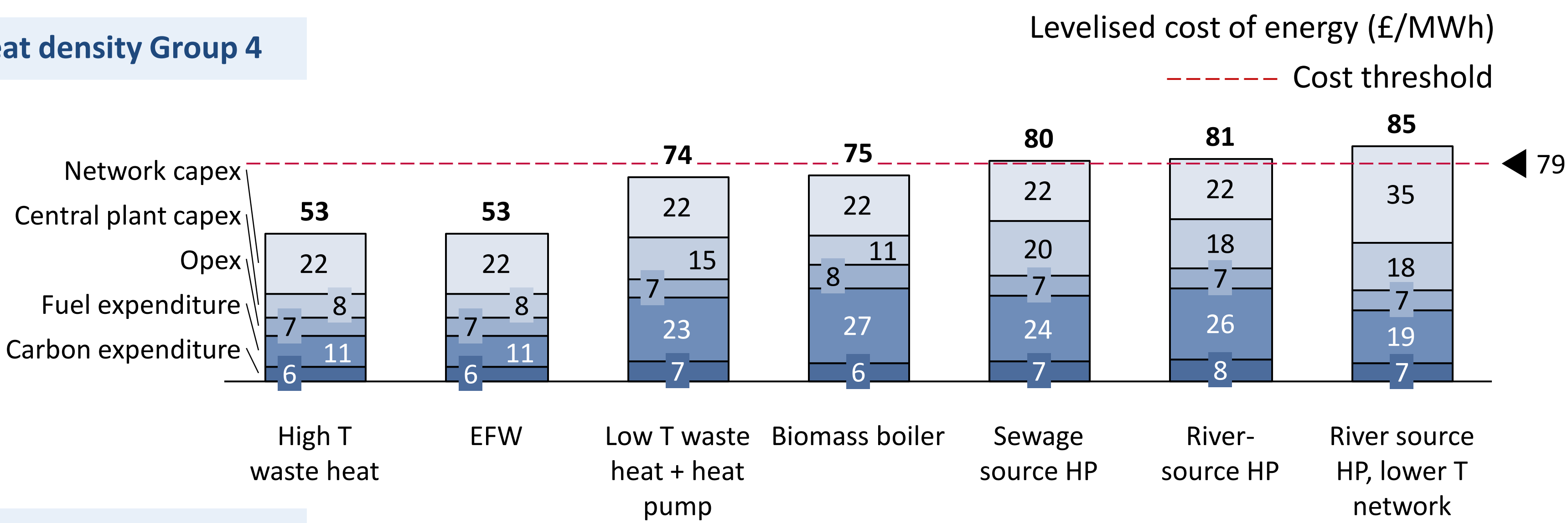


LCOE values shown here correspond to ZA with Heat demand group = 4, Fraction domestic group = 2, Fraction solid wall group = 2. LCOE values shown correspond to the Central scenario assumptions (see later slide).

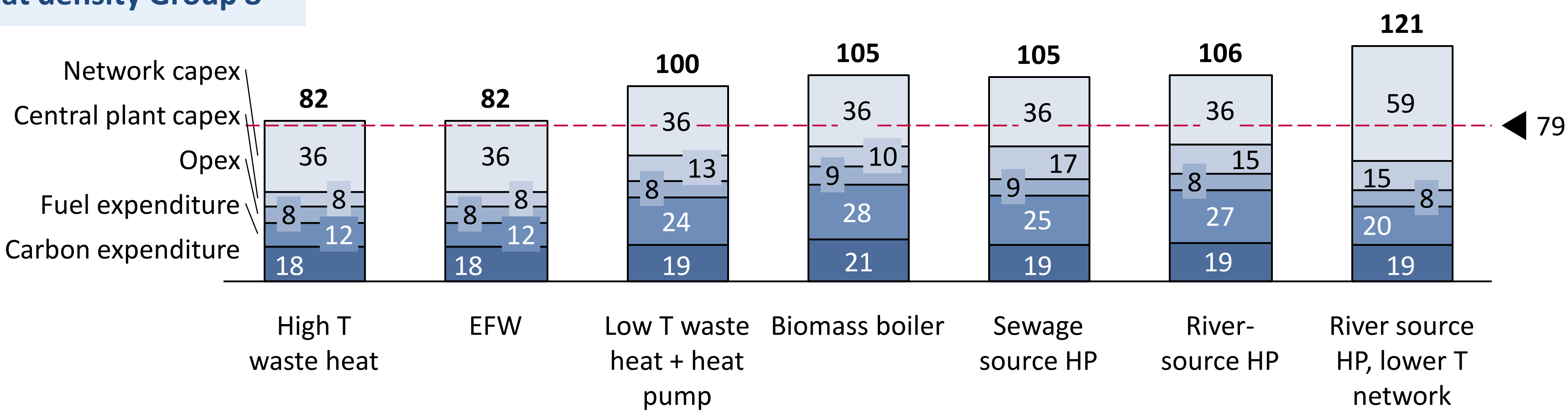
Comparison of the LCOE of heat supply options for two heat density groups

LCOE values for DH – Comparison of heat supply options for two heat density groups (2020)

Heat density Group 4



Heat density Group 8



LCOE values shown here correspond to ZA with Fraction domestic group = 2, Fraction solid wall group = 2. LCOE values shown correspond to the Central scenario assumptions (see later slide) and a build year of 2020.

Comparison of heat supply options for different build years and heat density groups

Comparison of heat supply options for build years of 2020 and 2040

- It can be seen that the **LCOE of all supply options increases** between 2020 and 2040.
- This is due largely to several contributing factors:
  - **Heat demand within all zones decreases** between 2020 and 2040 in the Central case due to energy efficiency improvements (and despite population growth);
  - LCOE values shown here include the cost of carbon for the scheme, based on the carbon value (see Appendix); since the **carbon value increases rapidly**, any supply options which lead to carbon emissions (including gas used for peaking plant and electricity used to drive heat pumps, which never fully decarbonises) experience increasing carbon costs;
  - The **gas price also rises** between 2020 and 2035; in all supply options shown, there is some remaining gas consumption used in Gas boiler peaking plant, which leads to an increase in fuel spend between 2020 and 2040.
- The above description refers to absolute LCOE values; the increasing carbon and gas price means, of course, that the cost threshold – representing the LCOE for the counterfactual – increases significantly between 2020 and 2040. As a result, all of the supply options shown become more cost-effective relative to the counterfactual.

Comparison of heat supply options for heat density groups 4 and 8

- A **low heat density has a larger negative impact on supply options based on a Low T network** as compared with supply options based on a High T network, since the network cost is a larger share of the overall cost in the case of a Low T network
- In the example shown, it can be seen that the **cost premium** for a River-source HP scheme based on a Low T network relative to a River-source HP scheme based on a High T network **increases from 5% for heat density group 4 to 14% for heat density group 8**.

Low temperature networks can increase scheme cost

Implications of low temperature networks

- The previous slide showed an example of low temperature networks led to a cost increase compared to conventional temperature.
- Running costs were lower but capital cost increased, partly due to changing the emitters in the buildings. This requirement for new emitters for existing buildings (based on stakeholder consultation) is an assumption used in the modelling results to be presented later.

Rules used in the model for equipment bought for different network types

- The table below shows the assumptions used for new equipment purchased in the model for different types of installation.

Equipment purchased

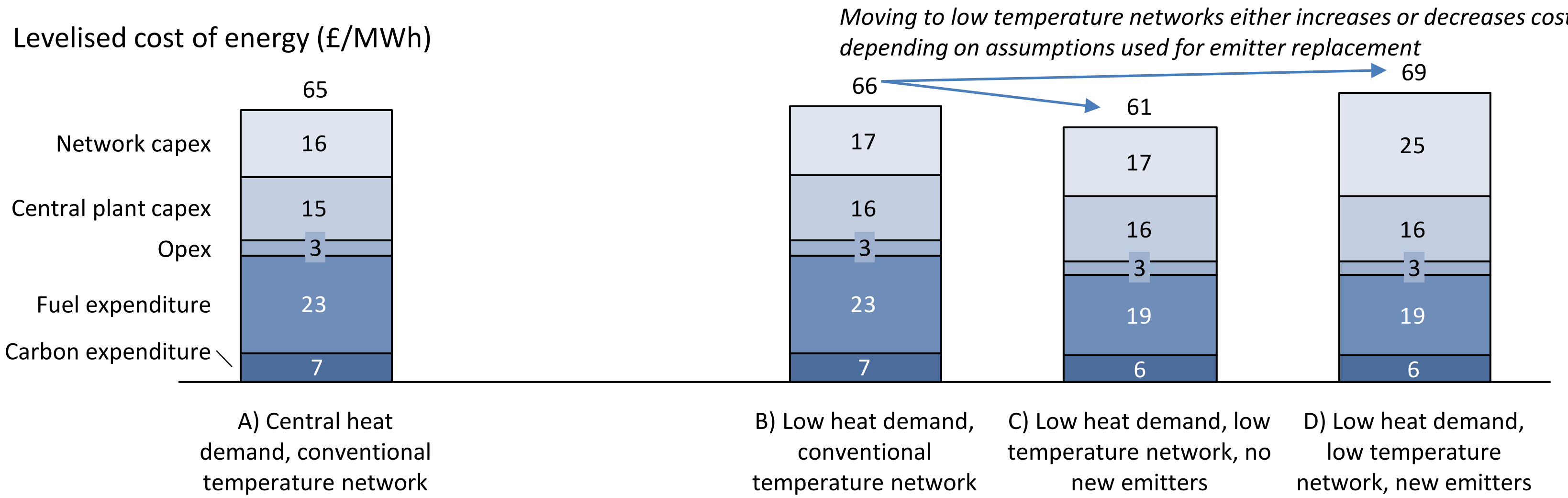
<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Network temperature</th></tr>
<tr><th>Conventional temperature</th><th>Low temperature</th></tr>
<tr><td rowspan="3">Type of DH scheme</td><td>New scheme</td><td>Network
Heating plant</td><td>Network
Heating plant
Emitters</td></tr>
<tr><td rowspan="2">Replacement scheme</td><td rowspan="2">Heating plant</td><td>If previous network was conventional temperature:
Network
Emitters</td></tr>
<tr><td>If previous network was low temperature:
Heating plant</td></tr>
</table>

- Networks are expected to last 40 years while heating plant lasts 20 years; a ‘replacement scheme’ therefore refers to a situation in which there is a network present and new heating equipment is needed.
- If, however, a zone transitions from a conventional to a low temperature network, then in addition to new heating plant, a new network and new emitters are purchased by the model.
- This drives up the cost of transitioning to low temperature networks.
- In reality, there may be a way of avoiding the purchase of new emitters for every building. This is explored on the next slide.

When combined with low temperature networks, improvements in building thermal efficiency could reduce cost of heat networks

Interaction between energy efficiency and network temperature

- Increasing the energy efficiency of the building stock – insofar as this has the effect of reducing the heat demand density – can have a negative effect on district heating viability if the network design is unaltered. This is demonstrated by a comparison of bars A and B below.
- However, an increase in the energy efficiency of the building stock also yields an opportunity to use lower temperature networks.
- The previous slide showed that transitioning to lower temperature networks can be expensive if new (larger) emitters need to be installed.
- However, it may be that buildings upgraded to very high thermal efficiencies do not require new emitters to work with low temperature networks, and can be heated sufficiently using their existing emitters.
- Bars C and D below show the impact of applying, or not applying, the cost of new emitters on the LCOE of a scheme
- It can be seen that the applying the cost of emitters on a transition from a conventional T to a low T network leads to an overall increase in the LCOE, where not applying the cost of emitters leads to an overall decrease. Furthermore, not applying the emitter cost results in a lower LCOE for a low heat demand, low T network case (bar C) than for a high heat demand, conventional T network case (bar A).
- Using low temperature networks with energy efficient buildings could therefore, as far as new emitters are not required, be less costly than using conventional temperature networks with less energy efficient buildings.
- However, in the core scenario modelling, we make the conservative assumption that the new emitter cost is always included for low T networks.



Contents

Summary description of scenarios presented

Core scenarios, sensitivities and additional scenario

Scenario type	Scenario	Description
Core	Central	• Cost-effective path to meeting the 2050 carbon emissions reduction target • Level of deployment achieved at abatement cost lower than the carbon value • Optimistic case where key barriers to consumer connection have been overcome by policy
	Barriers	• Similarly to Central case, DH only deployed at abatement cost lower than carbon value • Less optimistic case where key barriers to consumer connection have not been overcome
	High	• Deployment of district heating is pushed towards the maximum potential • Not limited to cost-effective abatement – a higher effective carbon value applies • Several special policies and actions are implemented to stimulate uptake of DH
	Critical path	• Level of deployment which leaves open the option to deploy DH at the level of the High scenario in 2050, accounting for the finite rate at which DH infrastructure can be rolled out • Developed using historic data on maximum achievable growth in DH in non-UK markets
Additional	Integrated	• Level of deployment consistent with optimisation of the whole energy system • Optimised for whole system cost using the same carbon value as in the Central scenario
Sensitivity	Gas price	• Uptake results from Central scenario, with abatement costs worked out using Low/High Gas prices
	Capital cost	• Uptake results from Central scenario, with abatement costs worked out using Low/High Capital cost for all technologies

Key financial assumptions used in scenarios

Key financial assumptions used

Item	Case used in scenarios
Discount rate	3.5% in Central and High, 7.5% in Barriers
Cost of capital	7.5%
Subsidy for DH	None
Gas price	Central case (see Appendix) + sensitivities
Carbon value	Varies by scenario
Capital costs	Central case (see Appendix) + sensitivities

Assumption on existing deployment of district heating

Item	Case used in scenarios
Existing DH in starting year of model (2015)	3 TWh of Gas CHP-based heat networks*

*The first year in which the model is allowed to build new DH is 2015. Therefore the resulting DH in 2015 is the sum of the 'Existing DH' and any new schemes built in that year (1-3 TWh depending on the scenario). The existing schemes are ascribed a build year pre-2015, so their heat sources can be replaced with new ones by the model when their lifetime is over if this is cost effective.

Ongoing work for the National Comprehensive Assessment (part of the Energy Efficiency Directive) suggests that there exist around 4 TWh of non-industrial heat networks in 2015, and that the majority of the heat is from natural gas combustion.

Central scenario: Summary of assumptions

Interpretation of the Central scenario

- The Central scenario represents the **cost-effective path to meeting the UK's 2050 emissions reduction target**.
- It therefore contains only the level of deployment which **can be achieved at an abatement cost lower than the CCC's Central carbon value**, with no further financial support.
- The Central scenario also **meets the Critical path for deployment** (see later slide), leaving open the option for the UK to deploy DH at a significant scale in 2050.
- Within these constraints, the Central scenario represents an optimistic level of deployment, to achieve which **a number of 'barriers' to deployment,** including market failures, a lack of consumer interest and trust, uncertainty of demand, high technology cost and institutional issues such as skills and knowledge, **will need to be removed**. Our recommended policy options to overcome these barriers are described in the Annex to this report, "Overcoming barriers to district heating", and summarised at a high level on the next slide. In the model, this is represented by the **'90% consumer connection fraction'**.
- **No further special policies or actions** – such as those employed in scenarios described later – are implemented in this case.

Key assumptions for the Central scenario

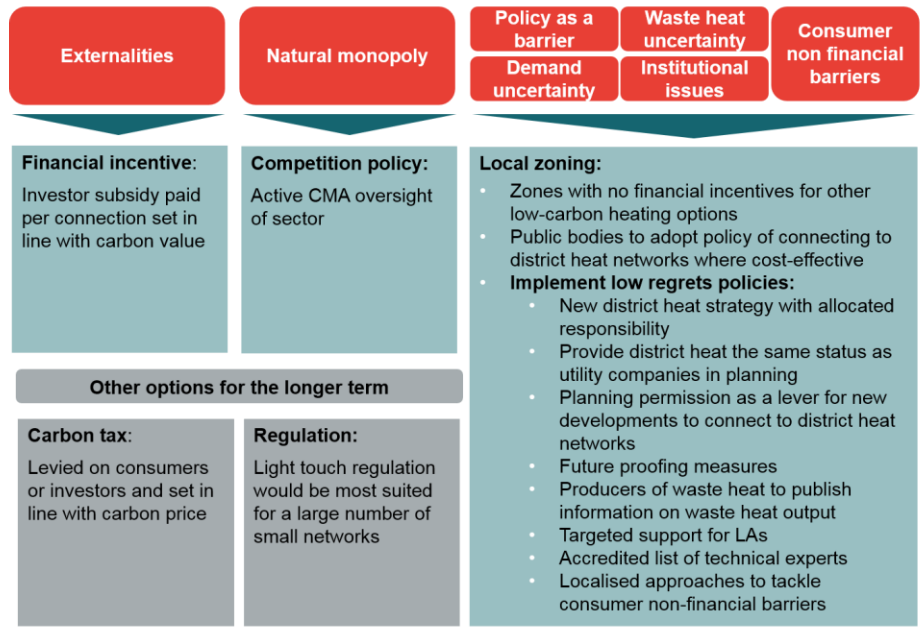
Item	Case used in scenario
Gas price	Central
Carbon value	Central
Capital costs	Central
Discount rate	3.5%
Consumer connection fraction	90% connection
Power station waste heat extraction temperature	Low T (40ºC) waste heat only
Siting of power stations, industry and energy from waste plant	Sited in existing locations
Biomass resource	2015: 10 TWh, 2030: 20 TWh, 2050: 10 TWh

The level of deployment seen in the Central scenario will require concerted policy action

Shortlisted policies to meet Central scenario

- A detailed assessment of the current and near-term market for heat networks in the UK is presented in the Annex: “Overcoming barriers to district heating”.
- Through the analysis detailed in the Annex, we have identified a wide range of policy measures which could be employed to overcome the existing barriers to district heating in the UK, assessed their suitability for the UK case and produced a **shortlist of policy recommendations** including:
  - ➢ A **financial incentive** paid to investors per connection that aims to address the externality in the market related to carbon emissions.
  - ➢ **Competition policy**, in the form of CMA oversight, to address natural monopoly concerns and help to ensure fair outcomes for consumers to preserve the reputation of the sector.
- The provision of dedicated **local zones** within which district heat is deemed most cost-effective. Within the local zones a number of other policies can be applied to tackle barriers in a targeted and cost-effective way, including public bodies’ adoption of a policy of connecting to district heat networks where cost-effective and the removal of financial incentives for other household -scale low-carbon technologies.
- This is to avoid incentivising consumers to take up alternatives to district heating, given that the fixed costs of district heat networks mean that high take up is required to ensure a scheme’s viability.

Graphical summary of policy recommendations

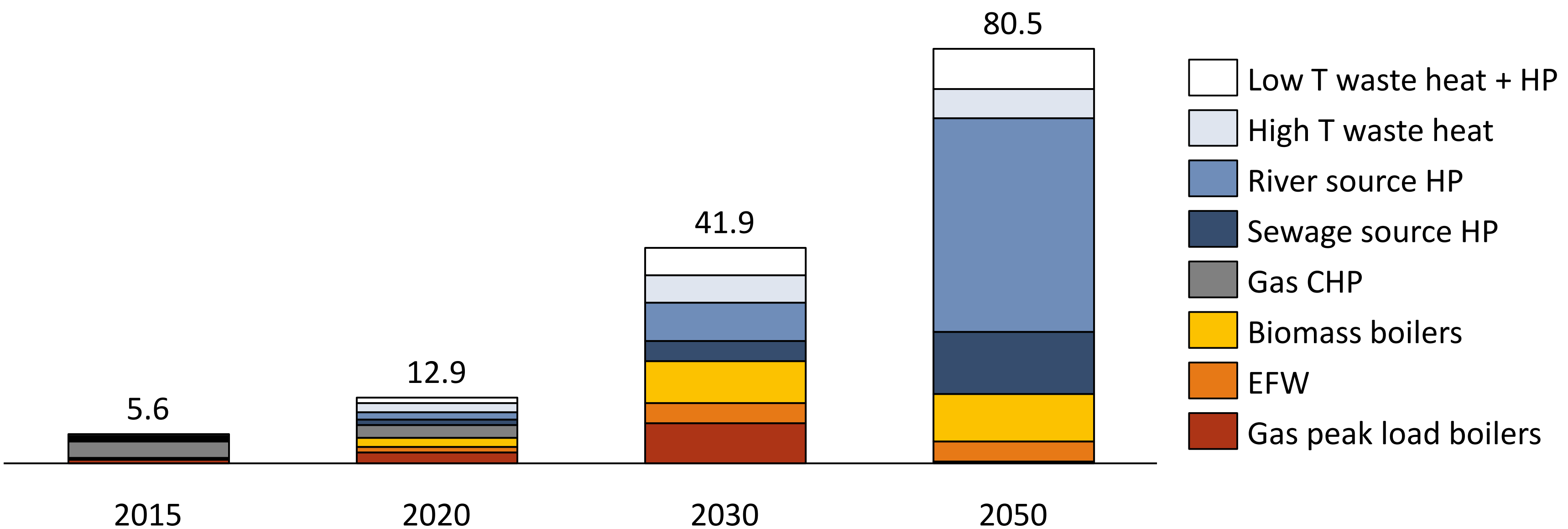


*Taken from the Annex to this report: “Overcoming barriers to district heating”.

Central scenario: District heating deployment

District heating deployment in the Central scenario

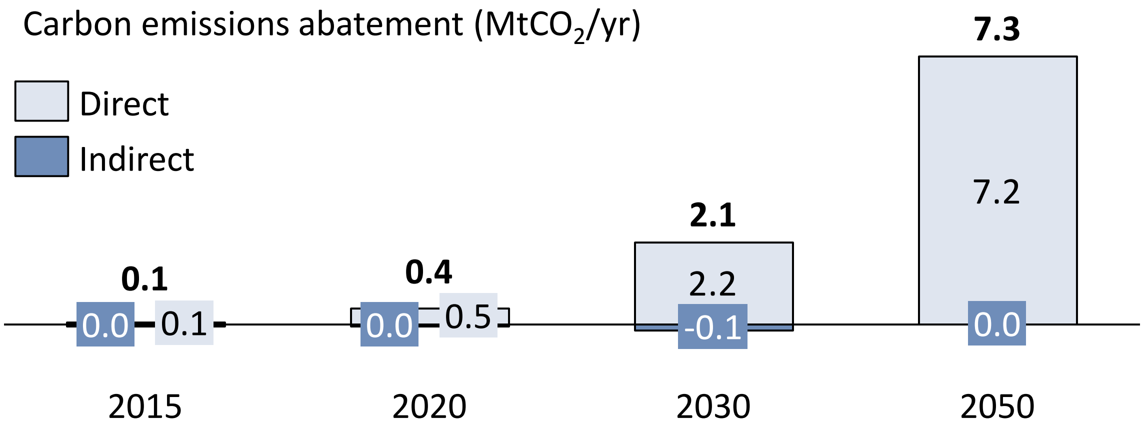
Heat delivered by DH, by technology (TWh)



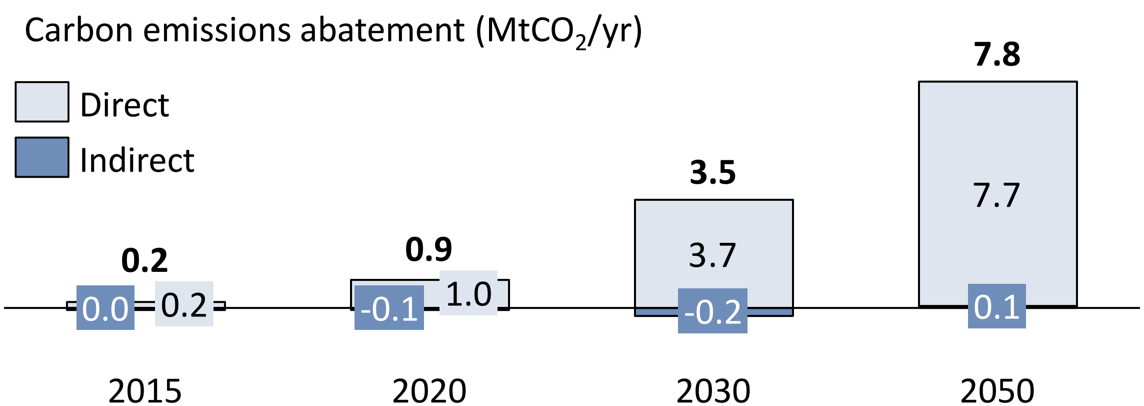
Year	Heat delivered by DH (TWh)	Fraction UK heat demand served by DH
2020	12.9	3%
2030	41.9	10%
2050	80.5	18%

Central scenario: Carbon emissions abatement by sector

Carbon emissions abatement in the domestic sector



Carbon emissions abatement in the non-domestic sector

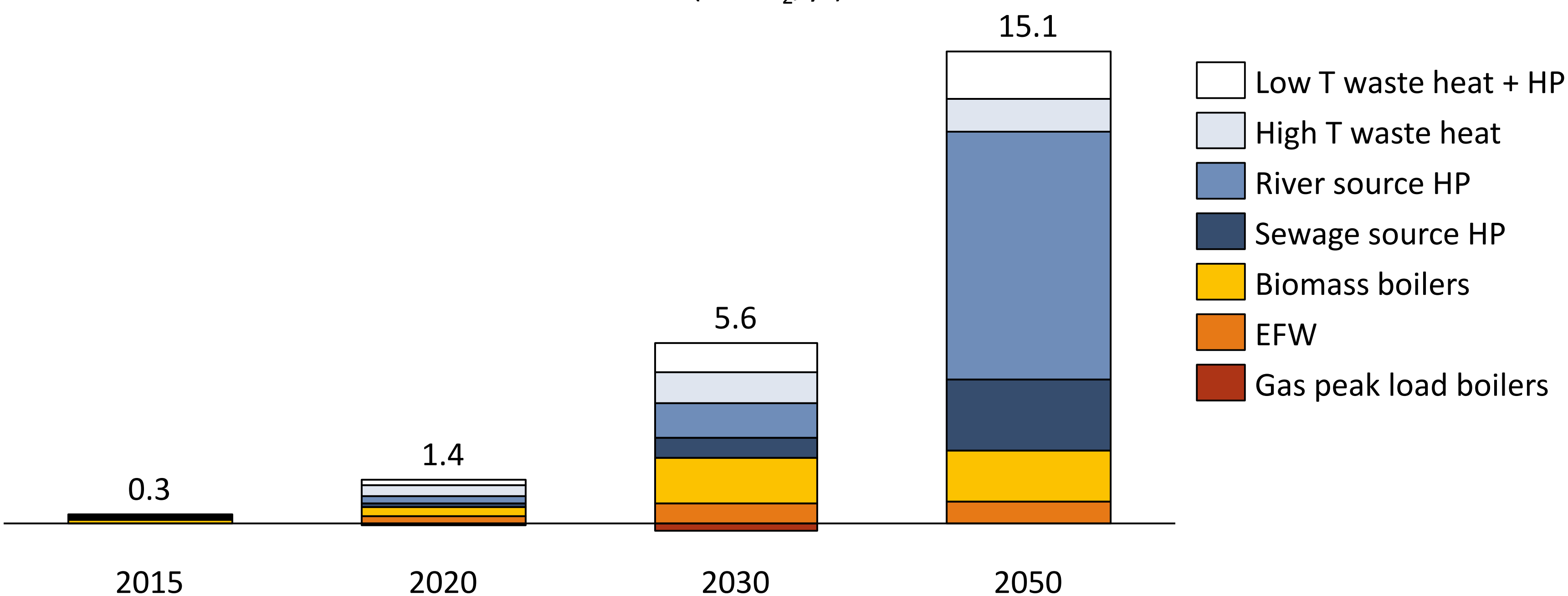


- We present here the total carbon emissions abatement, disaggregated into **direct** and **indirect** emissions
- Here, direct emissions are those emitted through the direct combustion of a fuel for heat; indirect emissions are those emitted through the production of electricity
- In the context of the district heating scenarios studied here, direct emissions abatement results from the **displacement of gas consumption** for heating in the counterfactual
- Indirect emissions abatement results from the **displacement of electricity consumption** in the counterfactual (though this is a minor component)
- Note that the increase in indirect emissions (in some years) results from additional electricity consumption through the use of **heat pumps in district heating**

Central scenario: Carbon emissions abatement by technology

Total (direct and indirect) carbon emissions abatement by technology

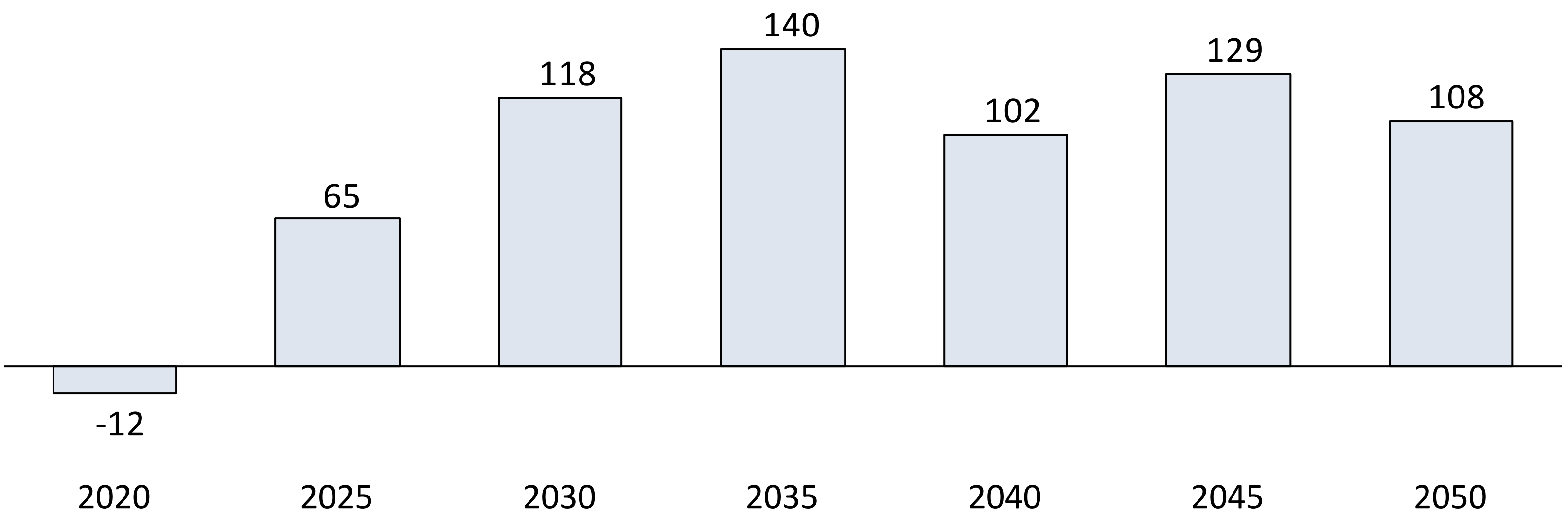
Direct and indirect carbon emissions abatement ($MtCO_2$/yr)



Central scenario: Carbon abatement cost

Carbon abatement cost in the Central scenario

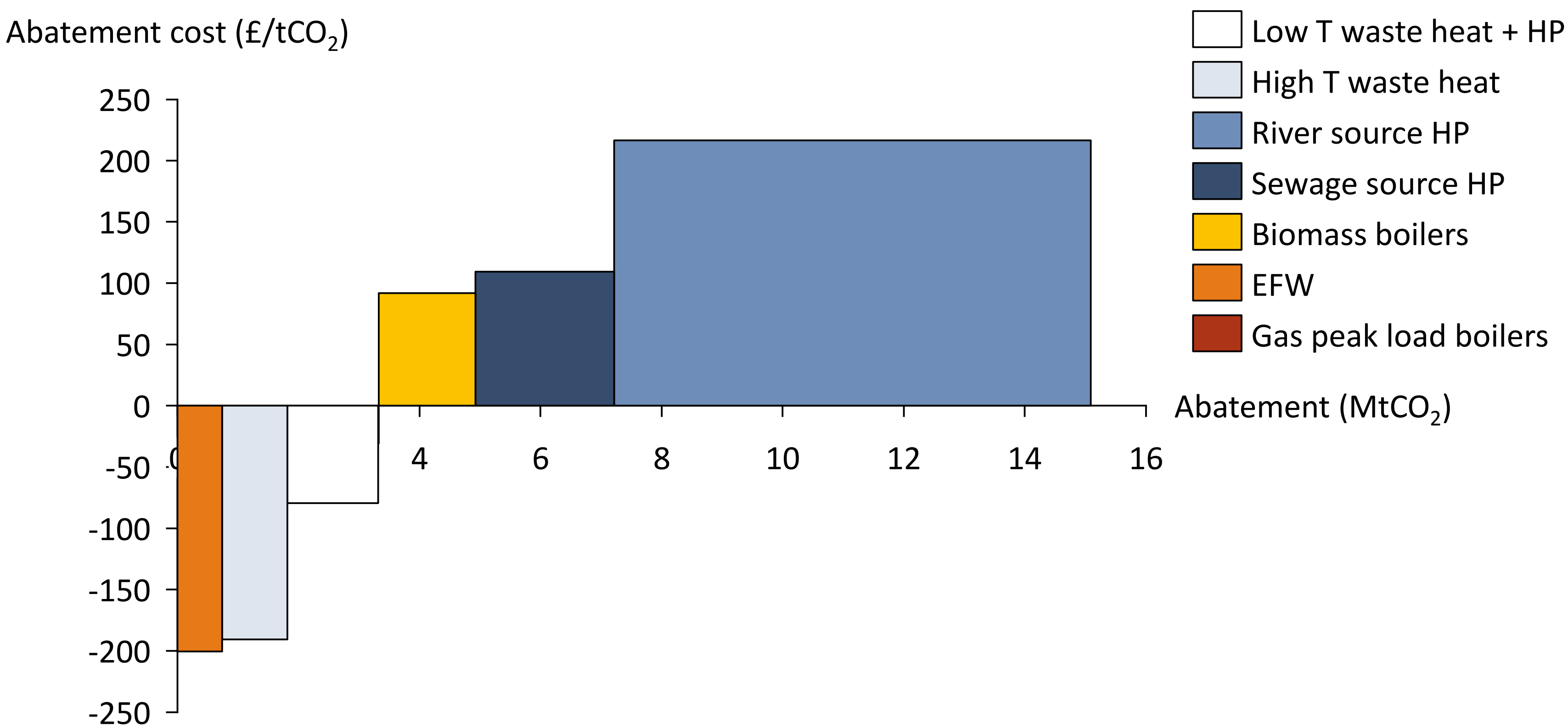
Average cost of direct and indirect carbon emissions abatement (£/tCO_2)



- The average abatement cost is, of course, the **aggregate of a wide range of supply options** with different abatement costs
- The abatement cost for different supply options changes substantially over the time period, in particular due to changes in fuel prices (note the cost of carbon is excluded from the abatement cost) and to the decarbonisation of the electricity grid

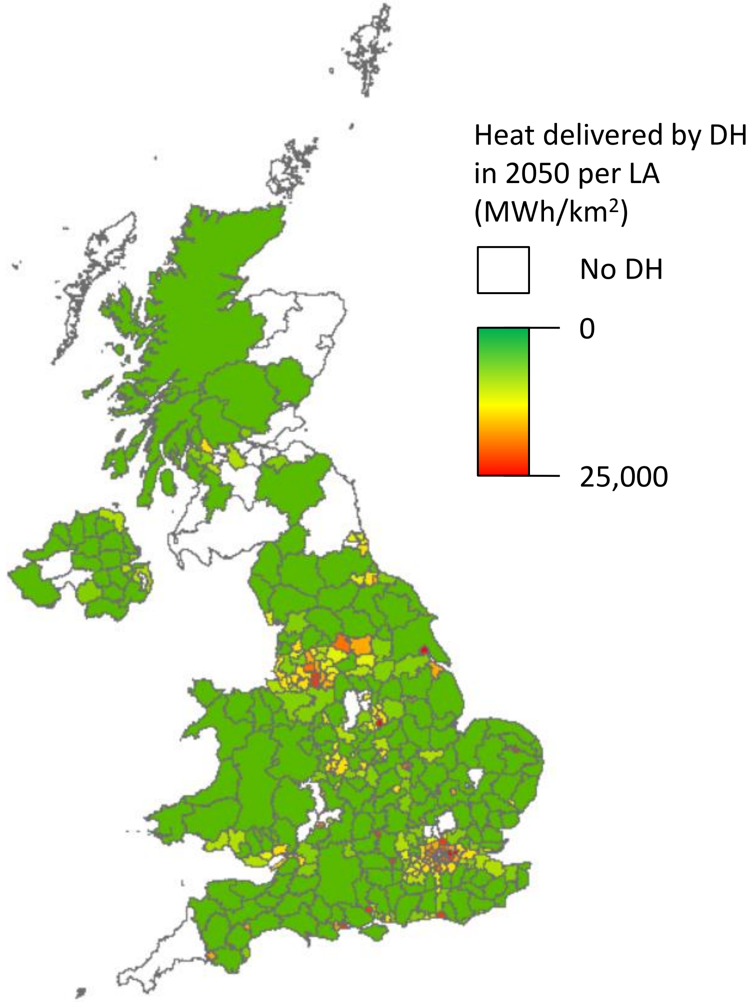
Abatement cost curve in 2050 by technology for the Central scenario

Average abatement cost curve in 2050 in Central scenario



Visualisation of district heating density by 2050 in the Central scenario

Local availability of heat sources and heat demand density determine the LAs with district heating



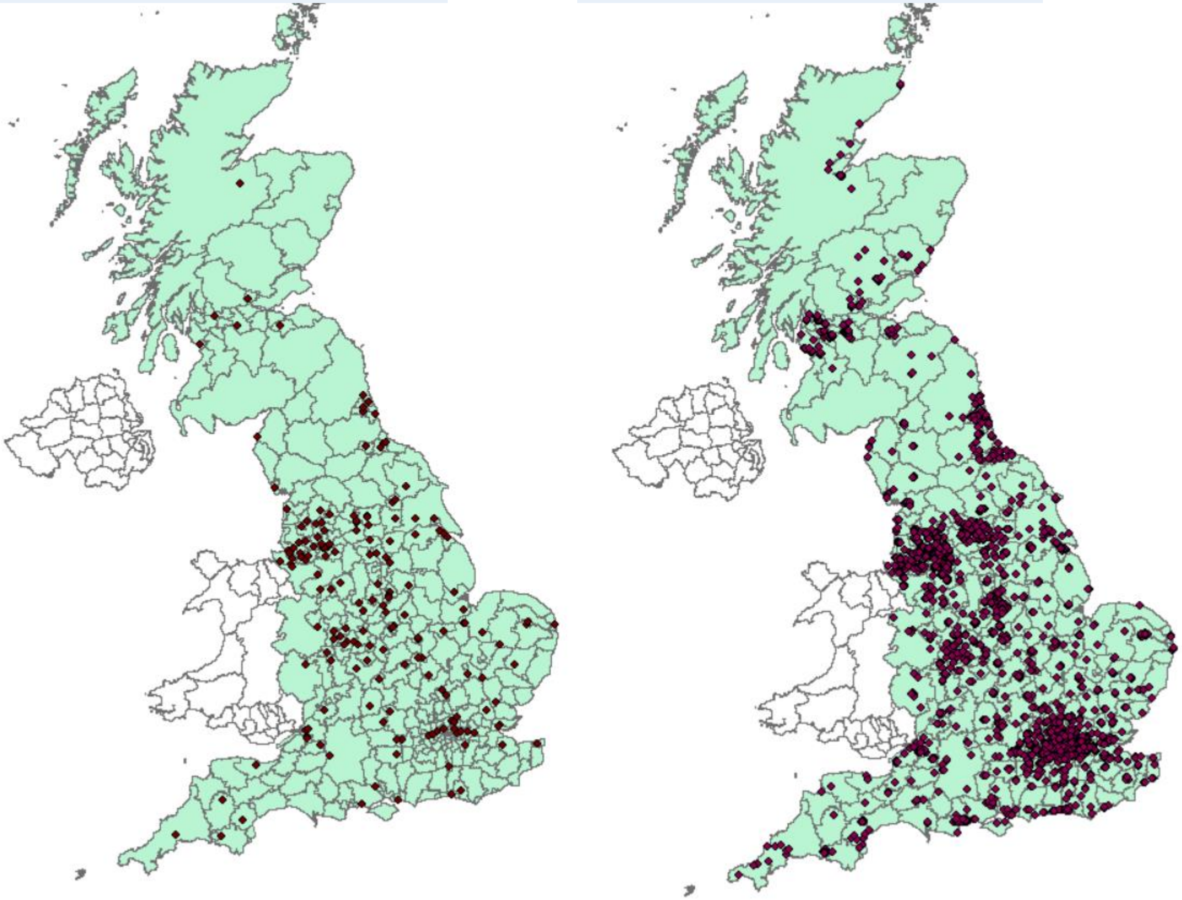
- As shown on the map on the left, uptake of DH in the Central scenario is **concentrated in urban areas** and isolated sites of high density development outside urban centres.
- However, the **local availability of heat sources** – particularly waste heat sources and water sources – also **plays a very important role** in determining the location of viable DH schemes.
- This is particularly the case in the scenarios we present here, given the constraints placed on the deployment of Gas CHP to 2050.
- By 2050, most LAs have at least one zone in which DH is installed.
- On the next slide, an illustration of the DH roll-out is given.

Visualisation of zones with district heating in the Central scenario (England and Scotland only)

Locations of DH schemes built in the Central scenario

2020: 171 schemes in England and Scotland

2050: 2,722 schemes in England and Scotland



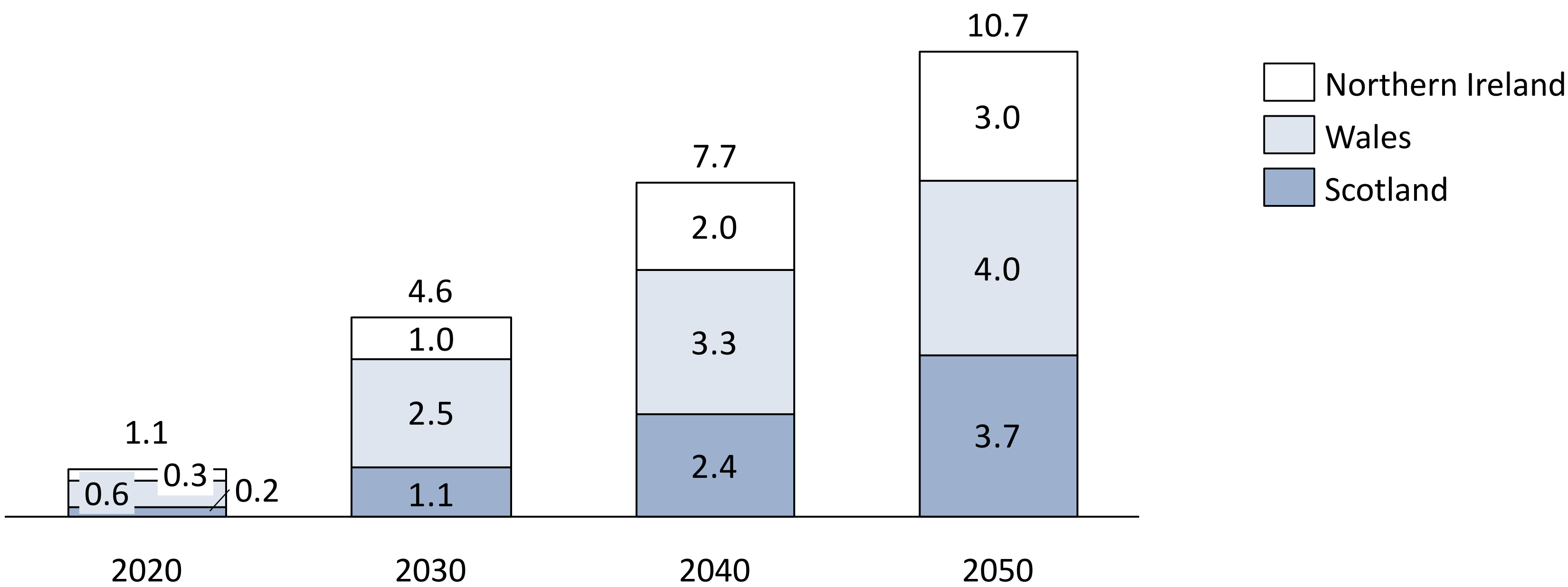
- The maps on the left show the location of zones served by DH in the Central scenario in England and Scotland only, since these are the countries for which heat demand data was available in 1km^2 zones*
- Local authorities are shown, with the dots representing zones in which DH was built by the model (note: dots not to scale)
- In 2015, the zones with DH are either those which have a waste heat source or which are particularly heat dense
- By 2050, DH has built up predominantly around cities
- However, this map also illustrates that most LAs have a centre of high heat demand in which it is viable to install DH in at least one zone.

*Zones in Wales and Northern Ireland were also modelled at 1km^2 resolution but using an inference method rather than actual 1 km^2 heat demand data, without ascribing x and y coordinates to each zone within an LA, therefore the zones with DH cannot be plotted in their actual locations on a map such as the above

Devolved administrations: uptake under Central Scenario

The devolved administrations together make up 13% of the UK DH uptake

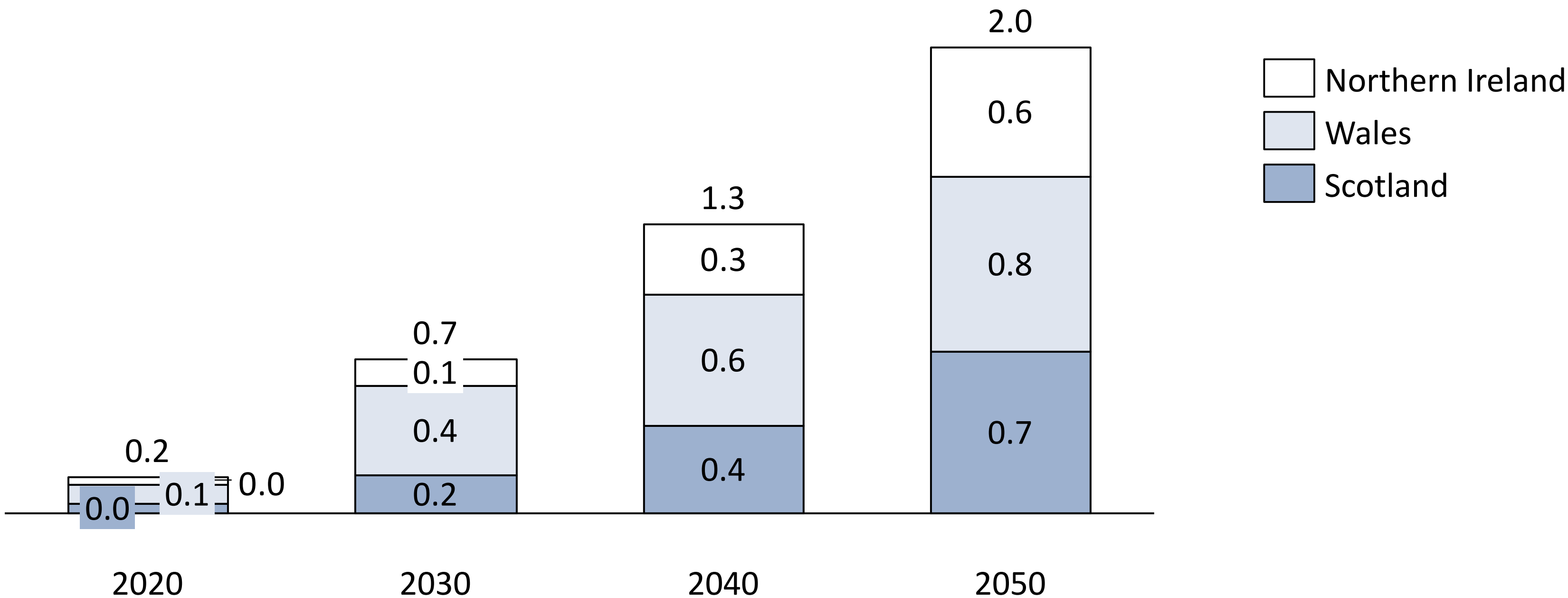
Heat delivered by DH (TWh)



Devolved administrations: abatement under Central Scenario

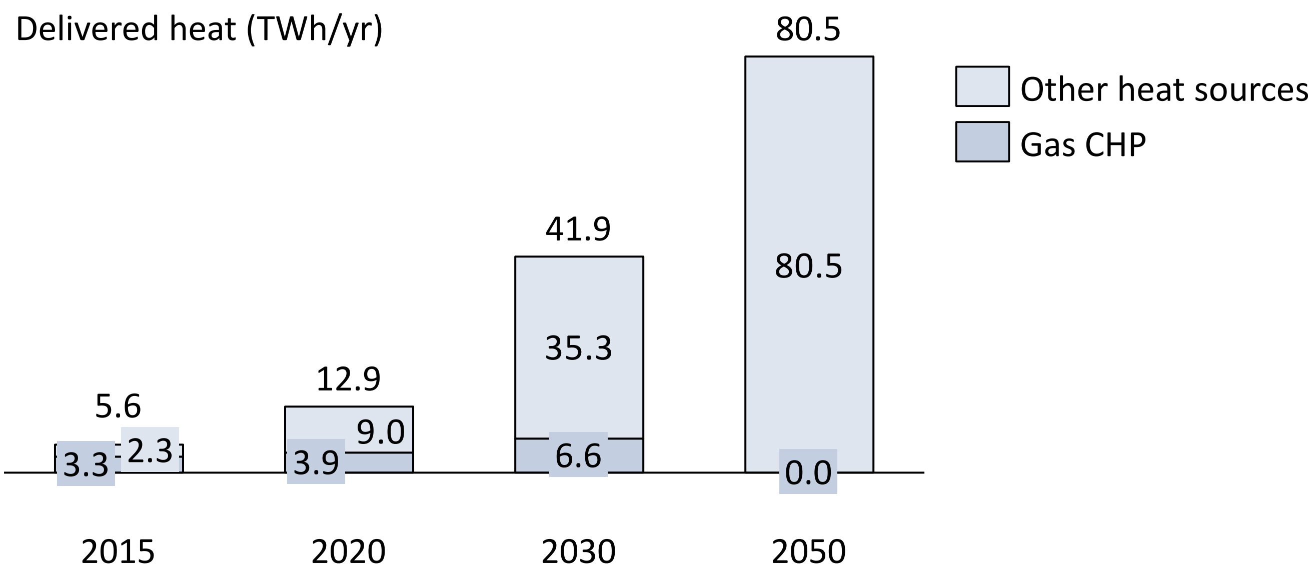
The devolved administrations together make up 13% of the UK carbon abatement from DH

Direct and indirect carbon emissions abatement ($MtCO_2$/yr)



Central scenario: sensitivity to use of gas CHP

Share of heat which would be supplied by gas CHP in the absence of constraints on its use



- As set out in the methodology section, the use of gas CHP was limited in this modelling to avoid lock in of high carbon DH schemes and/or stranded network assets as the electricity grid decarbonises.
- This slide presents a sensitivity in which new gas CHP schemes are allowed until 2030. When this plant comes to the end of its lifetime, then it must be replaced with low carbon options.
- Therefore gas CHP built in the next few years must be sited were there are low carbon alternative heat sources to replace it later (water, sewage etc).

Central scenario: Key results

Key results from Central scenario

- The Central scenario represents the **cost-effective path to meeting the UK's 2050 emissions reduction target**, containing only the level of deployment which **can be achieved at an abatement cost lower than the CCC's Central carbon value**.
- Deployment of district heating in the Central scenario is 13 TWh by 2020, **42 TWh by 2030** and **81 TWh by 2050**, corresponding to 10% of UK low T heat demand in 2030 and 18% in 2050.
- A varied **mix of technologies is deployed, according to the local availability of secondary heat resource**, including waste heat from power stations and industry, river-source heat and biomass.
- Where **waste heat from power stations and industry** is located near to centres of demand, this is taken up early as, along with **EFW**, these are the **most cost-effective supply options**.
- **In the longer term to 2030 and beyond**, where the carbon value and gas price increase and deployment of district heat becomes more widespread, **river-source heat pumps begin to dominate**. This reflects the limited resource of other low carbon supply options.
- **Biomass availability is limited** to 10 TWh in 2050 in the Central scenario; of this, around 9 TWh is taken up in the model.
- While the majority of district heating deployed prior to 2015 makes use of Gas CHP, the constraints imposed on Gas CHP in this modelling mean no new schemes based entirely on Gas CHP are built. Gas CHP is used as part of DH schemes based on industry and power station waste heat, in order to guarantee supply despite the intermittency of those sources.
- As a result of this deployment of DH, total carbon abatement is 5.6 $MtCO_2$ in 2030 and 15.1 $MtCO_2$ in 2050.
- The average carbon abatement cost is positive from 2025 onwards, ranging between £65/tCO_2 and £140/tCO_2.
- 13% of the uptake and abatement takes place in Scotland, Wales and Northern Ireland.

Contents

Barriers scenario: Summary of assumptions

Interpretation of the Barriers scenario

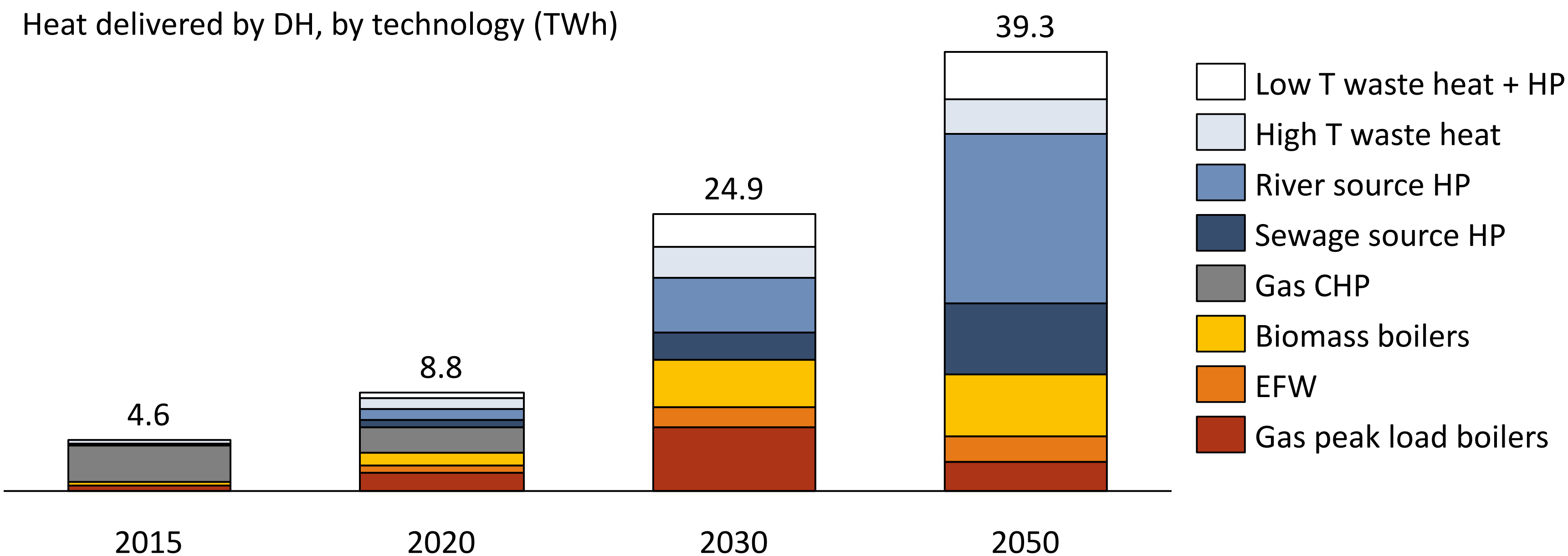
- The Barriers scenario represents a case where a number of the **barriers to the deployment of district heating**, as described in the last section, **have not been overcome**.
- The Barriers scenario, along with the Central scenario, includes a carbon value to reflect the financial incentive for low carbon heat. However, it represents a case where effective competition policy and local zoning initiatives have not been successfully implemented, and hence where **connection to district heating schemes occurs at a significantly lower level**.
- In the Central scenario, where these barriers are assumed to have been overcome by the types of policy measures described in the last section, the '90% consumer connection fraction' case (as described in the methodology section) was assumed.
- In the Barriers scenario, the impact of the **'50% consumer connection fraction'** is studied.
- In addition, a higher **discount rate of 7.5%** is used.

Key assumptions for the Barriers scenario

Item	Case used in scenario
Gas price	Central
Carbon value	Central
Capital costs	Central
Discount rate	7.5%
Consumer connection fraction	50% connection
Power station waste heat extraction temperature	Low T (40ºC) waste heat only
Siting of power stations, industry and energy from waste plant	Sited in existing locations
Biomass resource	2015: 10 TWh, 2030: 20 TWh, 2050: 12 TWh

Barriers scenario: District heating deployment

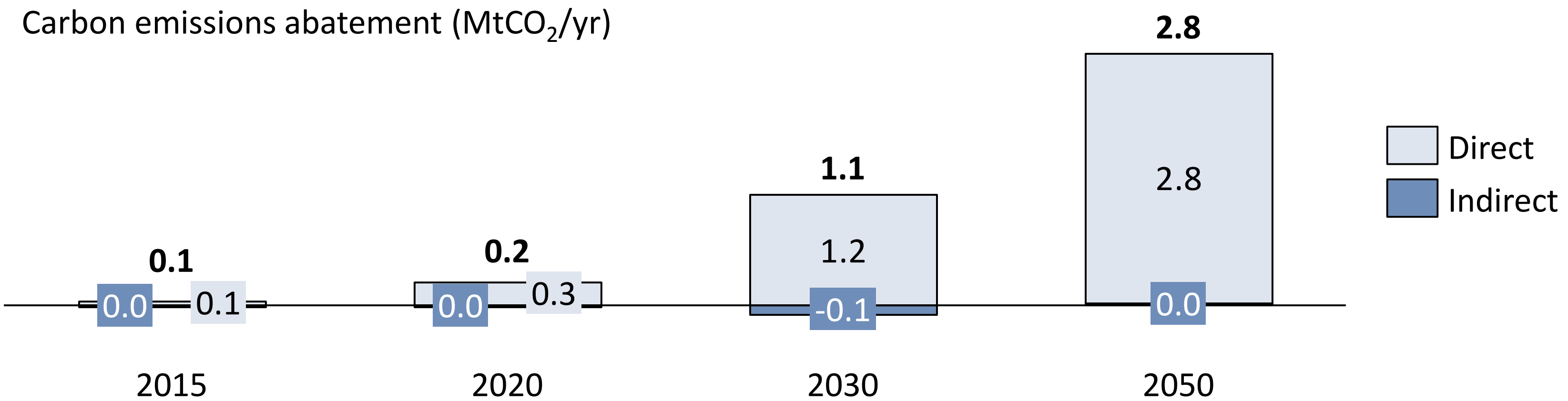
District heating deployment in the Barriers scenario



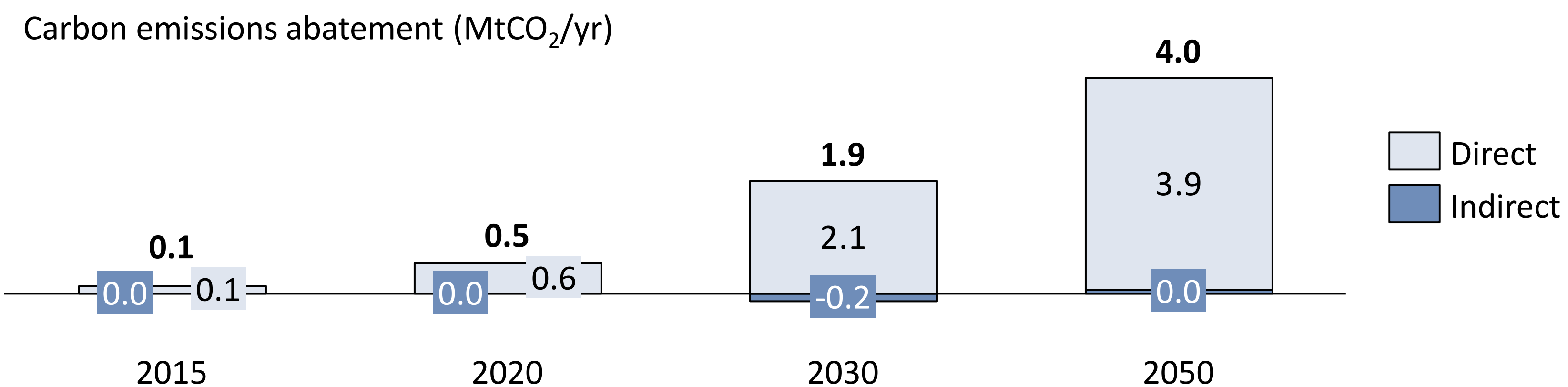
Year	Heat delivered by DH (TWh)	Fraction UK heat demand served by DH
2020	8.8	2%
2030	24.9	6%
2050	39.3	9%

Barriers scenario: Carbon emissions abatement by sector

Carbon emissions abatement in the domestic sector



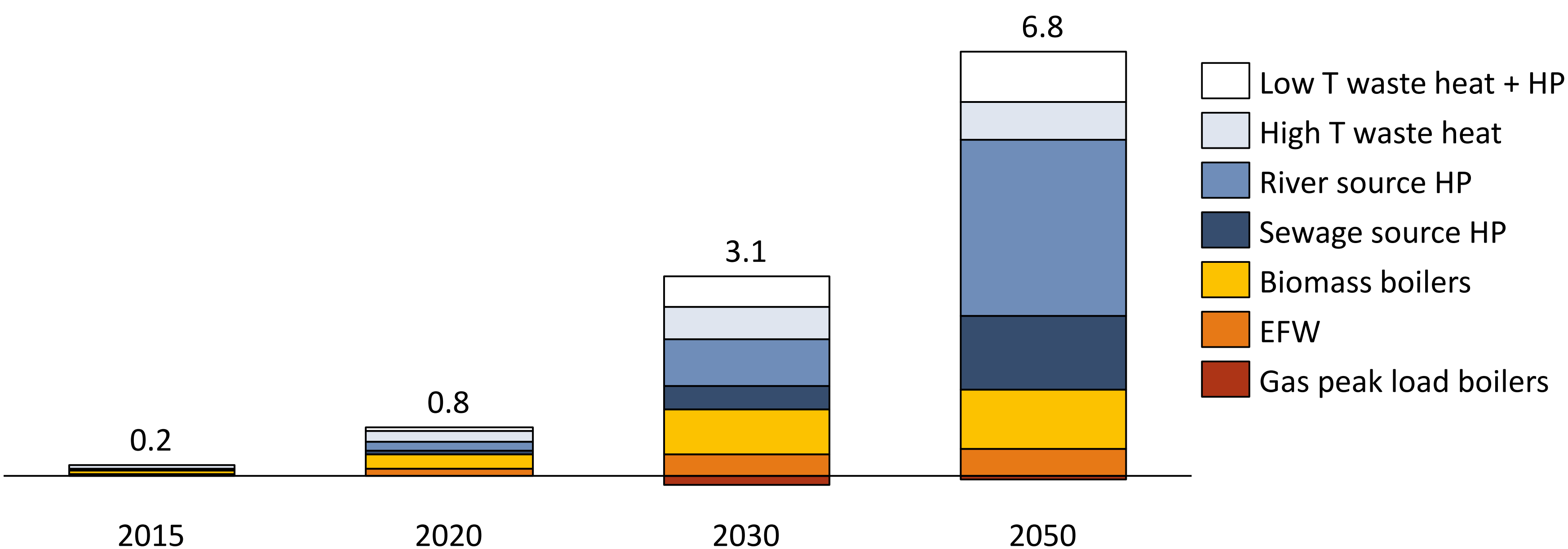
Carbon emissions abatement in the non-domestic sector



Barriers scenario: Carbon emissions abatement by technology

Total (direct and indirect) carbon emissions abatement by technology

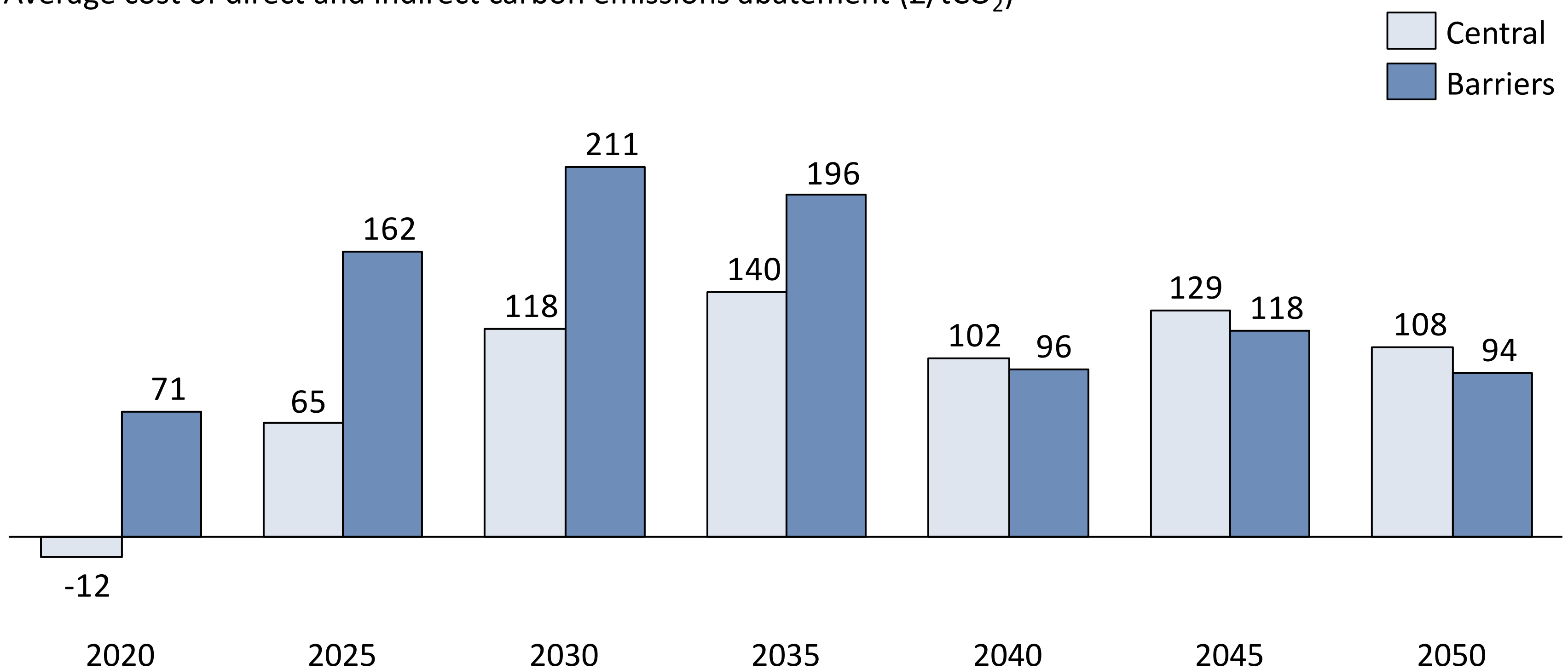
Direct and indirect carbon emissions abatement ($MtCO_2$/yr)



Barriers scenario: Carbon abatement cost

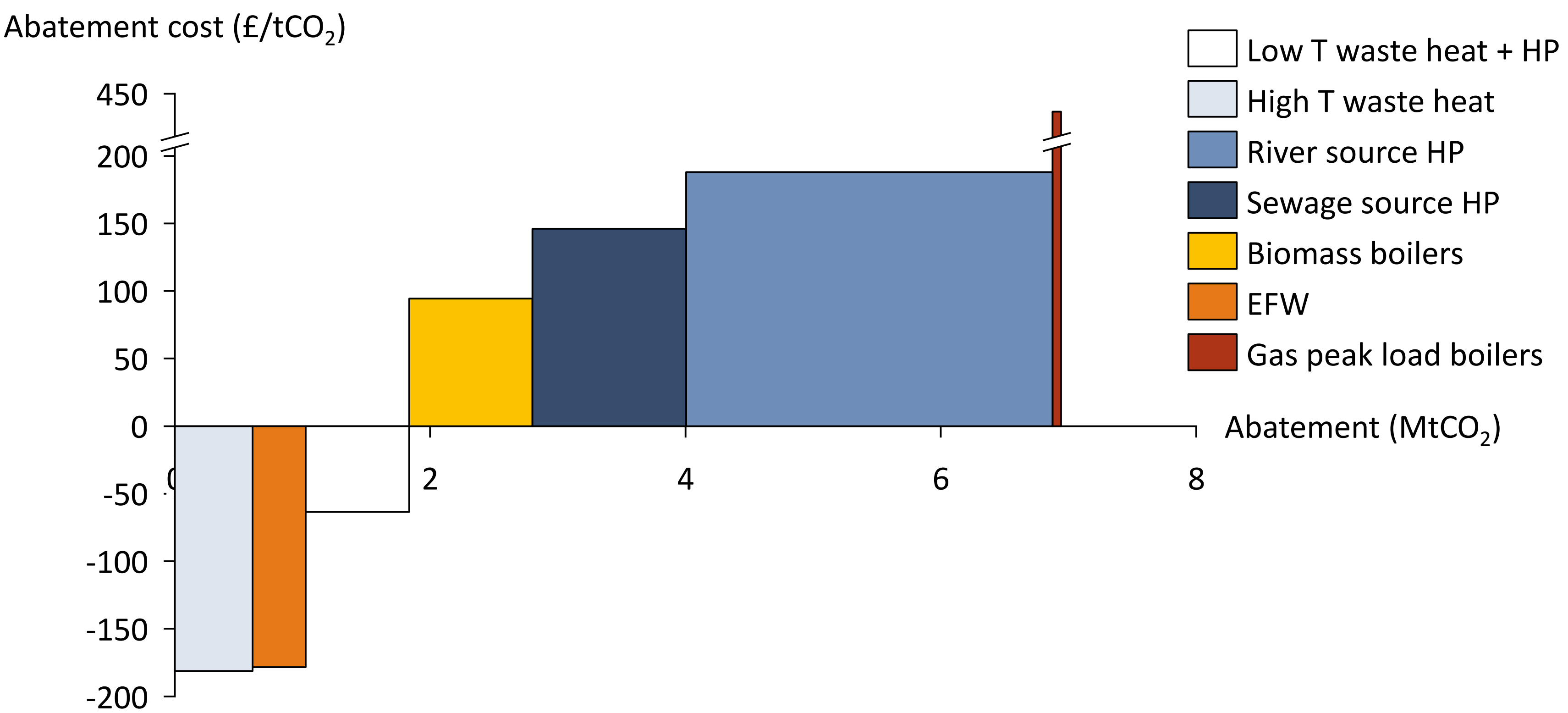
Carbon abatement cost in the Barriers scenario

Average cost of direct and indirect carbon emissions abatement (£/tCO_2)



Abatement cost curve in 2050 by technology for the Barriers scenario

Average carbon abatement cost curve in 2050 in the Barriers scenario



Note: the very high abatement cost from gas peak load boilers arises from the fact that they are not so much a supply technology themselves – as peak plant they enable the use of other technologies. In the scenarios studied here, gas boilers lead to very small abatement, in some cases with a slightly positive cost and in others with a slightly negative cost. The small abatement means the abatement cost can appear vary large, as here.

Barriers scenario: Key results

Key results from Barriers scenario

- The Barriers scenario represents a case where a number of **barriers to the deployment of district heating remain**, particularly with regard to encouraging consumers to connect to heat networks.
- In the Central scenario, where these barriers are assumed to have been overcome by the implementation of effective competition policy and local heat zoning initiatives, the consumer connection fraction was assumed to reach 90% after 10 years of scheme operation (as described in the methodology section); **in the Barriers scenario, the impact of a maximum consumer connection fraction of 50% is studied**. The discount rate is also set higher in the Barriers scenario.
- Deployment of DH in the Barriers scenario reaches 9 TWh by 2020, **25 TWh by 2030** and **40 TWh by 2050**, corresponding to 6% of UK low T heat demand in 2030 and 9% in 2050.
- This corresponds to around half of the deployment in the Central scenario in 2030 and 2050. This demonstrates the importance of a high connection fraction; while the fraction of consumers connected is reduced by 45%, the level of DH deployed falls by 50%.
- The **number of 1 km^2 zones with DH falls** from 2,488 in the Central scenario to 2,204 in the Barriers scenario.
- The technology mix is similar to the Central scenario; river source heat pumps still dominate but slightly less, and there is a greater share of more cost-effective options (waste heat). There are also more schemes with gas peak load boilers as opposed to extra thermal storage.
- The overall carbon abatement in the scenario is, of course, lower than in the Central scenario, at 3.1 $MtCO_2$ in 2030 and 6.8 $MtCO_2$ in 2050.

Contents

High scenario: Summary of assumptions

Interpretation of the High scenario

- The High scenario represents a case where the level of **deployment of district heating is pushed further towards the maximum potential** level.
- As shown below, several special policies or actions additional to those in the Central scenario are represented.
- These include:
  - An **increase in the carbon value**;
  - Refurbishment of power stations to allow the capture of **High T waste heat** rather than Low T waste heat only;
  - **Strategic siting of new power stations and industrial plant** near centres of high heat demand;
  - An **increase in the amount of biomass available** for district heating.

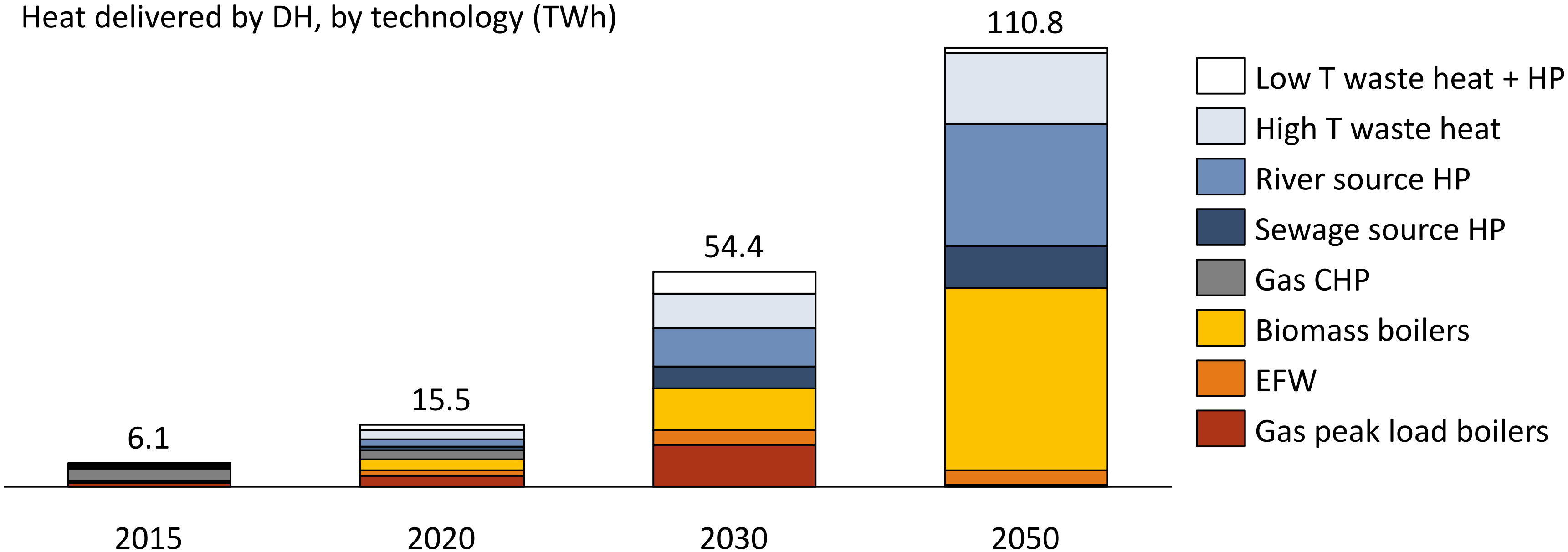
Key assumptions for the High scenario

Item	Case used in scenario
Gas price	Central
Carbon value	High
Capital costs	Central
Discount rate	3.5%
Consumer connection fraction	100% connection
Power station waste heat extraction temperature	Initially, cooling water at 40ºC used, but in this scenario power stations are refurbished over time to allow use of High T (>90ºC) waste heat
Siting of power stations, industry and EFW plant	Sited near demand centres to reduce connection cost
Biomass resource	2015: 10 TWh, 2030: 20 TWh, 2050: 50 TWh

High scenario: District heating deployment

District heating deployment in the High scenario

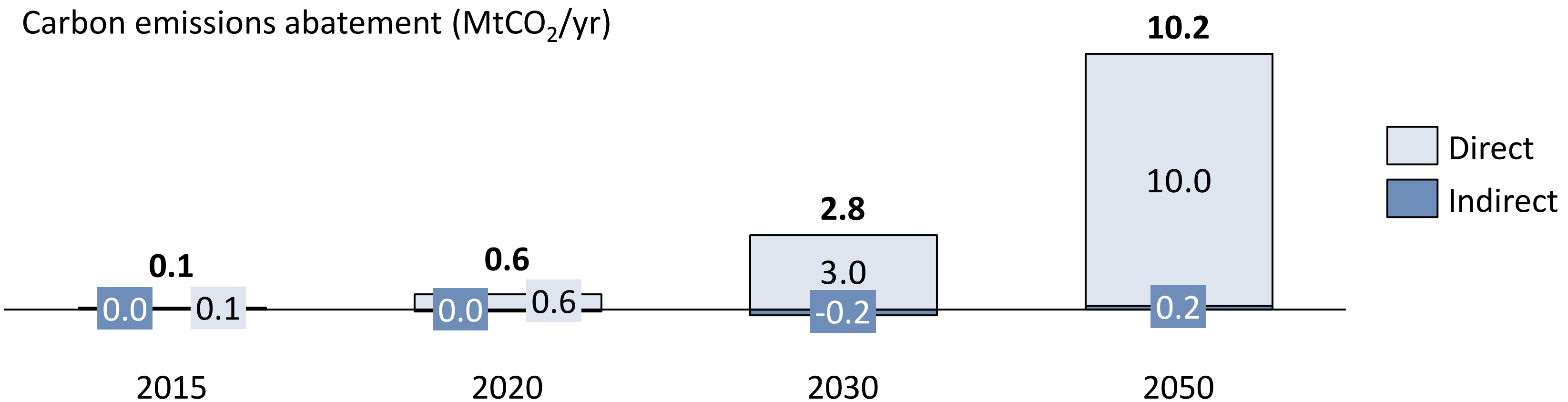
Heat delivered by DH, by technology (TWh)



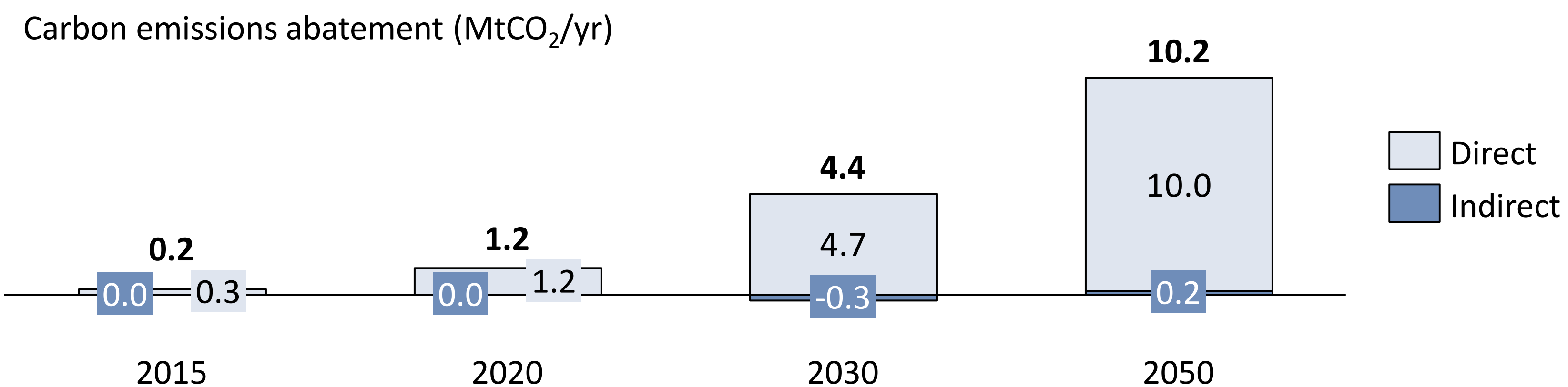
Year	Heat delivered by DH (TWh)	Fraction served by DH
2020	15.5	3%
2030	54.4	12%
2050	110.8	25%

High scenario: Carbon emissions abatement by sector

Carbon emissions abatement in the domestic sector



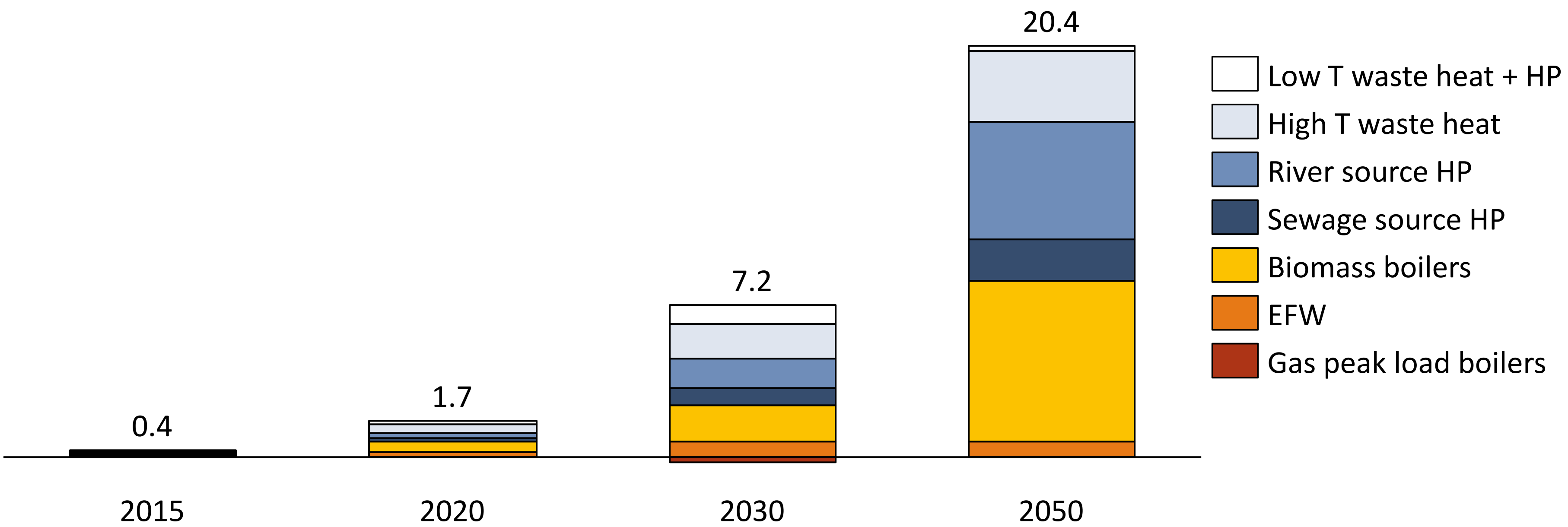
Carbon emissions abatement in the non-domestic sector



High scenario: Carbon emissions abatement by technology

Total (direct and indirect) carbon emissions abatement by technology

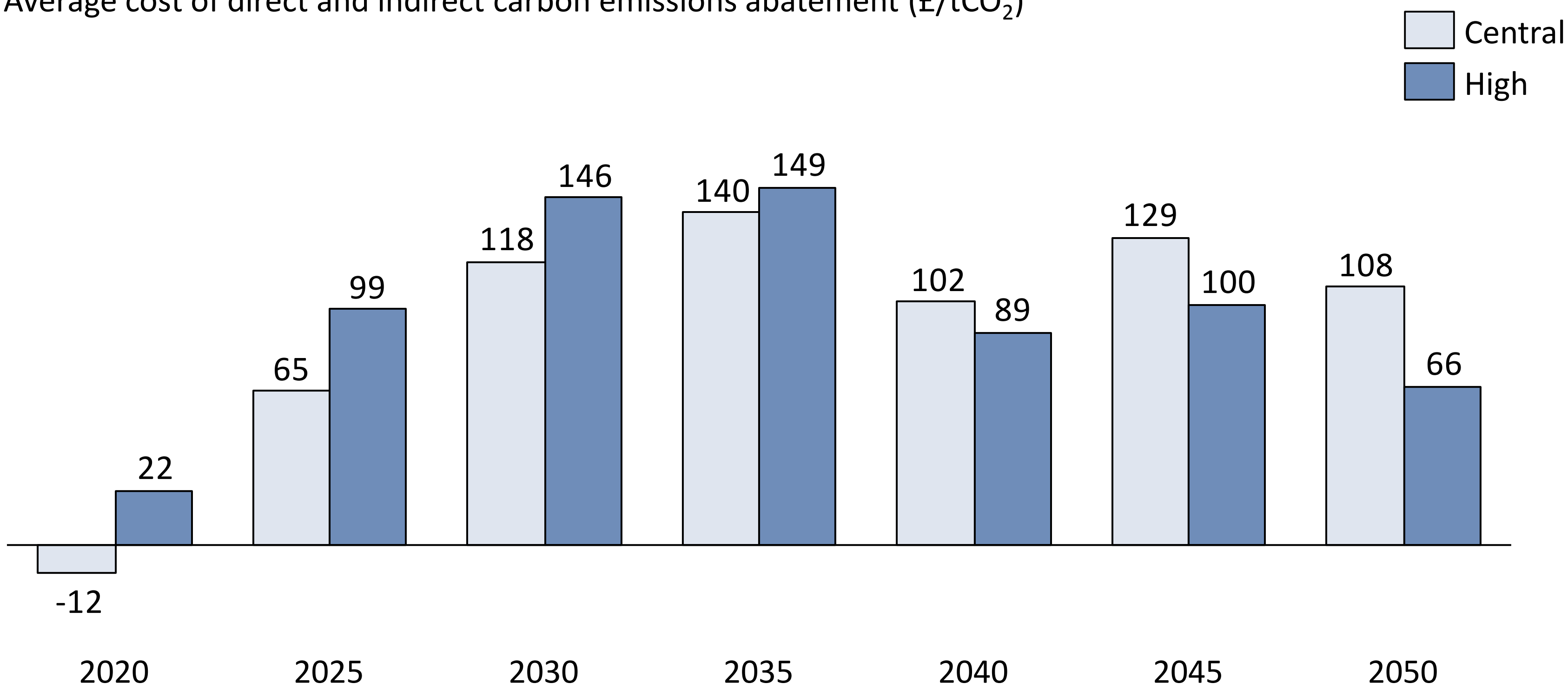
Direct and indirect carbon emissions abatement ($MtCO_2$/yr)



High scenario: Carbon abatement cost

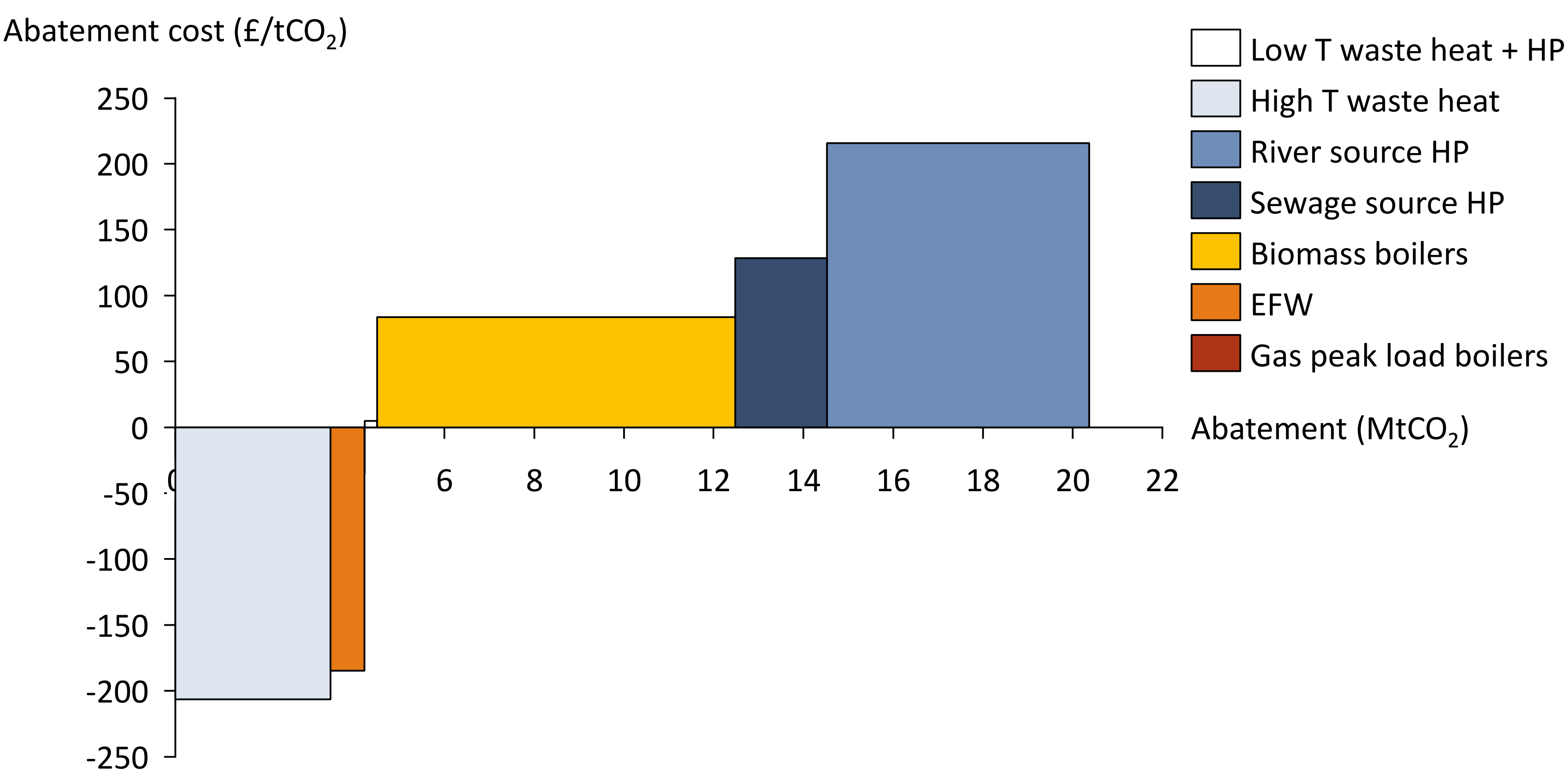
Carbon abatement cost in the High scenario

Average cost of direct and indirect carbon emissions abatement (£/tCO_2)



Abatement cost curve in 2050 by technology for the Max scenario

Average carbon abatement cost curve in 2050 the Max scenario



High scenario: Key results

Key results from High scenario

- The High scenario represents a case where the level of **deployment of district heating is pushed further towards the maximum potential** level.
- In the model, several policies and initiatives additional to those in the Central scenario are represented, including an **increase in the carbon value**; the **refurbishment of power stations to allow the capture of High T waste heat** rather than Low T waste heat only (an additional cost is incurred for this); the **strategic siting of new power stations and industrial plant** near centres of high heat demand; an **increase in the amount of biomass available** for district heating.
- Deployment of DH in the High scenario reaches 16 TWh by 2020, **54 TWh by 2030** and **111 TWh by 2050**, corresponding to 12% of UK low T heat demand in 2030 and 25% in 2050.
- This represents an increase versus the Central scenario of approximately 30% in 2030 and 38% in 2050.
- Compared with the Central scenario, the High scenario in 2050 includes a **larger share in percentage terms of Biomass and High T waste heat**, mainly at the expense of river source heat pumps and gas peak load plant.
- The increase in deployment of **Biomass**, at 46 TWh in 2050 as compared with 9 TWh in the Central scenario, is clearly attributable to the increase in biomass resource. We note that this corresponds to a significant deployment of biomass in urban areas. The **air quality impacts** of this would need to be considered; this is discussed in some more detail in the '*Overcoming barriers to district heating*' Annex accompanying this report.
- The greater use of High T waste heat comes at the direct expense of Low T waste heat, as the refurbishment of power stations means that the same heat is captured at a higher temperature. Note that the same waste heat resource is allocated to the central and high scenarios; it is just the temperature which varies according to the assumptions around the point of capture of the heat.
- There is an overall increase in the number of zones with DH from 2,488 in the Central scenario to 2,685 in the High scenario.
- The overall **carbon abatement** is 7.2 $MtCO_2$ in 2030 and 20.4 $MtCO_2$ in 2050, representing an **increase of around 35% versus the Central scenario in 2050**. This is similar to the percentage increase in uptake, which is to be expected as the change in supply mix (mainly shifting from river source heat pumps to biomass) does not have significant impact on CO_2 emissions by the time the grid is decarbonised.

(1) The following slides show a detailed comparison of the technology mix in the Central, Barriers and High scenario, both in TWh terms and in percentage terms.

Contents

Critical path scenario: Summary of assumptions

Interpretation of the Critical path scenario

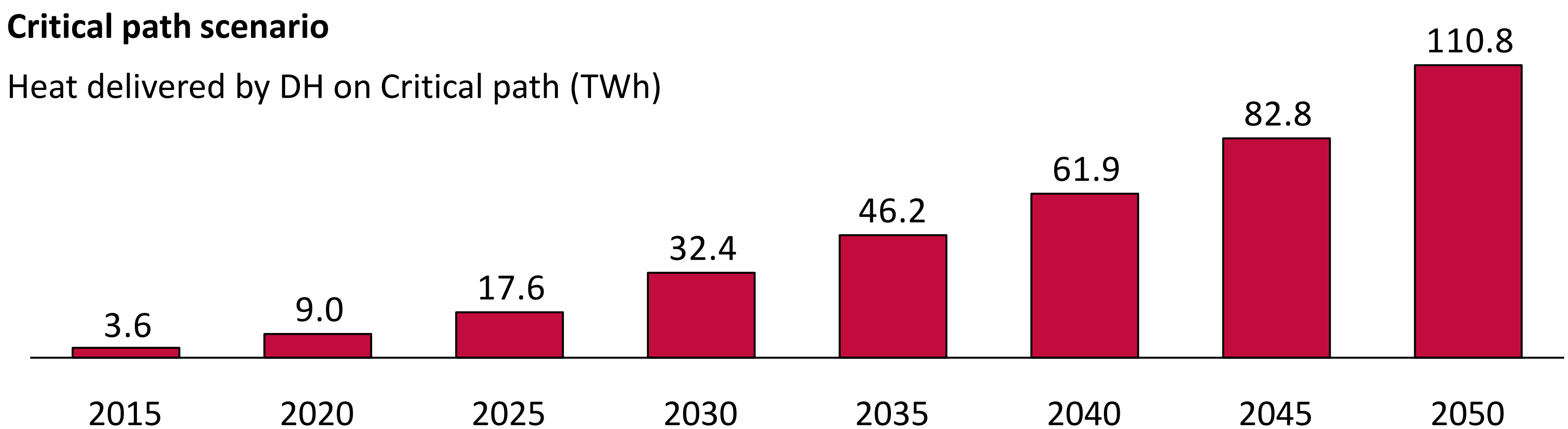
- The **Critical path describes a level of deployment at each year up to 2030 which leaves open the option to deploy district heating at 'large scale' in 2050,** accounting for the finite rate at which heat network infrastructure can be rolled out in practice.
- 'Large–scale' is here defined as the level of deployment in the High scenario – that is, **111 TWh in 2050**. In other words, therefore, the Critical path is the minimum level of deployment that needs to be in place in each year to 2030 for a 2050 deployment of 111 TWh still to be achievable.
- As described in the methodology section, the Critical path is not the result of a run of the core model. Rather, it has been **developed using historic data on the maximum achievable growth** in the deployment of district heating.
- To develop the Critical path, we have taken the 'Central' values for the maximum growth rate as described in the methodology section, summarised in the table below.
- We note that the Critical path does not include a description of the technology mix, only the overall deployment of district heating.

Maximum DH deployment growth rate assumptions used in Critical path scenario

Growth phase	Period	Maximum annual growth in heat delivered by DH
Emerging	2015-2020	20%
Growth	2021-2030	13%
Mature	2031-2050	6%

Critical path scenario: Summary results

District heating deployment in the Critical path scenario

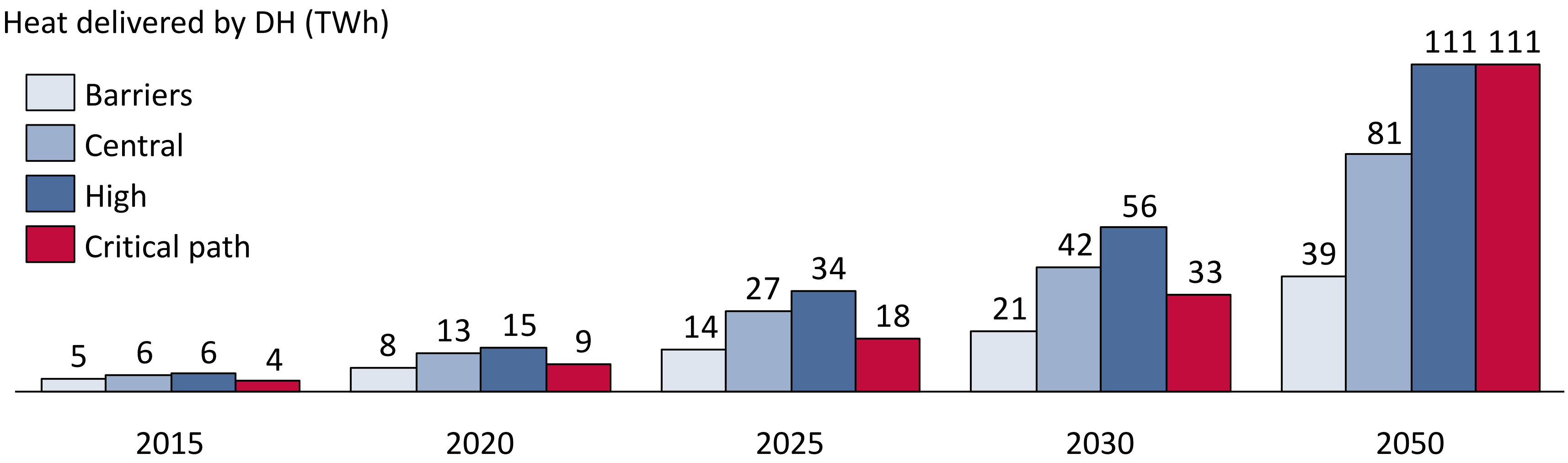


Summary of heat delivered in the Critical path scenario

Year	Heat delivered by DH (TWh)	Fraction served by DH
2020	9.0	2%
2030	32.4	7%
2050	110.8	25%

Central and High scenarios meet the Critical path to 2030, but the Barriers scenario does not

Comparison of the Central, Barriers and High scenarios with the Critical path to 2030



Do the core scenarios meet the Critical path to 2030?

- The chart above shows that the **Central scenario exceeds the Critical path at each point up to 2030.**
- The level of deployment associated with the Central scenario in 2030 therefore leaves open the option to deploy district heating at the level of the High scenario in 2050 (111 TWh) within the maximum growth rates identified.
- In contrast, however, the failure to overcome the barriers to consumer connection means that the **Barriers scenario fails to meet the Critical path**, falling behind the required level by 2020 and reaching 2030 with a deficit in deployment level equal to 23% of the Critical path deployment.
- This suggests that **no delay can be afforded in implementing the required policy measures** if the high levels of deployment presented in the High scenario – and even in the Central scenario – are to be achieved in the long-term.

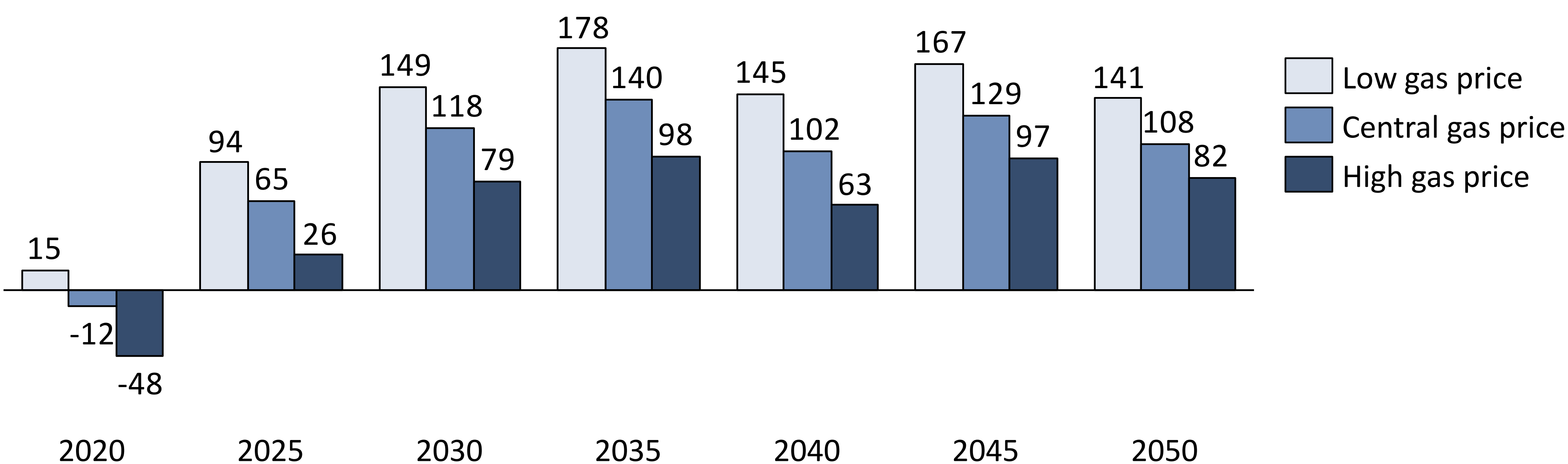
Contents

Gas price sensitivities: summary of assumptions

Introduction to sensitivities

- This sensitivity analysis takes the results of uptake and abatement from the Central Scenario, and calculates the cost of that abatement using different price assumptions for gas and capital cost of DH equipment.
- It is not a representation of how district heating uptake changes under different price assumptions.
- We have first studied the impact of using **Low and High Gas price projections** on the CO_2 abatement cost of the Central scenario.
- It is important to note that, within the model, the Electricity price is linked to the Gas price to the extent that Gas contributes to the electricity generation mix; the Low and High Electricity price cases correspond directly to the Low and High Gas price cases respectively.
- The appropriate Gas and Electricity prices (which can be found in the Appendix) are applied both to the counterfactual heating option and to the district heating scheme.

Average cost of direct and indirect carbon emissions abatement (£/tCO_2)

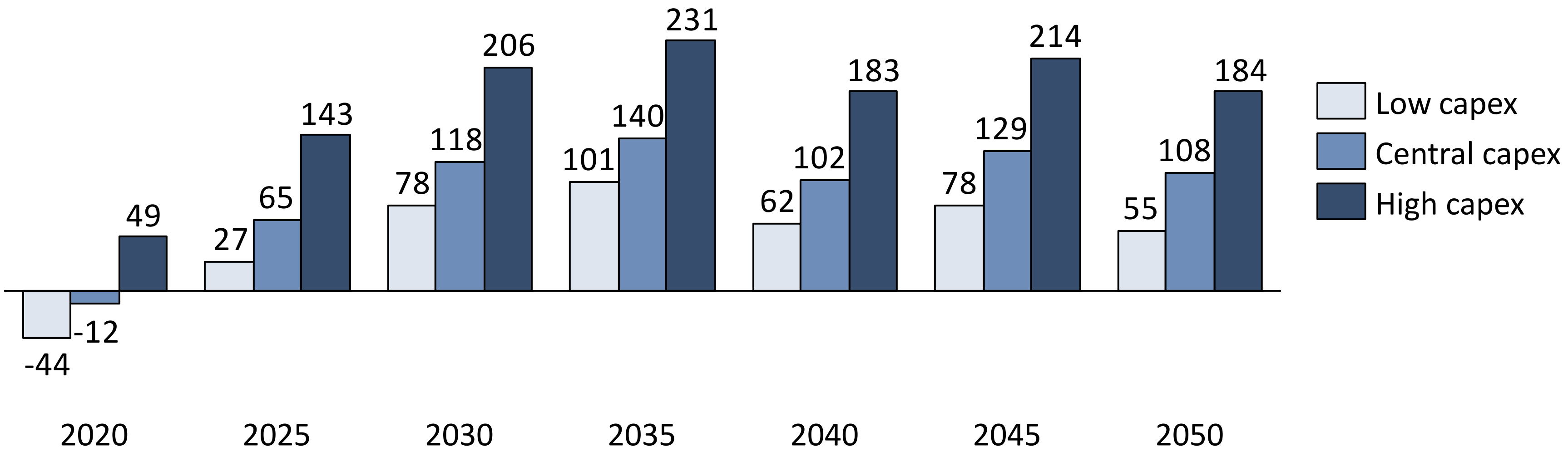


Capital cost sensitivities: summary of assumptions

Capital cost sensitivities

- We have also studied the impact of using **Low and High Capital cost projections** on the CO_2 abatement cost of district heating, using uptake and abatement from the output of the Central scenario.
- Low and High capital cost assumptions are applied across a range of technologies used in district heating schemes, including water-source and sewage-source heat pumps, biomass boilers, thermal storage, district heating pipework and heat interface units.
- Mature technologies such as Gas boilers (including building-level boilers in the counterfactual and district heating peaking plant) and Gas CHP have a fixed capital cost, with no Low or High values applied.

Average cost of direct and indirect carbon emissions abatement (£/tCO_2)



Gas price and Capital cost sensitivities: Key results

Gas price sensitivities: Key result

- Varying the gas price leads to a change in the abatement cost of 25-50% from the original Central abatement costs, over the period 2030 to 2050.
- High gas prices decrease the abatement cost, while low gas prices increase it.
- Increasing the gas price affects cost of the modelled schemes in two ways: increased cost of gas bought as a fuel for boilers and CHP, and also increased cost of electricity (due to gas being a component of the generation mix). The first effect is larger.
- The predominant use of gas purchased as a fuel in DH schemes in the model is peak load plant; this makes up a maximum of 35% of the annual demand of a zone. In the counterfactual heating option, gas makes up around 90% of the annual heat demand of a zone.
- Therefore an increased gas price increases the cost of the counterfactual more than it increases the cost of a DH scheme; thus the premium for installing a DH scheme is reduced and the CO_2 abatement cost decreases.

Capital cost sensitivities: Key result

- Changing the capital cost of DH-related technologies leads to a change in the abatement cost of 40-75% from the original Central abatement costs, over the period 2030 to 2050.
- The effect of the Low Capital cost case is to make all district heating options more cost-effective relative to the counterfactual – through the lower cost of DH infrastructure – and to make the less mature district heating supply options such as heat pumps and biomass boilers even more cost-effective. The High Capital cost case has the opposite effect.

Contents

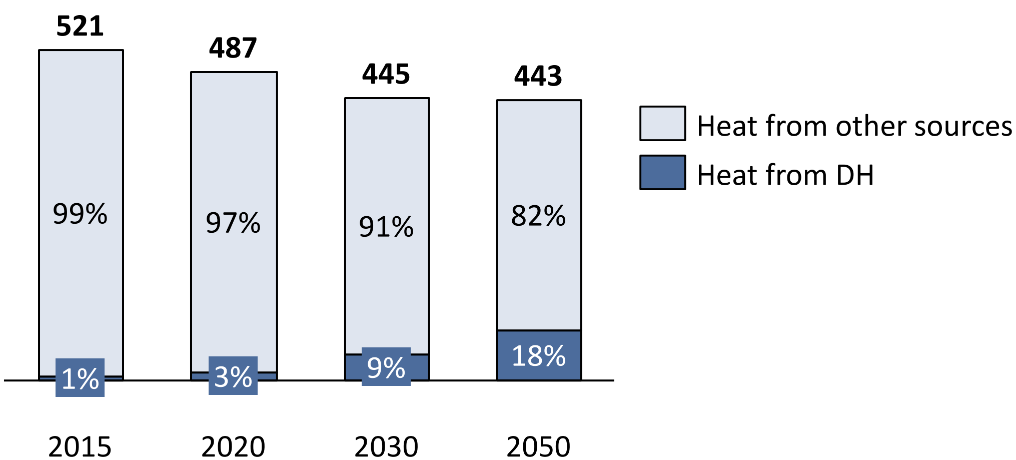
Summary of key findings (1)

In the Central scenario, 15 $MtCO_2$/yr of carbon emissions savings are achieved in 2050

- **Our Central scenario** represents a case where the **existing barriers to district heating**, including market and policy failures, a lack of consumer interest and trust, uncertainty of demand, high technology cost and institutional issues such as skills and knowledge, **have been overcome**.
- In our Central scenario, we find that 42 TWh of DH is deployed by 2030 (corresponding to 9% of total UK heat demand*), with **81 TWh deployed in 2050** (18% of total heat demand).
- This leads to carbon emissions savings in 2050 of more than **15 $MtCO_2$/yr**.
- The **number of 1 km^2 zones** in which DH is deployed by 2050 is found to be **less than 2,500** of the nearly 20,000 such zones which cover 90% of the UK heat demand.

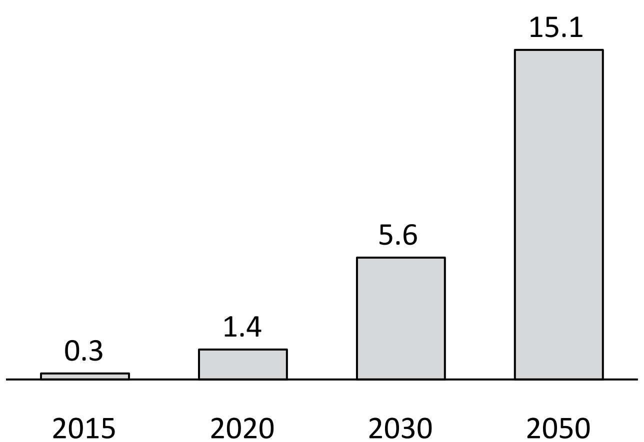
District heating deployment in the Central scenario

Heat supply in the domestic and non-domestic sectors* (TWh)



Associated CO_2 abatement

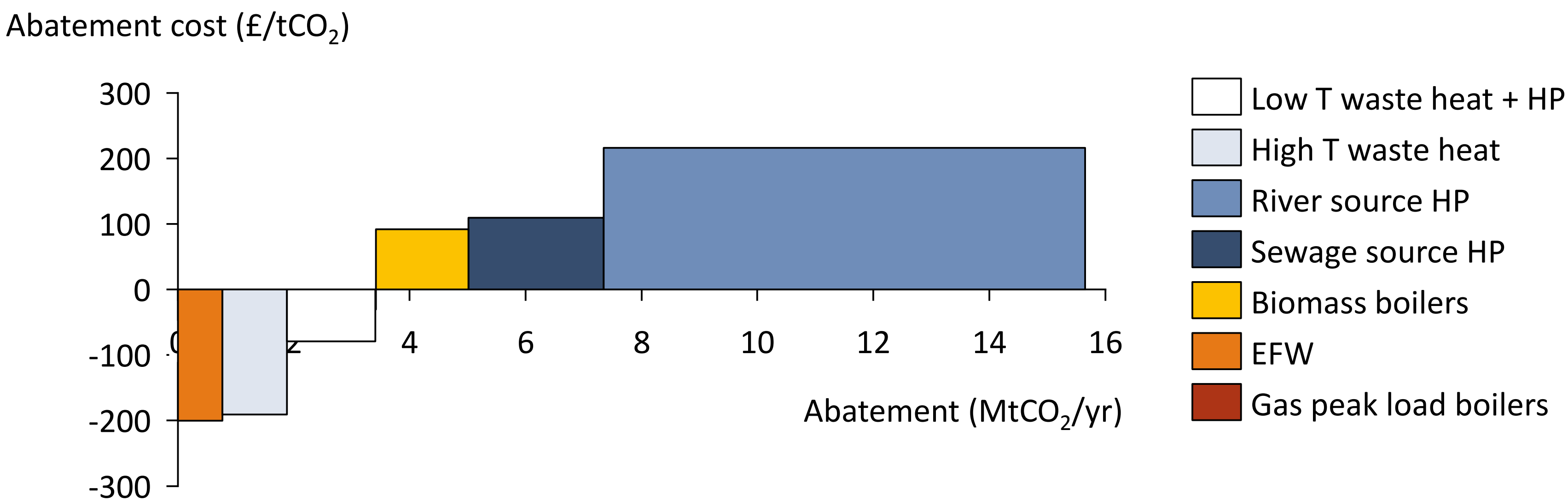
CO_2 emissions abatement from DH ($MtCO_2$)



*Excluding industry process heat demand.

Summary of key findings (2)

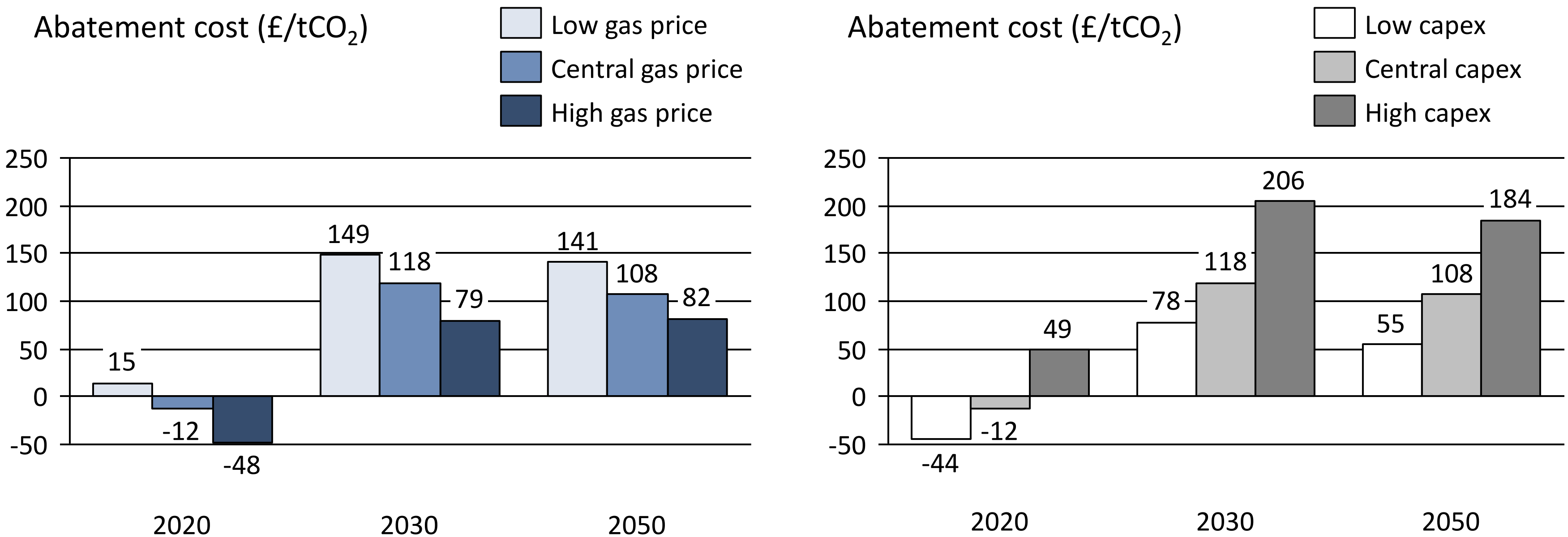
Waste heat and EFW are the most cost-effective heat supply options



- As described in Section 3, DH schemes are built where they are more cost-effective than the mainly gas-based counterfactual, accounting for the carbon value. In the Central case, the carbon value reaches £78/tCO_2 in 2030 and £333/tCO_2 in 2050.
- **Average abatement cost** in the Central scenario in 2050 is **£108/tCO_2.**
- The associated abatement cost varies strongly with heat supply technology. **Waste heat from power stations and industry** and **EFW heat** are typically the **most cost-effective options**, with negative average abatement costs in the range -£79/tCO_2 to -£200/tCO_2. We therefore expect these options to be taken up earlier wherever such sources are located near heat demand centres.
- Lower-grade heat sources, including **water-source heat** and **sewage-source heat**, are less cost-effective with average abatement costs of £109/tCO_2 and £216/tCO_2 respectively, but offer significant carbon abatement potential of more than 10 MtCO_2.
- **Biomass**-based DH is also reasonably costly, but under the assumptions made in the Central scenario is found to be more cost-effective than the water-source heat pumps, with an average abatement cost of £92/tCO_2.

Summary of key findings (3)

Abatement cost carries significant uncertainty relating to fuel prices and technology capex



- In the Central scenario, the **average abatement cost is negative in 2020** at -£12/tCO_2 (reflecting the fact that the most cost-effective schemes tend to be implemented earliest), **rising to £118/tCO_2 in 2030** and £108/tCO_2 in 2050.
- We have performed a **sensitivity analysis** on the abatement cost using the CCC's Low and High **Gas price scenarios*** (see Appendix), and our own Low and High **Capital cost scenarios** (applied to water-source and sewage-source HPs, biomass boilers, thermal storage, DH pipework and heat interface units). Note that, for the analysis shown, we have fixed the deployment of DH.
- **Higher Gas prices reduce the average abatement cost**, since the counterfactual (mainly gas boilers) is more strongly affected than the DH schemes based on a fuel mix of electricity (for HPs), gas (for peaking plant), biomass or no fuel (for High T waste heat). In 2050, the High Gas price leads to a 24% reduction in abatement cost to £82/tCO_2; the Low Gas price an increase of 31%.
- **High Capital costs impact only the DH scheme cost**, and not the counterfactual cost, and hence have a significant effect on the abatement cost. In 2050, the High Capital costs lead to a 70% increase in abatement cost; the Low Capital costs a 49% decrease.

*We note that the gas price affects the electricity price to the extent that gas power stations contribute to the electricity generation mix; Low and High Gas price cases lead to associated Low and High Electricity price cases respectively.

Summary of key findings (4)

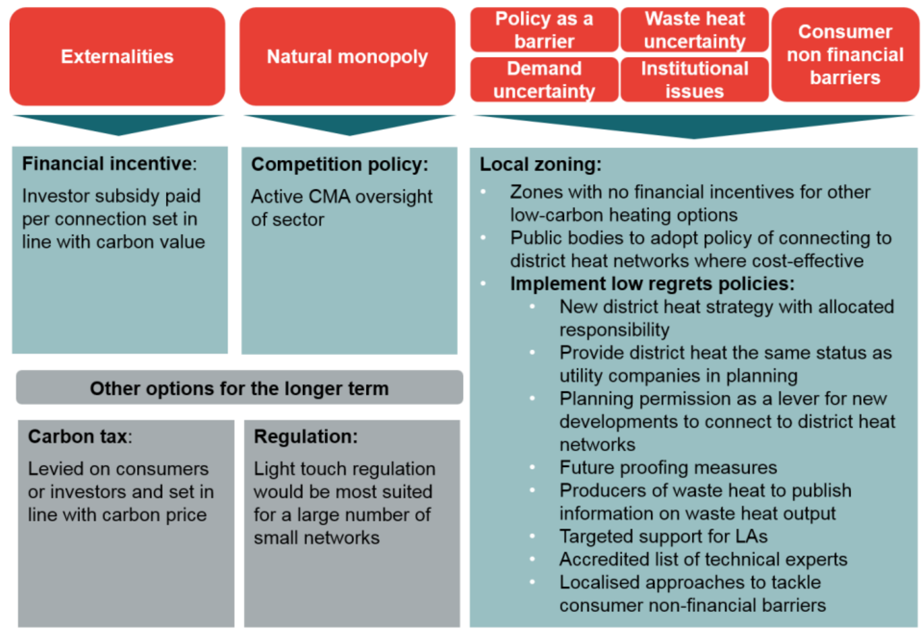
The level of DH deployment seen in the Central scenario will require concerted policy action

- The Central scenario represents a case where the **existing barriers to district heating have been overcome.**
- A detailed assessment of the barriers for heat networks in the UK, and potential policy solutions, is presented in the accompanying Annex "*Overcoming barriers to district heating*".
- Key barriers identified include **externalities, natural monopoly characteristics, demand uncertainty, barriers associated with policy, consumer barriers** and **institutional issues**.
- We have assessed a wide range of policy measures to overcome these barriers for their suitability to the UK case.

Key policy recommendations

1. **A financial incentive** paid to investors that aims to address the externality in the market related to carbon emissions.
2. **Competition policy**, in the form of CMA oversight, to address natural monopoly concerns and help to ensure fair outcomes for consumers to preserve the reputation of the sector.
3. **The provision of dedicated local heat zones** within which DH is deemed cost-effective. Within these zones relevant local policies can be applied in a targeted way, including a **public body policy of connecting to DH networks** where cost-effective, the **removal of financial incentives for other heating technologies**, and a number of other options as set out in the figure on the right.

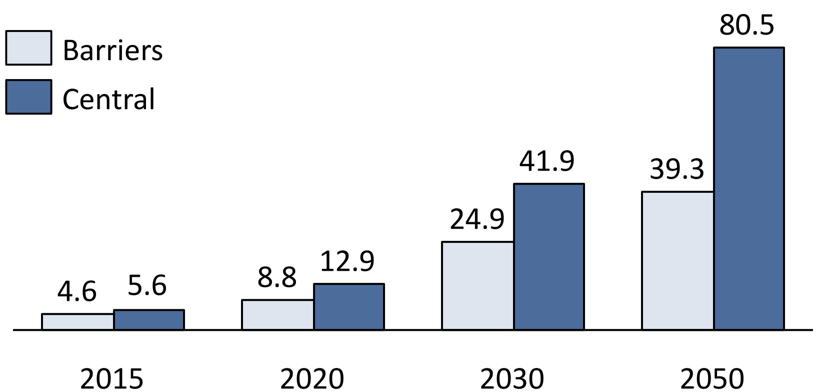
Graphical summary of policy recommendations



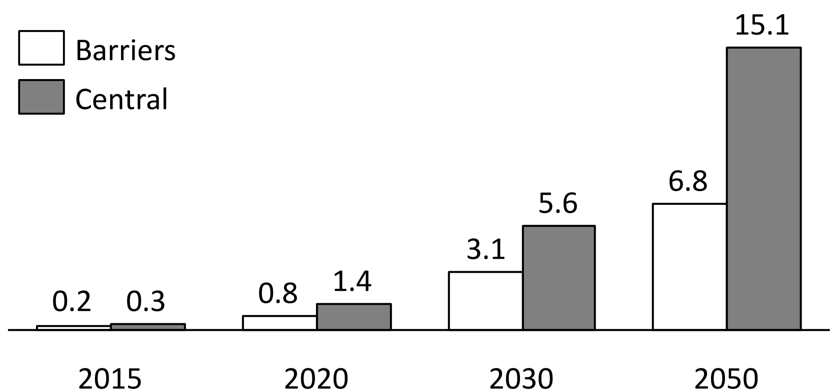
Summary of key findings (5)

Where only a subset of barriers to DH are overcome, deployment of DH could be much lower

Heat delivered by DH* (TWh)



Carbon emissions abatement ($MtCO_2$/yr)

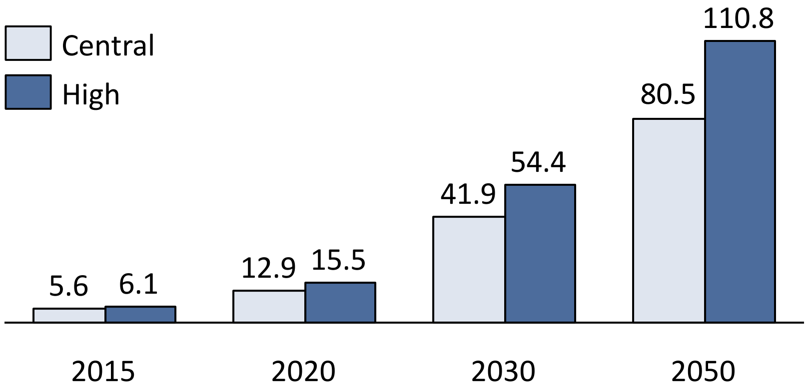


- Through the **Barriers scenario**, we have represented a case where a number of the key barriers to DH identified are not overcome – either through a choice of not to implement policies to address them, or a failure of those policies.
- In the modelling, this is represented by a significantly **lower connection fraction** to DH schemes than in the Central scenario (at 50% as compared with 90% - see sections 3 and 4 for more details). A lower connection fraction within an area suitable for DH is likely to result from a **lower level of consumer trust and engagement**, a **lower level of adoption of the public body policy of connecting to DH**, and from **competition with other incentivised low carbon heating** technologies.
- We note that in the Barriers scenario shown here, the financial incentive for low carbon DH is still applied in the form of the same carbon value as used in the Central scenario.
- The impact of the lower connection fraction is that the deployment of DH falls by 41% in 2030 to 25 TWh, and by 51% in 2050 to 39 TWh. This leads to a **55% drop in carbon emissions savings** in 2050 to 6.8 $MtCO_2$/yr.

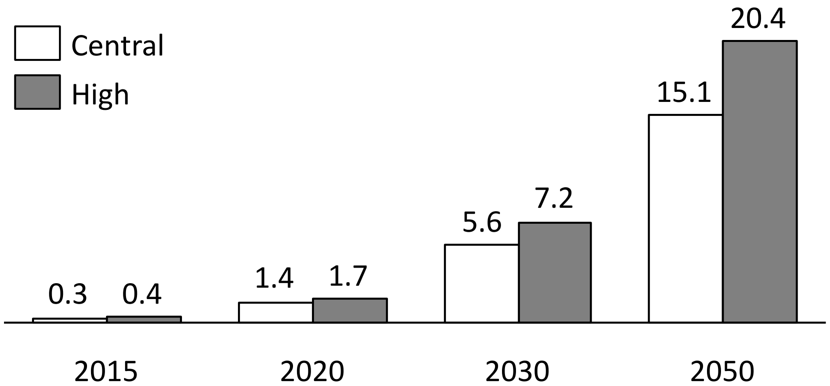
Summary of key findings (6)

Additional policy action could lead to up to 111 TWh of district heating by 2050

Heat delivered by DH (TWh)



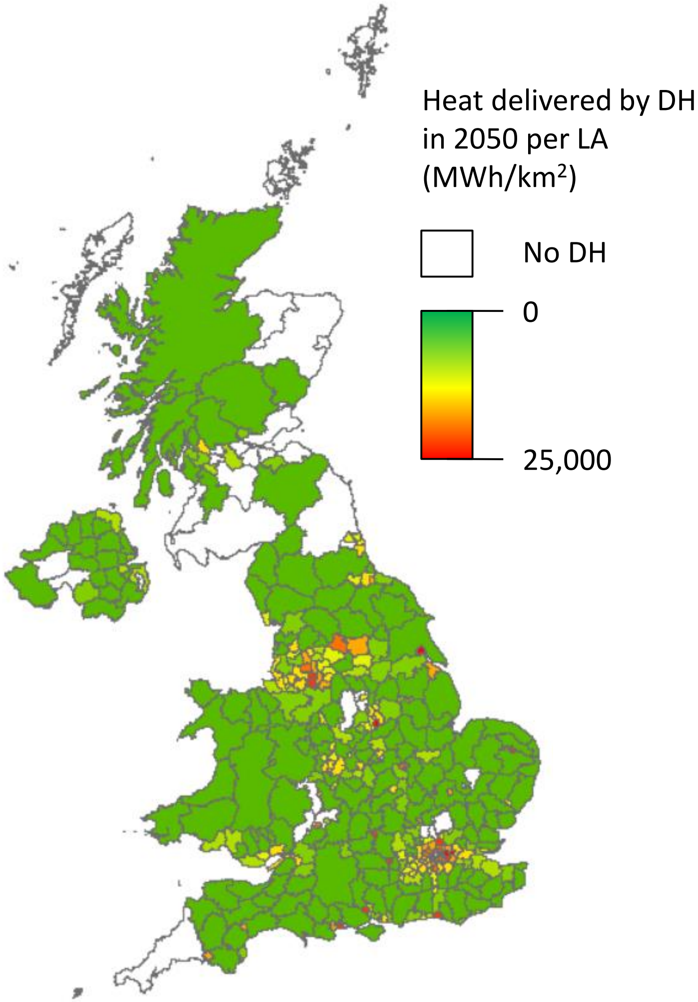
Carbon emissions abatement ($MtCO_2$/yr)



- The High scenario reflects an estimate of the **'maximum' level of DH deployment in the case of a very strong policy push**, including:
  - **higher incentives** for low-carbon DH;
  - **very strong local heat zoning policy** to ensure almost full connection in areas suitable for DH and to influence the siting of new industry and power stations and the grade of heat captured from the plant;
  - **greater allocation of biomass** to DH networks.
- The higher incentive for low-carbon DH is represented in the modelling through the use of a higher carbon value reaching £116/tCO_2 in 2030 and £555/tCO_2 in 2050, and a connection fraction of 100% is used. We also represent the refurbishment over time of power stations to allow the capture of high T waste heat and, to represent the siting of new plant near demand centres, reduce the distance between plant and the network to a lower limit of 1 km.
- Deployment of DH in the High scenario is around 38% higher than in the Central scenario, and the **carbon emissions savings around 35% higher than in the Central scenario, at more than 20 $MtCO_2$/yr**.

Summary of key findings (7)

Heat networks will be concentrated in urban areas with access to suitable heat sources



- Heat networks are suitable for **areas of high heat demand density**, where the high capital cost of the required infrastructure can be justified by the high utilization factor (and high value of heat sales)
- Accordingly, as shown on the map on the left, uptake of DH in the Central scenario is **concentrated in urban areas** and isolated sites of high density development outside urban centres
- However, the **local availability of heat sources** – particularly waste heat sources and water sources – also **plays a very important role** in determining the location of viable DH schemes
- This is particularly the case in the scenarios we present here, given the constraints placed on the deployment of Gas CHP to 2050*

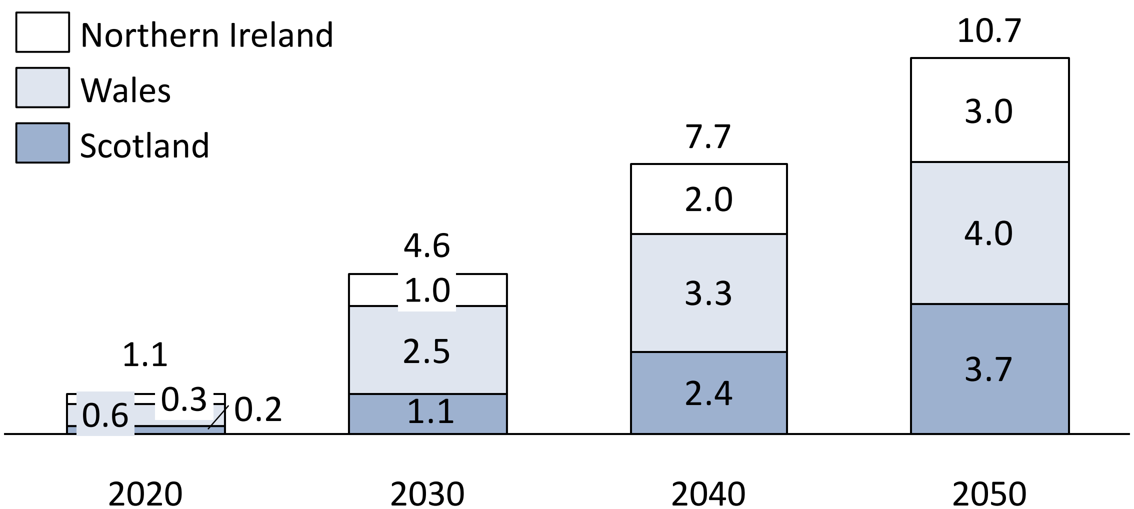
*As described in Section 3

Summary of key findings (8)

The devolved administrations together make up 13% of the UK DH uptake

	Heat delivered by DH (MWh/km²)	Fraction of total (%)
England	69.6	87%
Scotland	3.7	5%
Wales	4.0	5%
Northern Ireland	3.0	4%
Total	**80.3**	**100%**

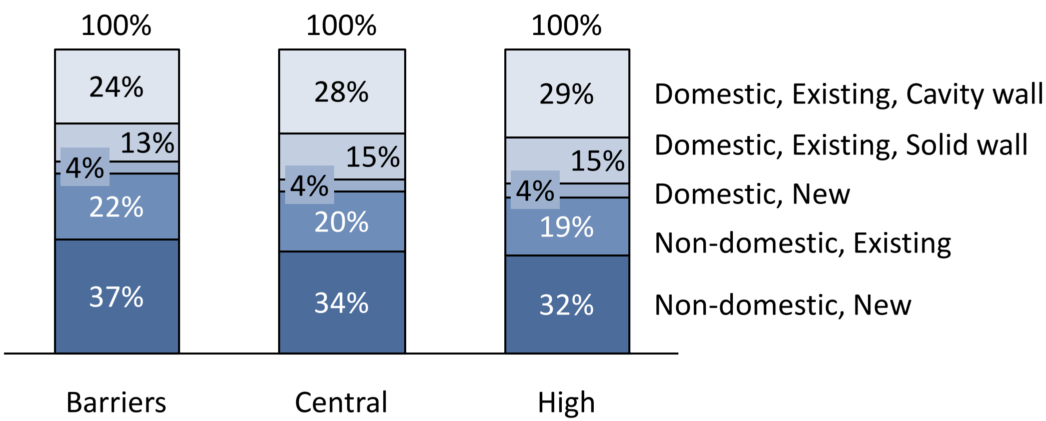
- We have found the deployment of DH across each of the Devolved Administrations.
- We find that, where policy is aligned across all regions, **more than 13% of the DH is deployed outside England.**



Summary of key findings (9)

District heating is likely to be deployed more widely in the non-domestic sector

Heat delivered by DH in 2050, by sector
(% of total heat delivered by DH)



	Share of total heat delivered by DH (2050)		Share of UK heat demand in sector (2050)	
	Domestic	Non-domestic	Domestic	Non-domestic
Barriers	41%	59%		
Central	47%	53%	72%	28%
High	48%	52%		

- Our bottom-up modelling has found that the deployment of district heating is likely to be significantly greater in the non-domestic sector than in the domestic sector.
- In the Central scenario, **53% of the heat delivered by district heating in 2050 is associated with the non-domestic sector**, despite the non-domestic sector representing only 28% of UK heat demand in that year.
- Whereas around **34% of non-domestic heat demand is served by DH in 2050** in the Central scenario, that fraction is only around **12% for the domestic sector**.
- This result reflects the fact that **non-domestic buildings tend to be concentrated** in areas with a higher building density and therefore heat density, such as **town and city centres**.
- Another important contributing factor is that non-domestic buildings are on average larger than domestic buildings, and act as better '**anchor loads**' for DH schemes, leading to lower connection costs per kWh of heat delivered.

Contents

Integrated scenario, based on TIMES modelling, represents a case which minimises the total energy system cost, including electricity as well as heat

Description of the Integrated scenario

- One aim of this study was to provide insight into the potential **systemic benefits of district heating** – that is, **cost reductions across the wider energy system** brought by district heating.
- We have explored this theme through the development of an Integrated scenario, to represent a case which minimises the total system cost (including electricity and heat) to reflect optimisation of the whole energy system.
- The integrated scenario trades off electricity, heat, and gas infrastructure and end-use technologies in a single consistent framework.

Whole system energy modelling based on the TIMES framework

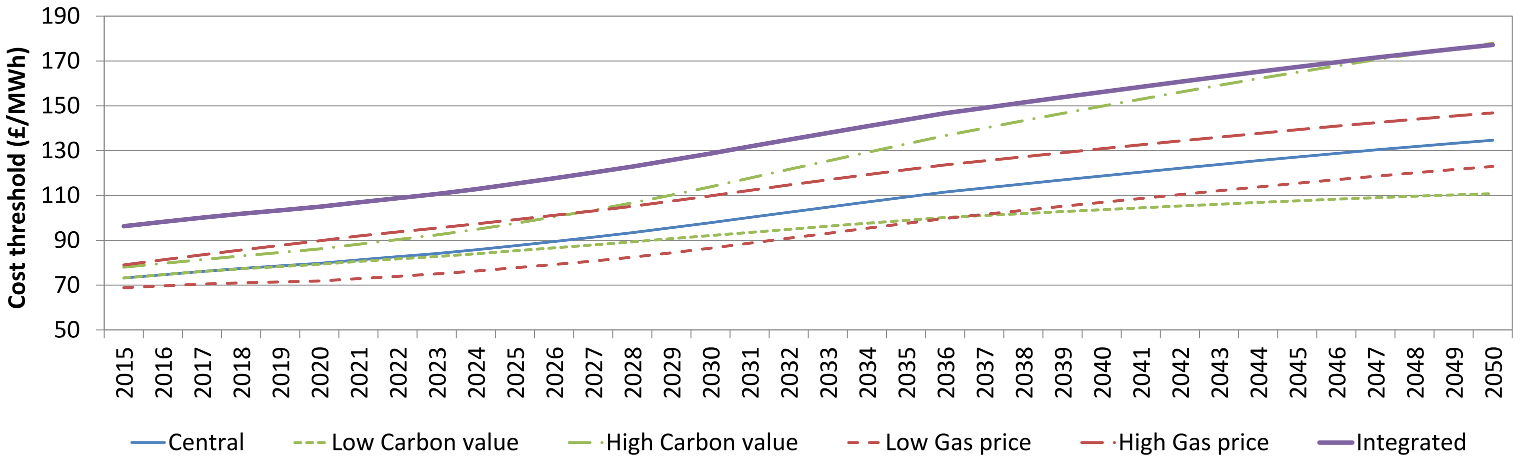
- The approach taken was to perform an initially separate modelling exercise using the proven techno-economic **"The Integrated MARKAL-EFOM System"** or **TIMES** framework*.
- The model implementation in the TIMES modelling environment does the following:
  - **Minimises the cost** of uptake of competing low carbon and conventional technologies, **taking an integrated view of heat and electricity provision** at spatially-disaggregated urban length scales.
  - **Trades off technologies that serve heat and/or electricity demand**, considering those options that consume heat, gas, electricity or biomass, and produce heat and/or electricity. For example, the model considers competing options such as district CHP (producing heat and electricity for distribution), PV (producing electricity only), boilers (heat only), and conservation measures such as loft insulation within a single integrated framework.
  - Is highly **spatially resolved**, modelling each MSOA in the relevant local authority as a spatial unit. This provides more robust insight with regard to infrastructure build options.
  - Is more **temporally resolved** than most system-level heat decarbonisation models, using the same time-slice definition as the national UK-TIMES model.

*http://www.iea-etsap.org/

A new cost threshold was derived for the Integrated scenario, based on the LCOE of the least cost-effective scheme built in the TIMES model

Implementation of the Integrated scenario in the Element core model

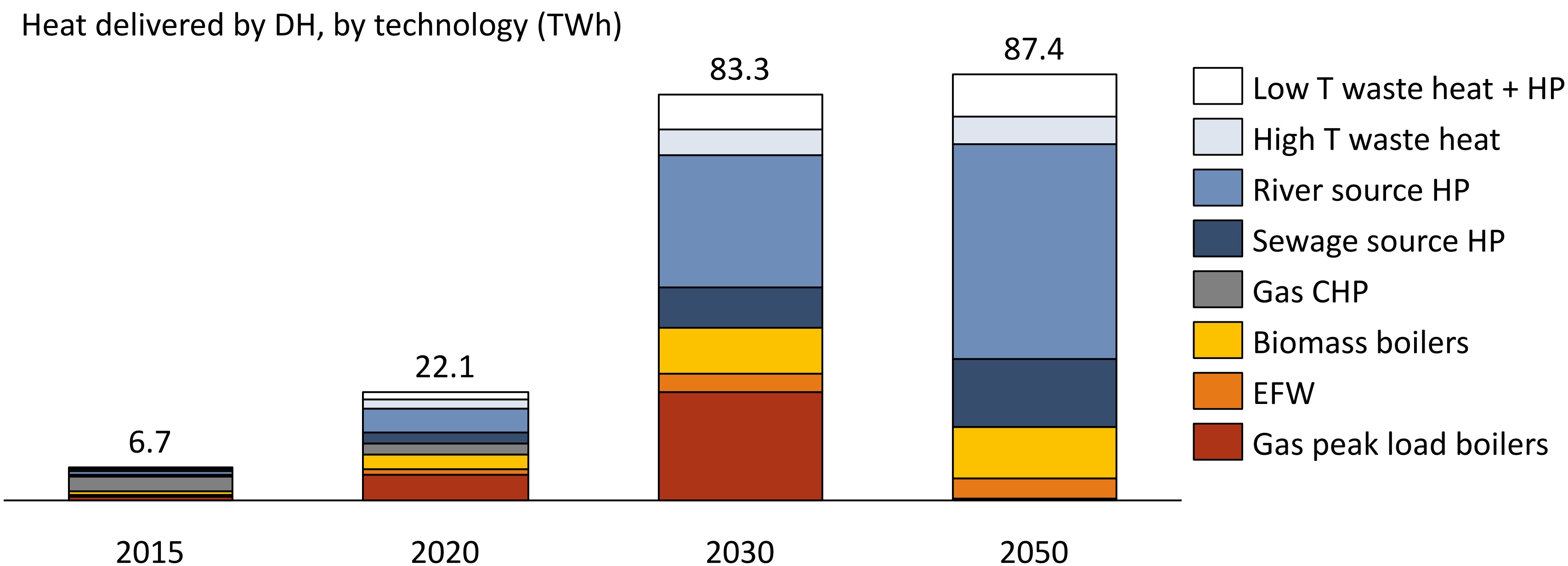
- In order to develop the Integrated scenario, the deployment of district heating in each of a number of 'zones' – in this case, Middle Layer Super Outputs Areas (MSOAs) – across a number of representative, real study areas was studied within the TIMES framework. The result of this modelling was a projection to 2037 of the level of uptake (or not) of district heating in each MSOA.
- For each MSOA, a dataset was developed including the domestic/non-domestic heat demand, the number of domestic/non-domestic connections, and the area (in km^2) of the MSOA, allowing the MSOA to be assigned to one of the zone archetypes used in the core modelling.
- Within the Element model, the levelised cost of energy (LCOE) for district heating was calculated for each MSOA in which district heating was taken up in the TIMES model, for each build year. The highest LCOE obtained for an MSOA in which district heating was built was then taken as the cost threshold for the corresponding year in the Integrated scenario. Outside the build years observed in the TIMES model, the cost threshold was interpolated based on the trend over time of the cost threshold in the Central scenario. The cost threshold used in the Integrated scenario is shown in the figure below.
- Apart from the cost threshold, the modelling assumptions used in the Integrated Scenario are the same as those in the Central Scenario.



*http://www.iea-etsap.org/

Integrated scenario: District heating deployment

District heating deployment in the Integrated scenario

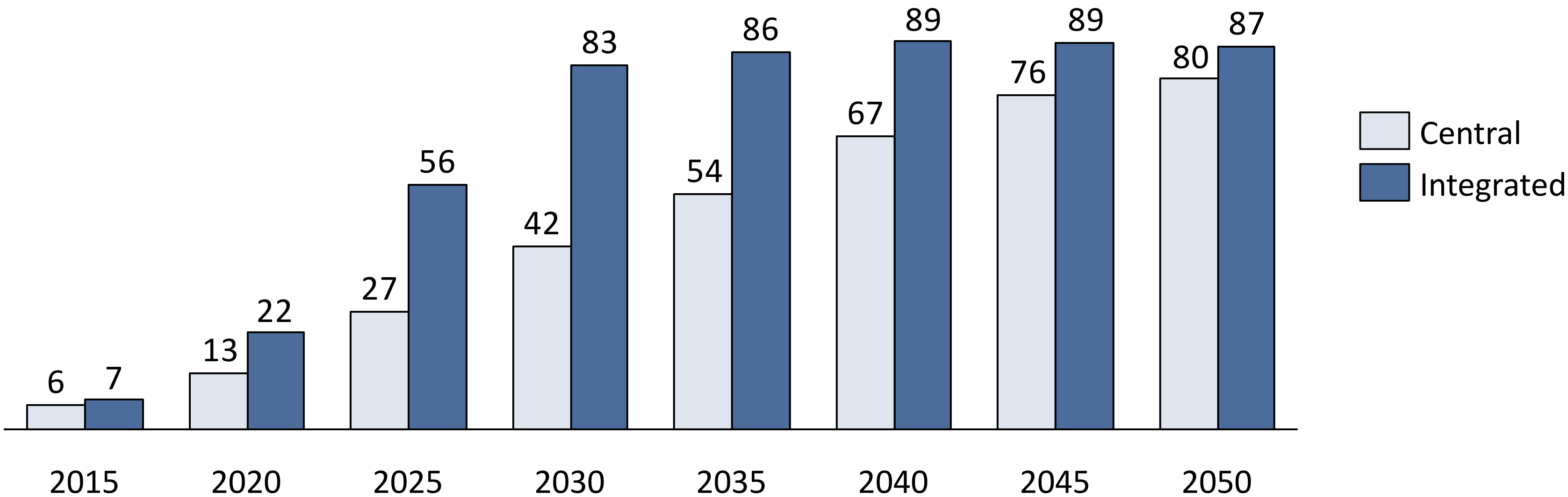


Year	Heat delivered by DH (TWh)	Fraction served by DH
2020	22.1	5%
2030	83.3	19%
2050	87.5	20%

Integrated scenario: District heating deployment

District heating deployment in the Integrated scenario compared with Central scenario

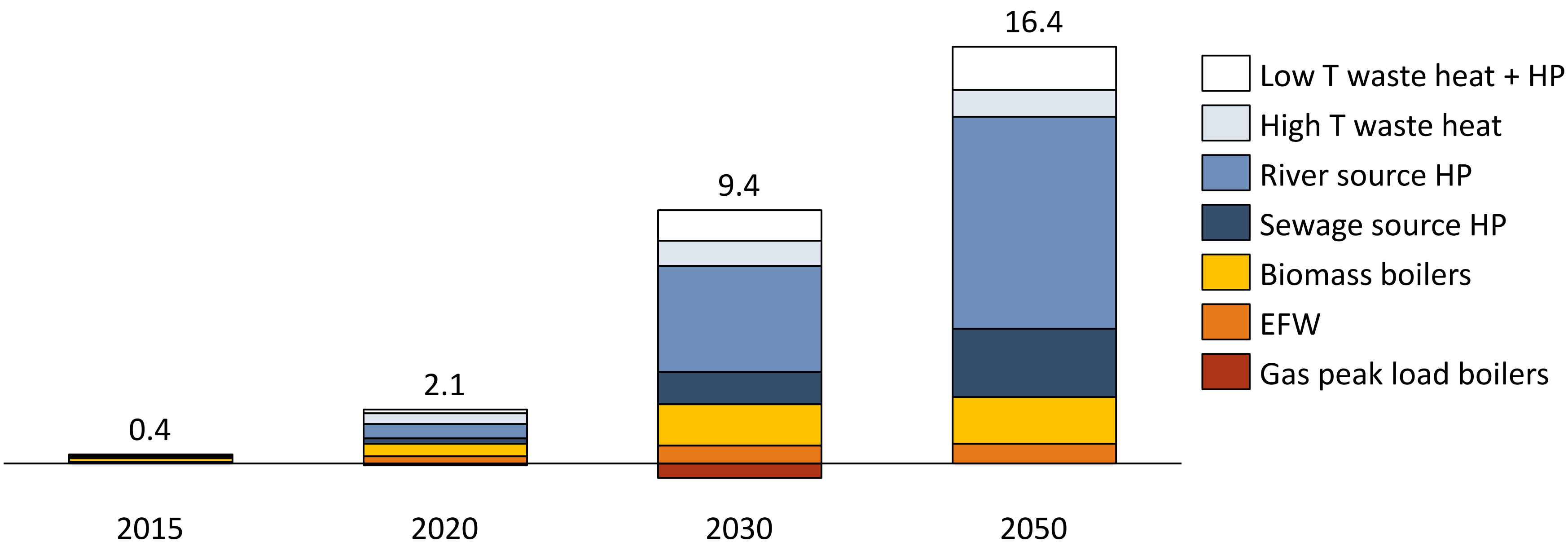
Heat delivered by DH, by technology (TWh)



Integrated scenario: Carbon emissions abatement by technology

CO_2 emissions abatement in Integrated scenario

Direct and indirect carbon emissions abatement ($MtCO_2$/yr)



Integrated scenario: Key results

Key results from Integrated scenario

- A **bespoke implementation of TIMES** was developed in order to quantify the wider system benefits of district heating, taking an **integrated view of heat and electricity provision**. The assumptions were aligned as far as possible with those used in the main model developed for and described in this report.
- The cost threshold derived for the Integrated scenario, was found to be £129/MWh in 2030, significantly higher than the cost threshold used in the Central scenario, at £98/MWh.
- This difference may be due to the systemic benefits of district heating, and/or additional modelling differences between TIMES and the main model.
- When this potential additional value is incorporated by increasing the cost threshold by a corresponding amount, this leads to a significantly higher rate of uptake of district heating, reaching **83 TWh by 2030** as compared with 42 TWh in the Central scenario.
- Following this high early uptake, however, the available resource for district heating located near centres of heat demand – including waste heat, biomass and river-source heat – becomes depleted, and **growth saturates to 2050**. Few new schemes are built after 2035, but existing schemes are replaced with new heating plant.
- This means that the higher cost threshold does not ultimately lead to a significantly greater deployment of DH. This reflects the presence of an effective **natural limit to the potential for DH deployment** based on the existence of available heat sources and biomass fuel co-located with heat demand of 80-90 TWh under the current assumptions. We note that in the High scenario, this effective limit is increased due to the increase in biomass resource made available to DH.
- Although uptake of DH saturates after 2030, the **carbon abatement continues to increase to 2050** as the electricity grid continues to decarbonise, and the schemes based on HPs abate a greater amount of CO_2.
- In summary, **accounting for the system-level benefits of DH** as compared with individual building-level heating technologies may **lead to a nearly 50% higher cost-effective uptake of DH by 2030**. In the scenario studied, however, natural limits to the availability of cost-effective heat sources mean that beyond 2030 DH **uptake saturates at around 90 TWh**.

Contents

Electricity price data

Category	Case	Unit	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
Export price with flexibility premium	Low	p/kWh	4.5	4.6	5.6	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
	Central	p/kWh	5.0	6.1	7.5	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7
	High	p/kWh	5.5	7.6	9.5	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
Export price without flexibility premium	Low	p/kWh	3.8	3.2	3.7	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
	Central	p/kWh	4.3	4.7	5.6	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
	High	p/kWh	4.8	6.1	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Purchase price with flexibility discount	Low	p/kWh	7.4	6.9	6.9	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3
	Central	p/kWh	7.9	8.4	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7
	High	p/kWh	8.5	9.9	10.8	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
Purchase price without flexibility discount	Low	p/kWh	8.1	8.3	8.8	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3
	Central	p/kWh	8.7	9.8	10.6	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7
	High	p/kWh	9.2	11.3	12.7	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6

- N.B. The electricity prices above are derived from CCC projections based on interim IAG fossil fuel prices.
- We have removed the “carbon price”, “Discount on the carbon price” and “Support for Low Carbon” components of the original data for modelling purposes, as advised by CCC.

Other fuel price data

Fuel	Category	Case	Unit	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
Gas	Domestic	Low	p/kWh	4.0	4.3	4.4	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
		Central	p/kWh	4.0	4.7	5.0	5.2	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
		High	p/kWh	4.0	5.0	6.3	6.4	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8
	Commercial/Public	Low	p/kWh	2.6	2.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		Central	p/kWh	2.6	3.1	3.2	3.6	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
		High	p/kWh	2.6	3.9	4.3	4.7	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Industrial	Low	p/kWh	1.9	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
		Central	p/kWh	1.9	2.7	2.7	3.1	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
		High	p/kWh	1.9	3.4	3.8	4.2	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Biomass			p/kWh	3.1	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
EFW heat			p/kWh	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Waste heat from industry and power stations			p/kWh	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Source for gas prices: DECC, Supporting Tables for DECC HMT Supplementary Appraisal Guidance, Table 5 - Retail Gas Prices (real 2014 p/kWh) Link: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360323/20141001_Supporting_Tables_for_DECC-HMT_Supplementary_Appraisal_Guidance.xlsx
Source for biomass: Derived from E4Tech (2010): Biomass prices in the heat and electricity sectors in the UK
Source for industrial waste heat prices: Element Energy et al (2014): The potential for recovering and using surplus heat from industry
Source for EFW prices: Stakeholder consultation (assuming peak wholesale price of electricity foregone through capturing waste heat and Z-factor of 10)

Carbon value and carbon intensity data

Category	Scenario	Unit	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
Carbon value	Barriers	£/tCO_2e	46.4	55.1	65.4	77.7	113.7	149.8	185.8	221.9	260.0	295.2	319.1	333.9
	Central	£/tCO_2e	46.4	55.1	65.4	77.7	141.5	205.3	269.0	332.8	396.5	457.6	502.5	534.3
	High	£/tCO_2e	69.5	82.6	98.1	116.5	170.6	224.7	278.8	332.8	396.5	457.6	502.5	534.3

Category	Case	Unit	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
Carbon intensity of fuels	Electricity	gCO_2/kWh	392	245	172	100	78	55	33	10	10	10	10	10
	Gas	gCO_2/kWh	185	185	185	185	185	185	185	185	185	185	185	185
	Biomass	gCO_2/kWh	16	16	16	16	16	16	16	16	16	16	16	16
	EFW heat	gCO_2/kWh	0	0	0	0	0	0	0	0	0	0	0	0
	Waste heat	gCO_2/kWh	0	0	0	0	0	0	0	0	0	0	0	0

Carbon values based on DECC and CCC analysis

Contents

Capex data for DH equipment (1)

Technology	Source	Scenario	Capacity (MW_{th})	Capex, £2014/MW_{th} 2015	2030	2050
River source heat pump	Element Energy, Heat Pumps in District Heating, for DECC (2015); Industry consultation and literature review	Low	All sizes	750,000	600,000	525,000
		Central	All sizes	1,500,000	1,200,000	1,050,000
		High	All sizes	2,000,000	1,600,000	1,400,000
Sewage source heat pump		Low	All sizes	900,000	720,000	630,000
		Central	All sizes	1,800,000	1,440,000	1,260,000
		High	All sizes	2,400,000	1,920,000	1,680,000
Industrial waste heat source heat pump	Industry consultation	Low	All sizes	525,000	420,000	367,500
		Central	All sizes	1,050,000	840,000	735,000
		High	All sizes	1,400,000	1,120,000	980,000
Thermal power station heat source heat pump		Low	All sizes	525,000	420,000	367,500
		Central	All sizes	1,050,000	840,000	735,000
		High	All sizes	1,400,000	1,120,000	980,000
Gas CHP	Data based on Ricardo-AEA, Bespoke Gas CHP Policy - Cost curves and Analysis of Impacts on Deployment (2015); modified (smoothed) by Element Energy	All scenarios	less than 0.1	1,001,000	1,001,000	1,001,000
		All scenarios	0.1 to 12	844,000	844,000	844,000
		All scenarios	12 to 24	720,000	720,000	720,000
		All scenarios	24 to 36	656,000	656,000	656,000
		All scenarios	36 to 48	656,000	656,000	656,000
		All scenarios	48 to 72	630,889	630,889	630,889
		All scenarios	72 to 96	656,000	656,000	656,000
		All scenarios	more than 96	656,000	656,000	656,000
Gas boiler	NERA/AEA, The UK Supply Curve for Renewable Heat, Report for DECC (2009)	Low	All sizes	72,116	72,116	72,116
		Central	All sizes	72,116	72,116	72,116
		High	All sizes	72,116	72,116	72,116
Biomass boiler		Low	All sizes	351,705	316,535	316,535
		Central	All sizes	410,508	369,457	369,457
		High	All sizes	469,310	422,379	422,379

Capex data for DH equipment (2)

Thermal storage

				Capex, £2014/MWh		
Technology	**Source**	**Scenario**	**Capacity (MWh)**	**2015**	**2030**	**2050**
Thermal storage	AECOM, Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (2015); Tyndall Centre, The potential for thermal storage to reduce the overall carbon emissions from district heating systems (2013)	Low	All sizes	36,000	36,000	36,000
		Central	All sizes	41,000	41,000	41,000
		High	All sizes	46,000	46,000	46,000

District heating network: domestic building infrastructure

				Capex, £2014/MW_{th}		
Technology	**Source**	**Scenario**	**Unit of cost**	**2015**	**2030**	**2050**
Heat interface unit (HIU) and heat meter - Domestic	AECOM, Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (2015); Poyry/AECOM, The Potential and Costs of District Heating Networks (2009); Industry consultation	Low	£2014/dwelling	1,700	1,518	1,275
		Central	£2014/dwelling	2,000	1,786	1,500
		High	£2014/dwelling	2,300	2,300	2,300
Upgrade emitters for Low T network - Domestic	Poyry/AECOM, The Potential and Costs of District Heating Networks (2009) v4_0; Industry consultation.	Low	£2014/dwelling	0	0	0
		Central	£2014/dwelling	3,969	3,969	3,969
		High	£2014/dwelling	5,670	5,670	5,670

Capex data for DH equipment (3)

District heating network: non-domestic building infrastructure

					Capex, £2014/MW$_{th}$		
Technology	**Source**	**Scenario**	**Unit of cost**	**Item**	**2015**	**2030**	**2050**
Heat interface unit (HIU) and heat meter – non-domestic	Same as previous slide	Low	£	Minimum capex per connection	1,928	1,721	1,446
		Central	£	Minimum capex per connection	2,268	2,025	1,701
		High	£	Minimum capex per connection	2,608	2,608	2,608
		Low	£/MW$_{th}$	Capex per MWth	19,279	17,213	14,459
		Central	£/MW$_{th}$	Capex per MWth	22,681	20,251	17,010
		High	£/MW$_{th}$	Capex per MWth	26,083	26,083	26,083
Upgrade emitters for Low T network – non-domestic	Same as previous slide	Low	£	Minimum capex per connection	0	0	0
		Central	£	Minimum capex per connection	3,969	3,969	3,969
		High	£	Minimum capex per connection	5,670	5,670	5,670
		Low	£/MW$_{th}$	Capex per MWth	0	0	0
		Central	£/MW$_{th}$	Capex per MWth	39,691	39,691	39,691
		High	£/MW$_{th}$	Capex per MWth	56,702	56,702	56,702

Capex data for DH equipment (4)

Transmission, distribution and service pipe costs

		Capex, £2014/m length		
Scenario	Pipe radius (mm)	2015	2030	2050
Low	less than 25	559	523	475
Low	0 to 25	565	529	480
Low	25 to 32	605	566	514
Low	32 to 40	631	590	536
Low	40 to 50	703	658	598
Low	50 to 65	729	683	620
Low	65 to 80	795	744	676
Low	80 to 100	874	818	743
Low	100 to 125	943	883	802
Low	125 to 150	1,091	1,021	927
Low	150 to 200	1,252	1,172	1,064
Low	200 to 250	1,406	1,316	1,195
Low	250 to 300	1,715	1,605	1,458
Low	300 to 400	2,023	1,893	1,720
Low	more than 600	2,104	1,969	1,788

		Capex, £2014/m length		
Scenario	Pipe radius (mm)	2015	2030	2050
Central	less than 25	559	541	517
Central	0 to 25	565	547	523
Central	25 to 32	605	585	559
Central	32 to 40	631	611	584
Central	40 to 50	703	681	650
Central	50 to 65	729	706	675
Central	65 to 80	795	770	736
Central	80 to 100	874	846	808
Central	100 to 125	943	913	873
Central	125 to 150	1,091	1,056	1,009
Central	150 to 200	1,252	1,212	1,158
Central	200 to 250	1,406	1,361	1,301
Central	250 to 300	1,715	1,660	1,587
Central	300 to 400	2,023	1,958	1,871
Central	more than 600	2,104	2,036	1,946

		Capex, £2014/m length		
Scenario	Pipe radius (mm)	2015	2030	2050
High	less than 25	559	559	559
High	0 to 25	565	565	565
High	25 to 32	605	605	605
High	32 to 40	631	631	631
High	40 to 50	703	703	703
High	50 to 65	729	729	729
High	65 to 80	795	795	795
High	80 to 100	874	874	874
High	100 to 125	943	943	943
High	125 to 150	1,091	1,091	1,091
High	150 to 200	1,252	1,252	1,252
High	200 to 250	1,406	1,406	1,406
High	250 to 300	1,715	1,715	1,715
High	300 to 400	2,023	2,023	2,023
High	more than 600	2,104	2,104	2,104

Source for pipe costs: GLA, Decentralised Energy Capacity Study Phase 2 (2011); AECOM, Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (2015)

Opex data for DH equipment (1)

Technology	Source	Scenario	Capacity (MW_{th})	Opex, £2014/MW_{th} All years
River source heat pump	Element Energy, Heat Pumps in District Heating, for DECC (2015) [publication pending]; Industry consultation and literature review; Frontier/Element Energy, Pathways to high penetration of heat pumps (2013); Poyry/AECOM, The Potential and Costs of District Heating Networks (2009)	Low	All sizes	3,750
		Central	All sizes	7,500
		High	All sizes	10,000
Sewage source heat pump		Low	All sizes	4,500
		Central	All sizes	9,000
		High	All sizes	12,000
Industrial waste heat source heat pump		Low	All sizes	2,625
		Central	All sizes	5,250
		High	All sizes	7,000
Thermal power station heat source heat pump		Low	All sizes	2,625
		Central	All sizes	5,250
		High	All sizes	7,000
Gas CHP	Poyry/AECOM, The Potential and Costs of District Heating Networks (2009)	All scenarios	less than 0.1	90,090
		All scenarios	0.1 to 12	67,520
		All scenarios	12 to 24	50,400
		All scenarios	24 to 36	39,360
		All scenarios	36 to 48	32,800
		All scenarios	48 to 72	25,236
		All scenarios	72 to 96	26,240
		All scenarios	more than 96	26,240
Gas boiler		Low	All sizes	3,606
		Central	All sizes	3,606
		High	All sizes	3,606
Biomass boiler	NERA/AEA, The UK Supply Curve for Renewable Heat, Report for DECC (2009)	Low	All sizes	17,585
		Central	All sizes	20,525
		High	All sizes	23,466

Opex data for DH equipment (2)

Thermal storage

				Opex, £2014/MWh
Technology	**Souce**	**Scenario**	**Capacity (MWh)**	**All years**
Thermal storage	Element Energy assumptions based on AECOM (2015)	Low	All sizes	0
		Central	All sizes	0
		High	All sizes	0

District heating network: domestic building infrastructure

				Opex, £2014/MW_{th}
Technology	**Source**	**Scenario**	**Unit of cost**	**All years**
Heat interface unit (HIU) and heat meter - Domestic	AECOM, Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (2015); Poyry/AECOM, The Potential and Costs of District Heating Networks (2009)	Low	£2014/dwelling	51
		Central	£2014/dwelling	60
		High	£2014/dwelling	69
Upgrade emitters for Low T network - Domestic		Low	£2014/dwelling	0
		Central	£2014/dwelling	0
		High	£2014/dwelling	0

Opex data for DH equipment (3)

District heating network: non-domestic building infrastructure

Technology	Source	Scenario	Unit of cost	Item	Opex, £2014/MW$_{th}$ All years
Heat interface unit (HIU) and heat meter – non-domestic	Same as previous slide	Low	£	Minimum opex per connection	58
		Central	£	Minimum opex per connection	68
		High	£	Minimum opex per connection	78
		Low	£/MW$_{th}$	Opex per MWth	578
		Central	£/MW$_{th}$	Opex per MWth	680
		High	£/MW$_{th}$	Opex per MWth	782
Upgrade emitters for Low T network – non-domestic	Same as previous slide	Low	£	Minimum opex per connection	0
		Central	£	Minimum opex per connection	0
		High	£	Minimum opex per connection	0
		Low	£/MW$_{th}$	Opex per MWth	0
		Central	£/MW$_{th}$	Opex per MWth	0
		High	£/MW$_{th}$	Opex per MWth	0

Opex data for DH equipment (4)

Transmission, distribution and service pipe operating costs

		Opex, £2014/m length
Scenario	Pipe radius (mm)	All years
Low	less than 25	2
Low	0 to 25	2
Low	25 to 32	2
Low	32 to 40	3
Low	40 to 50	3
Low	50 to 65	3
Low	65 to 80	3
Low	80 to 100	3
Low	100 to 125	4
Low	125 to 150	4
Low	150 to 200	5
Low	200 to 250	6
Low	250 to 300	7
Low	300 to 400	8
Low	more than 600	8

		Opex, £2014/m length
Scenario	Pipe radius (mm)	All years
Central	less than 25	2
Central	0 to 25	2
Central	25 to 32	2
Central	32 to 40	3
Central	40 to 50	3
Central	50 to 65	3
Central	65 to 80	3
Central	80 to 100	3
Central	100 to 125	4
Central	125 to 150	4
Central	150 to 200	5
Central	200 to 250	6
Central	250 to 300	7
Central	300 to 400	8
Central	more than 600	8

		Opex, £2014/m length
Scenario	Pipe radius (mm)	All years
High	less than 25	2
High	0 to 25	2
High	25 to 32	2
High	32 to 40	3
High	40 to 50	3
High	50 to 65	3
High	65 to 80	3
High	80 to 100	3
High	100 to 125	4
High	125 to 150	4
High	150 to 200	5
High	200 to 250	6
High	250 to 300	7
High	300 to 400	8
High	more than 600	8

Source for network operating costs: GLA, Decentralised Energy Capacity Study Phase 2 (2011); AECOM, Assessment of the Costs, Performance, and Characteristics of UK Heat Networks (2015)

Contents

Sources used in the development of the Critical path scenario

Case	Time period	Source
Germany	1960-1995	Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion, JRC (2012)
Copenhagen	1970-2005	Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion, JRC (2012)
Gothenberg	1953-2009	Göteborg Energi's district energy system, Göteborg Energi (2009)
Chinese cities	1990-2008	Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion, JRC (2012)
Frankfurt	1991-2006	Background Report on EU-27 District Heating and Cooling Potentials, Barriers, Best Practice and Measures of Promotion, JRC (2012)
Austria	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Belgium	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Finland	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Italy	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Netherlands	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Portugal	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Norway	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Denmark	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
Sweden	1992-2003	Work package 4: Possibilities with more district heating in Europe, EcoHeatCool (2006)
China	2000-2005	CHP and DHC in China: An Assessment of Market and Policy Potential, IEA International CHP/DHC Collaborative

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