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UKERC Energy Strategy Under Uncertainties

Uncertainties in UK heat infrastructure development

Working Paper

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Executive Summary

Meeting the 80% carbon emission reduction target by 2050 is likely to require heat related emissions of CO_2 from buildings are near zero by 2050 and there is a 70% reduction in emissions from industry (from 1990 levels). This will require laying the foundations for these emission reductions by 2030.

A review of the barriers and uncertainties associated with the transition to a low-carbon heat supply in the UK out to 2030 were explored. This work was commissioned as part of the UK Energy Research Centre's 'Energy strategy under Uncertainty' project undertaken to synthesise evidence on the range and nature of the risks and uncertainties facing UK energy policy and the achievement of its goals to reduce carbon emissions, enhance energy security while ensuring affordability.

Current status

Domestic and the non-domestic buildings (service sector) accounts for 62% and 21% of the total heat demand in the UK. These demands are at present predominantly met by burning natural gas in boiler units (80% of domestic buildings and 67% of non-domestic buildings/service sector demand).

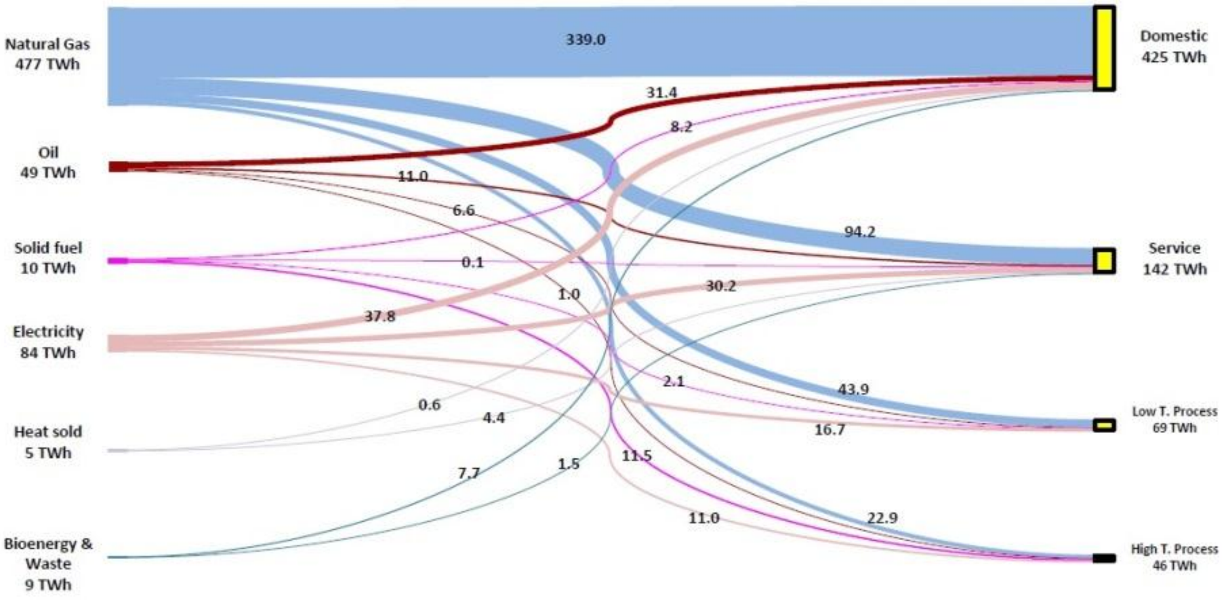

Figure 1: UK's annual heat demand by different sectors and different fuels (2012) (DECC, 2012a)

In terms of carbon emissions, domestic buildings in 2009 accounted for around 47% of the total heat related emissions and non-domestic buildings to a further 20%. Heat related emissions from industry accounts for approximately 30% of the total heat related emissions in the UK. The 4th carbon budget review estimates that by 2030, emissions from domestic buildings will be reduced by approximately 30% and in non-domestic buildings (service) a reduction of over 90% will be delivered.

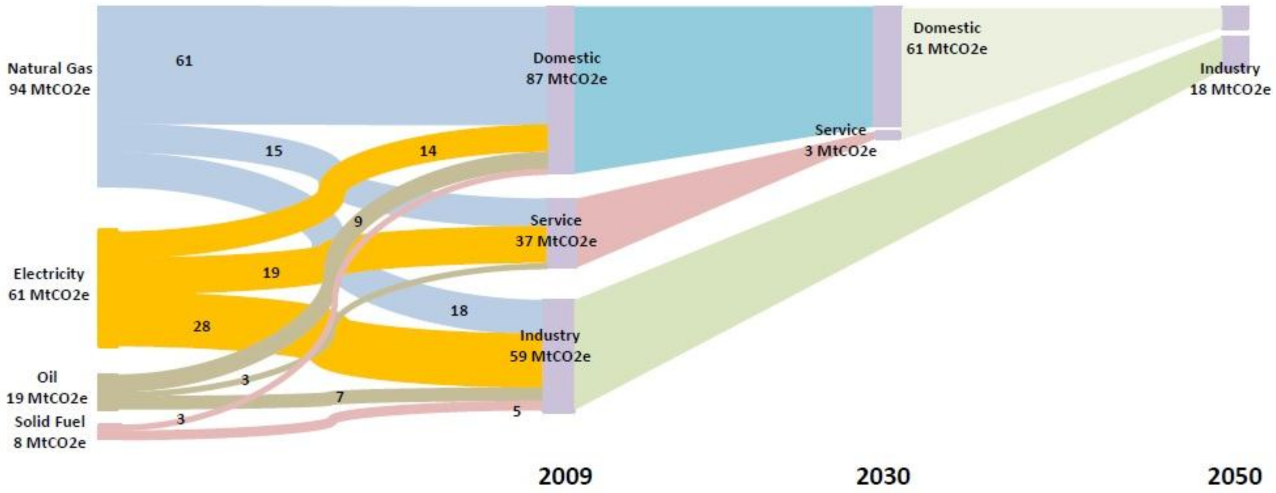

Figure 2: Reduction of heat related emissions in each sector estimated by CCC projections

How to decarbonise heat

Reducing carbon emissions from the UK's heat sector requires a three way approach. Figure 3 shows the three essential elements in achieving an effective reduction of carbon emissions in heat supply.

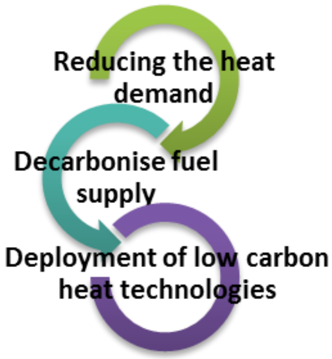

Figure 3: Three way approach to decarbonising heat in the UK

The relative carbon abatement potential of a particular technology is dependent upon the carbon emission intensity of the fuel used and the thermal efficiency of the heat supply appliance. The amount of emissions savings will further increase if the supplied heat demand is reduced. There are many potential low-carbon heating appliance/ network options available; however the technologies and markets are in most cases immature today. Additionally the UK's building stock presents a unique set of challenges to the uptake of low-carbon heat technology. Together these combine to offer a range of technology options to the consumer who will ultimately make the decision to invest on a new heat supply system.

4th carbon budget review estimates

The Committee on Climate Change (CCC) updated the 4th Carbon Budget recommendations in late 2013 which presented new estimates for heat sector decarbonisation. The initial estimates on technology uptake were revised due to new evidence. Table 1 shows a comparison between the original estimates on the cost effective path to 2050 published as the central scenario and the revised estimates due to the latest evidence.

Table 1: Comparison of original and updated 4th carbon budget recommendations

Item	Original target	Updated target
Heat pumps by 2030	160 TWh	82 TWh
District heat by 2030	10 TWh	30 TWh
Biomass by 2030	13 TWh	–
2030 penetration of renewable heat	28% of total heat demand	–
2030 residential buildings abatement potential	–	27 $MtCO_2e$
2030 residential buildings emissions	–	61 $MtCO_2e$

Key uncertainties and mitigation measures

There is a great deal of uncertainty regarding the achievement of low-carbon heat technology deployment levels and ultimately the abatement of CO_2 emissions by 2030. The 4th carbon budget review ascribes prominent roles to demand reduction, efficiency improvements and to the deployment of heat pumps in efforts to reduce CO_2 emissions by 2030 (see Table 1). If the electricity sector does not decarbonise as planned and if heat pump uptake is lower than expected or efficiencies do not improve, CO_2 emissions reduction will not meet expectations. In the longer term, out to 2050, the heat system decarbonisation agenda very much rests on the shoulders of decarbonising the electricity grid to meet the 2050 CO_2 emissions target.

The analysis showed that the performance of key technologies such as heat pumps to be of paramount importance (see Figure 4). There is a great emphasis on improving the performance of heat pumps through the period to 2020 and beyond. This can only be achieved if the uptake of low-carbon heat technologies is relatively steady now and increases so technological learning can take place.

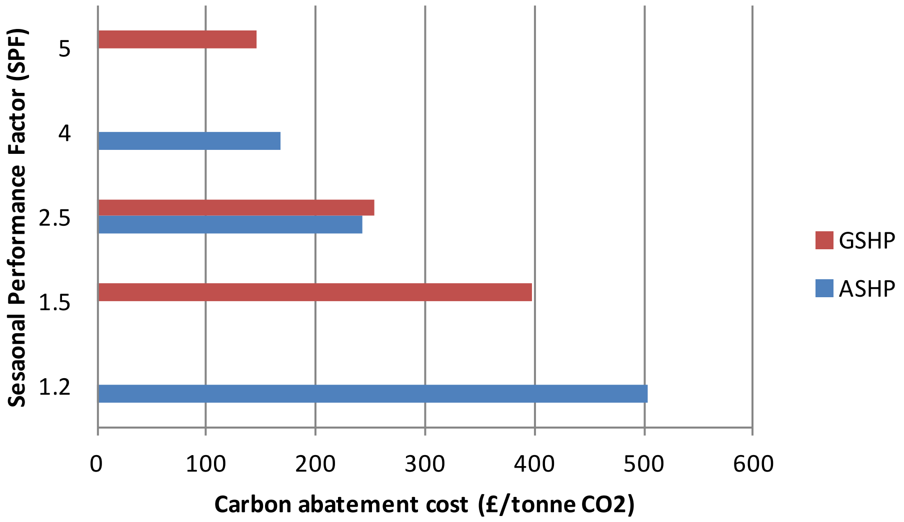

Figure 4: Carbon abatement cost of heat technologies with respect to SPF*

*** (Electricity grid emission intensity: 50 g CO2/kWh)**

Most low-carbon heat technologies have high upfront capital costs that make a large contribution to levelised energy costs, in comparison with incumbent technologies, such as gas boilers. This is a major barrier for deployment and can be resolved by technological learning (cost and efficiencies) and experience gained by installers to appropriately design heat-based systems.

The 4th carbon budget review provided a boost to heat network deployment estimates increasing from 10 to 30 TWh by 2030. This is a significant increase that like most of the low-carbon heat technology options comes with a number of challenges. Firstly, there are significant economic barriers, mainly focussed around high upfront capital costs and secondly public perception issues. Measures can be put in place to manage uncertainties related to public perception for these technologies. For instance heat technology performance could be highlighted and awareness could be increased by government and industry via exemplars.

Extending the Renewable Heat Incentive (RHI) subsidy beyond 2020 (albeit at lower tariff levels to accommodate an anticipated larger installed base of heat technology capacity and to keep the overall budget to around £500 million per annum) might be required to maintain sustained growth in the heat pump market if consumers are to make savings by adopting heat pump systems.

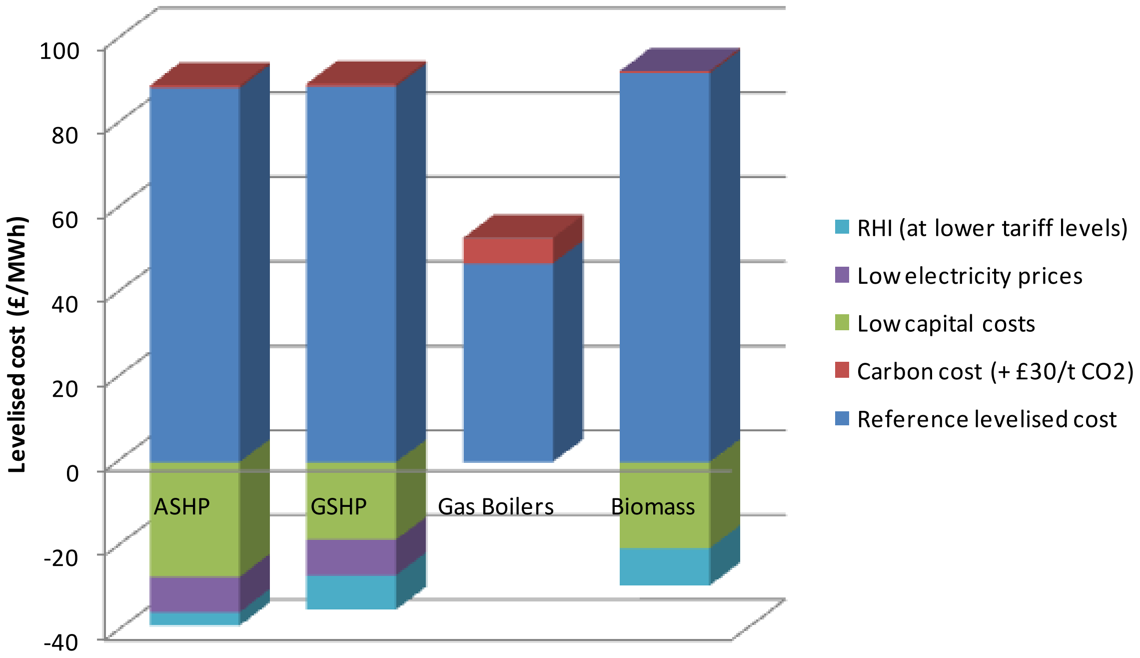

Figure 5: Impact of policies and costs on levelised energy cost of heat technologies

The modelling showed that if the RHI (at lower levels of tariff support) is maintained beyond the 2020s, heat pumps become more competitive with incumbent gas boilers but only if capital costs are reduced to the lower end of the uncertainty range and carbon costs are increased (by + £30 t/CO_2) from the expected value in 2030 (see Figure 5); under these favourable conditions carbon abatement costs drop to around £150-175/tonne of CO_2 across all low-carbon heat technologies. With technology learning especially with heat pump technologies (SPF improvements) the carbon abatement costs will drop further to below £100/tonne CO_2.

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1 Introduction

All of the anticipated pathways to a low-carbon heat system will overtime mean significant changes for the UK's energy infrastructure. The relative roles played by gas, electricity and heat networks in the supply of the UK's heat demand will vary with policy interventions, technology costs, availability of investment and socio-economic uncertainties.

Heat constitutes the single biggest use of energy in the UK. Almost half (46%) of the final energy consumed is used to provide heat, while other uses are split between energy for transport (41%), to generate electricity for lighting and appliances (8%) and a variety of other uses including agriculture and waste (5%). Of this heat, around three quarters is used by households and in commercial and public buildings; the rest is used in industrial processes. Household heating demand is primarily met today using gas-fired boilers connected to the natural gas network (81%). The remaining domestic buildings heat demand is from electricity (7%), heating oil (9%) and from solid fuels, such as wood and coal (3%). These alternative fuels are mainly used in areas not supplied by mains gas network (DECC, 2012c).

The UK's very low penetration of renewable technologies for heating is a direct consequence of ample supplies of low cost natural gas. As a consequence of a relatively high annual heating demand, low requirement for cooling and access to North Sea gas the UK has over the years invested on building an extensive natural gas network. However, with the decline of North Sea gas supplies the UK is exposed to price volatility of natural gas in the global market.

Meeting the 80% carbon emission reduction target is likely to require that heat related emissions of CO_2 from buildings are near zero by 2050 and there is a 70% reduction in emissions from industry (from 1990 levels). Though it is clear that the use of the gas network will reduce over time, recent modelling suggests a role for gas in 2050 to help meet peaks in heat demand. Parts of the gas network are expected to be decarbonised using substitute renewable gas (bio-methane, hydrogen, synthetic natural gas) or used to transport carbon dioxide from carbon capture and storage (CCS). However, there is a significant amount of uncertainty in the strategic role envisioned for the future of the gas network (Hughes *et al.* 2010, 2013).

The government is progressing policy incentives that will reduce the heat demand of the existing building stock while promoting the uptake of renewable heating technologies. The Green Deal is expected to remove the barrier of initial costs of energy efficiency improvements, while the Renewable Heat Incentive (RHI) attempts to support market rollout of renewable heat technologies. However, the success of these policy initiatives is uncertain and the impact on technology deployment is yet to be identified.

Heating is one of the most difficult sectors to decarbonise in the UK’s energy system. There is significant amount of uncertainty in what the UK heat supply might look like in the period from now to 2030 and beyond. High levels of uncertainty present a great challenge to policy makers to make sound strategic decisions about the future. It is essential to identify and manage these uncertainties in order to support plausible pathways to a low-carbon energy system.

2 Objectives and methodology

The aim of this work is to explore the risks and uncertainties associated with the transition to a low-carbon heat system in the UK out to 2030 and investigate the potential impact of these uncertainties in the development of energy supply infrastructure (gas, electricity and district heating).

Specific research questions are:

- What are the key heat decarbonisation uncertainties?
- What are the different ways through which the UK might decarbonise the heat sector?
- How will these affect the development of the energy network infrastructure (gas, electricity and district heat networks)?
- What policies/incentives are required to decarbonise the heat sector?

2.1 Uncertainties framework

There are many techniques that can be used to measure uncertainty across various levels of the energy system (operational, strategic and policy). These techniques have been defined and categorised using a novel approach by Prpich *et al.* (UKERC*,* 2014) in their work on *'Conceptual approaches and frameworks for addressing uncertainty in the energy system'*. The approach classifies techniques for measuring uncertainty according to their relevance to decisions being made about risk at the operational, strategic/tactical and policy level of the energy system.

The paper describes two components that together allow you to select the appropriate technique to assess uncertainties. These components are the 'decision stakes' and 'system uncertainties'. The decision stakes refer to uncertainty associated with multiple stakeholder perspectives (location of uncertainty) from low (data precision) to high (human variability). On the other hand, system uncertainties refer to the inexactness, uncertainty and ignorance encountered (level of knowledge) in scientific and technical studies across different levels of energy system.

The research questions addressed in this project concern operational, strategic and policy uncertainties. These uncertainties are spread across a number of locations (e.g. household heat demand, future heat technologies etc.) and where there is some degree of knowledge available on operational/tactical system uncertainties (e.g. possible future technology characteristics) although probabilistic uncertainties (policies/consumer behaviour etc.) are also present. Given these set of characteristics a pathway/sensitivity analysis approach is used to address these uncertainties in a systematic way.

2.2 Approach to analysis

In order to address the specific research questions, the following objectives will be addressed:

1. Review and summarise the existing literature on the various ways in which the UK can decarbonise the heat sector.
2. Identify key economic (cost), technical and policy related uncertainties associated with decarbonising the heat sector.
3. Use the Committee on Climate Change (CCC) 4th carbon budget as a reference to explore impact of key uncertainties in decarbonising the heat sector.
4. Assess the impact of technical uncertainties on energy network infrastructure (gas, electricity and district heat networks).
5. Analyse the impact of policy changes on the development of heat infrastructure.

Figure 2.1 illustrates the methodology that will be used.

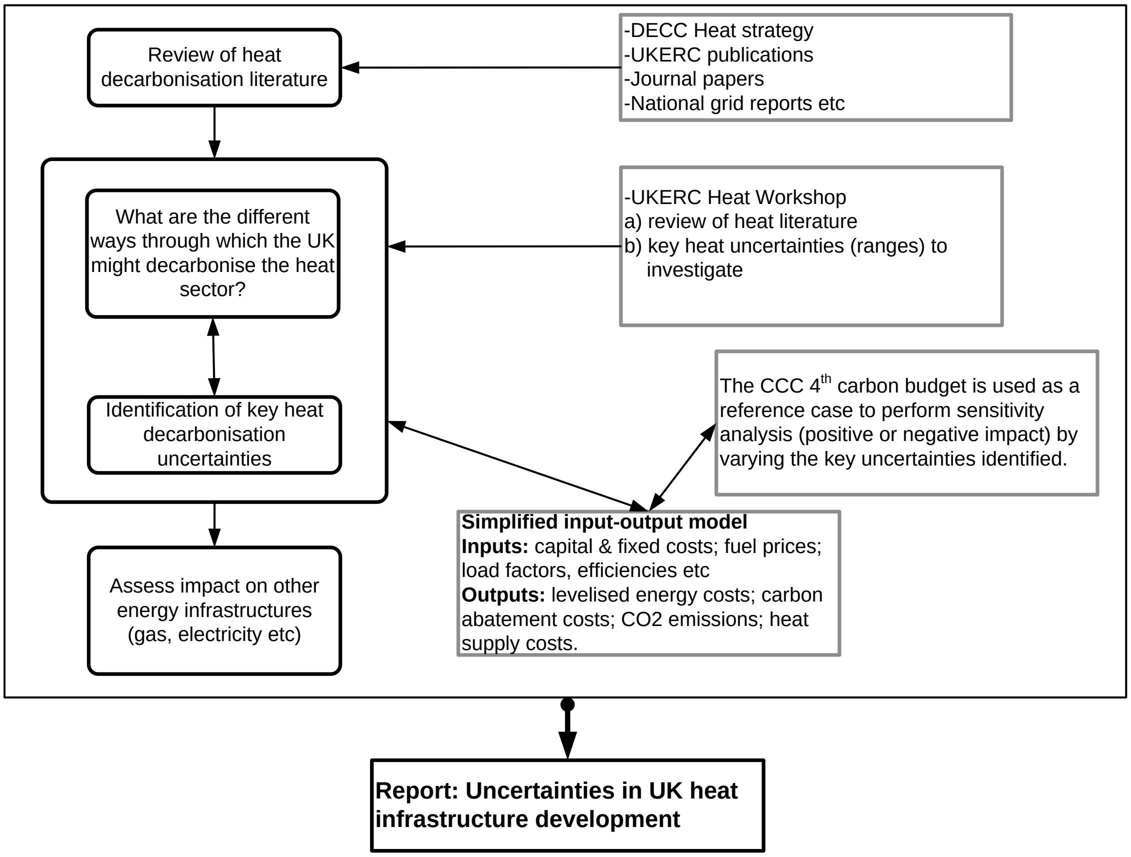

Figure 2.1: Methodology for analysing uncertainties in decarbonising the heat sector

The data collection will include a wide ranging overview of heat decarbonisation pathways, technology and policy literature. The synthesis of current UKERC projects will explore the impact of heat decarbonisation on the electricity sector and the role of the gas network.

The methodology is summarised as follows:

1. A literature review will summarise the various ways in which the UK can decarbonise the heat sector. The DECC Heat Strategy, UKERC publications and other relevant literature will be used (Sorrell, 2007; UKERC, 2012). The literature review will draw together research outputs from other UKERC themes, such as TPA (Technology and Policy Assessment), Energy Demand and Energy Systems themes.
2. The literature review, aided by a workshop, will help identify key heat decarbonisation uncertainties.
3. The CCC 4th carbon budget will be assessed using a simplified input-output model. The model will calculate levelised energy costs and the cost of carbon abatement given inputs, such as capital cost and fuel prices. The model will be used to perform sensitivity analysis on the 4th carbon budget by varying the values of the key uncertainties. The levelised costs are calculated by using the following formula:

   Levelised energy cost (£/MWh)[1] = (Annualised capital costs + Fixed cost O&M + Fuel costs + Carbon costs) / Total energy output

4. An assessment will be undertaken to identify the impact of technical uncertainties on the development of energy network infrastructure (gas, electricity and district heating).
5. The evidence will be used to inform on policy implications; what needs to be done to minimise uncertainties (maximise opportunities) to decarbonise the heat sector.

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[1] Discount factor for capital costs was assumed to be 10% and load factors were used as part of the calculation of levelised energy costs.

3 The current heat demand and emissions

The current status of heat demand in the UK, the amount of consumption of various fuels for heating different sectors in the country and the levels of heat related emissions is presented in this section.

3.1 The current heat demand

The UK heat demand can be segmented as follows (National Grid, 2012):

- Sectors – Domestic/non-domestic buildings and Industry
- Service demand type – hot water, space heating, cooking and high and low temperature process heat for industry
- Location – urban, sub-urban and, rural and on/off gas grid
- Building types/age – such as large pre-war detached house and new build flat

The type of heat demand will have implications on technology choice and associated costs. Domestic buildings heat demand accounts for 62% of the total annual heat demand in the UK in 2012. Non-domestic buildings (service sector)[2] accounts for another 21%. The low temperature and high temperature industry processes accounts for 10% and 7% of the total heat demand (Figure 3.1).

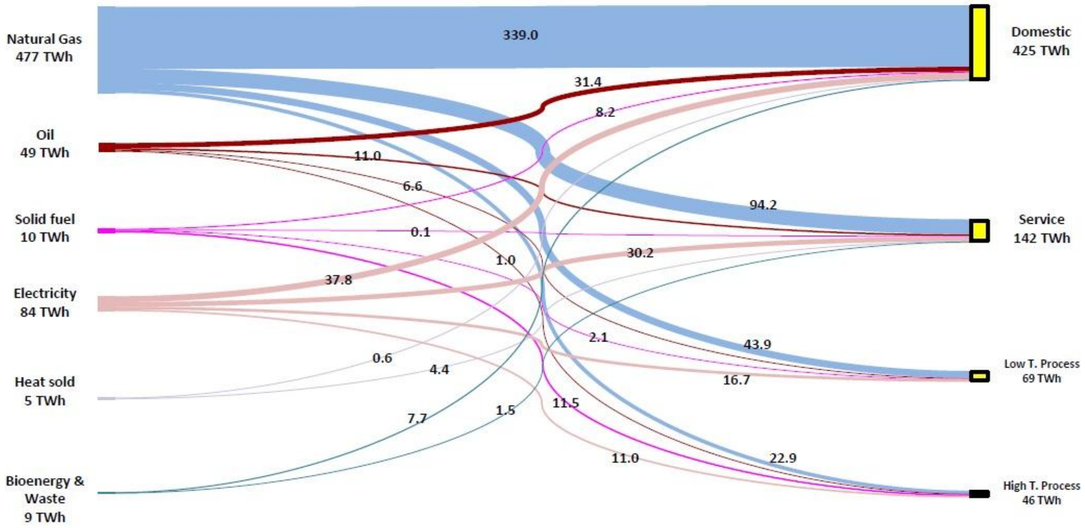

Figure 3.1: UK's annual heat demand by different sectors and fuels (2012) (DECC, 2012a)

Both domestic and non-domestic buildings heat demand are at present predominantly met by natural gas fired boilers as shown in Figure 3.1 (80% of domestic buildings demand and 67% of the non-domestic buildings/service sector demand). Electricity is

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[2] Non-domestic sector refers to public buildings, schools, recreational and sports facilities, business complexes and all other buildings with heat demands excluding domestic buildings.

the second most used energy vector supplying 9% of domestic buildings and 21% of non-domestic buildings heat demand. Fuel oil is the next most prevalent with 7% of domestic buildings and 8% of non-domestic buildings demand being supplied. It is important to note that heat supplied via heat networks accounts for a mere 0.5% and 3% in domestic and non-domestic buildings heat demand supply.

Domestic and non-domestic buildings heat demands are an aggregate of service demand types; hot water, space heating and cooking heat demand. The supply temperatures required in domestic and non-domestic buildings service demand types are mostly similar even if the capacities can vary.

However in industry, the service demand types are unique for each application. Temperature, quality and stability required in heat supply will be determined by each industrial process. Broadly these are classified as low temperature and high temperature process heat applications. Natural gas is again the predominant fuel being used in industry supplying 49% of high temperature process heat applications and 63% of low temperature process heat applications (see figure 3.1). Solid fuel (Mainly coal) is used extensively in high temperature applications (25%). The steel industry is a leading consumer of coal for its high temperature iron-making processes. Electricity supply accounts for 24% of both the low temperature and high temperature industrial heat demands. Fuel oil is used in 10% of the low temperature process heat applications (DECC, 2012a).

The seasonal variability is a key factor to be taken into account when analysing the heat demand. This is largely a concern in domestic and non-domestic (service sector) buildings where the winter heat demand is much higher than that in summer. Figure 3.2 shows the seasonal variation of domestic buildings heat demand compared to the electrical demand during a typical year.

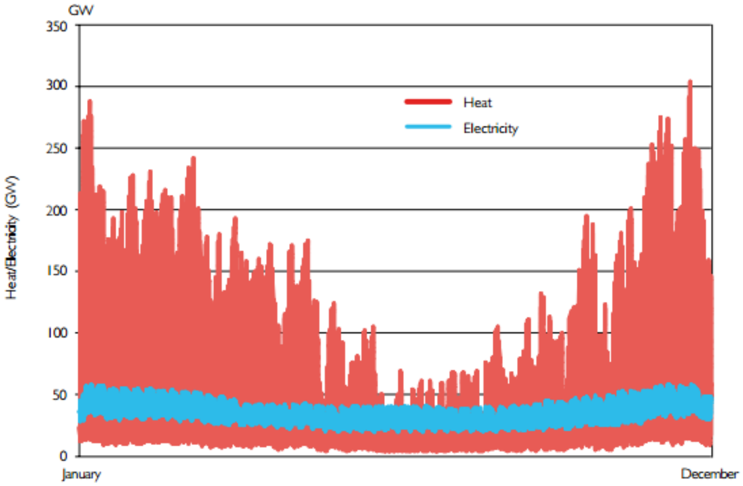


Figure 3.2: Seasonal variation of the heat demand compared to the electrical demand (DECC, 2012d)

The seasonal variability is important as a decision to electrify heating will have consequences on peak generation and network reinforcement requirements. The impact will be even more significant when considering meeting peak heat demand during extremely cold winters and with the potential drop in heat pump SPF (Seasonal Performance Factor) during these conditions.

3.2 Heat related emissions

Heat related emissions account for around 32% of the total greenhouse gas emissions in the UK (182 MtCO2e). Emissions, based on the place they are produced, can be divided into direct and indirect emissions. Direct emissions are produced by the fuels that are burned at the location of consumption and hence produce emissions. These include gas, oil and solid fuel. Indirect emissions are mainly due to electricity which doesn't have any emissions at the location of consumption. Figure 3.3 shows emissions by fuel types and sector (DECC, 2012b) in relation-to updated projections made by the CCC (CCC, 2013).

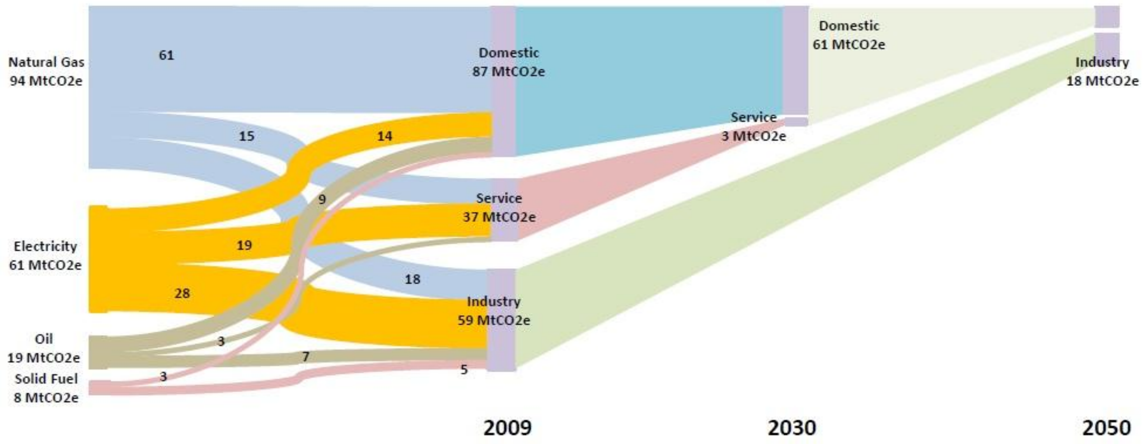


Figure 3.3: Reduction of heat related emissions in each sector estimated by CCC projections

As observed, indirect emission from electricity is about 33% of total GHG emissions. Among direct emissions natural gas contributes the most at about 52% of total GHG emissions. It should be noted that the industrial sector has the most amount of indirect emissions. Emissions from domestic buildings due to natural gas are high and there exists a high potential for reduction of GHG emissions in this sector. Domestic buildings in 2009 accounted for around 47% of the total heat related emissions and non-domestic buildings to a further 20%. Heat related emissions from industry accounts for approximately 30% of total heat related emissions in the UK. The 4th carbon budget review estimates by 2030, approximately a 30% reduction in emissions from domestic buildings and over 90% reduction in non-domestic buildings could be delivered.

4 Low-carbon heat supply technology overview

The scale of the challenge to decarbonise heat, requires a major change in the heating appliance mix. Around 80% of the carbon emissions related to heating are from burning natural gas in buildings. The growth in biomethane production and reducing thermal demand will not in itself be able to meet the emissions reduction targets (Delta-ee, 2012).

4.1 How to decarbonise heat

Reducing carbon emissions from the UK's heat sector requires a three way approach. Figure 4.1 shows the three essential elements in achieving an effective reduction of carbon emissions in heat supply.

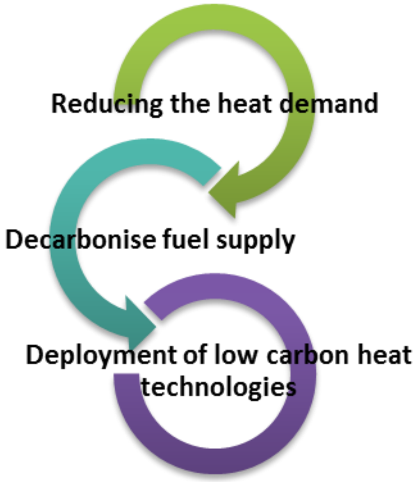


Figure 4.1: Three point approach to decarbonising heat in the UK

For example switching from the use of gas fired boilers to heat pumps will not guarantee a saving in carbon emissions. The average carbon emission intensity of grid electricity in 2013 was reported approximately ~0.44 $kgCO_2/kWh$ (Carbon Trust, 2013). The emissions intensity of natural gas is ~0.184 $kgCO_2/kWh$. At these emission intensity levels, for the technology switchover to generate any carbon savings the heat pump efficiency should be more than 2.4 times that of gas boiler efficiency. For an effective reduction of emissions the carbon emissions intensity of the electricity grid should reduce significantly and the HP system efficiency should increase.

The relative carbon abatement potential of a particular technology is therefore dependent upon the carbon emission intensity of the fuel used and the thermal efficiency of the heat supply appliance. The amount of emissions savings will further increase if the supplied heat demand is reduced.

There are many potential low-carbon heating appliance/network options available; however the technologies and markets are in most cases immature today. Additionally the UK's building stock present unique challenges to the uptake of low-carbon heat technology. Together these combine to offer a range of technology options to the consumer who will ultimately make the decision to invest in a new heat supply system. Figure 4.2 shows a schematic of the considerations in technology uptake that drives the decision making process.

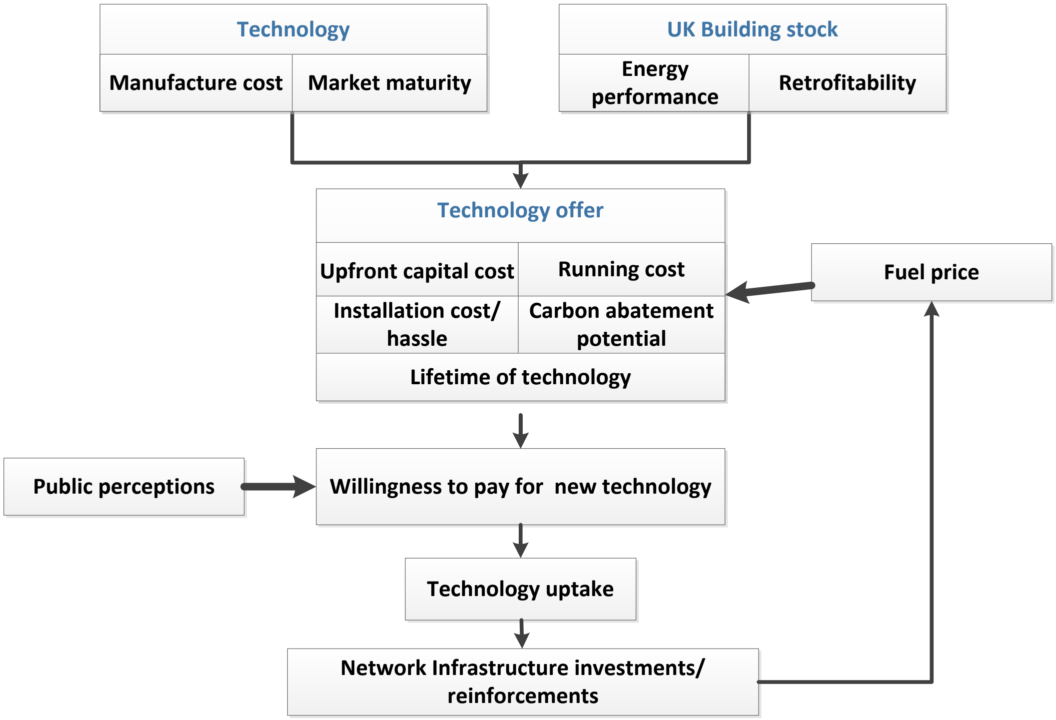


Figure 4.2: Schematic of the decision making process to technology uptake

The technology offer to the consumer will be made with:

- Upfront capital cost
- Running cost (related to the fuel price)
- Installation cost and the hassle of installation
- Lifetime of technology
- Carbon abatement potential

In most cases, new heating systems are 'distress purchases'. Therefore customers will usually be inclined towards the most cost effective, easy to understand and hassle-free installation available in the market. The trusted expert, the installer will have a crucial role as most customers generally rely on their recommendations. The rate of technology uptake will have repercussions on the fuel/energy supply infrastructure as it must meet the increasing demand.

The current status of low-carbon heat supply technologies are discussed in the following section.

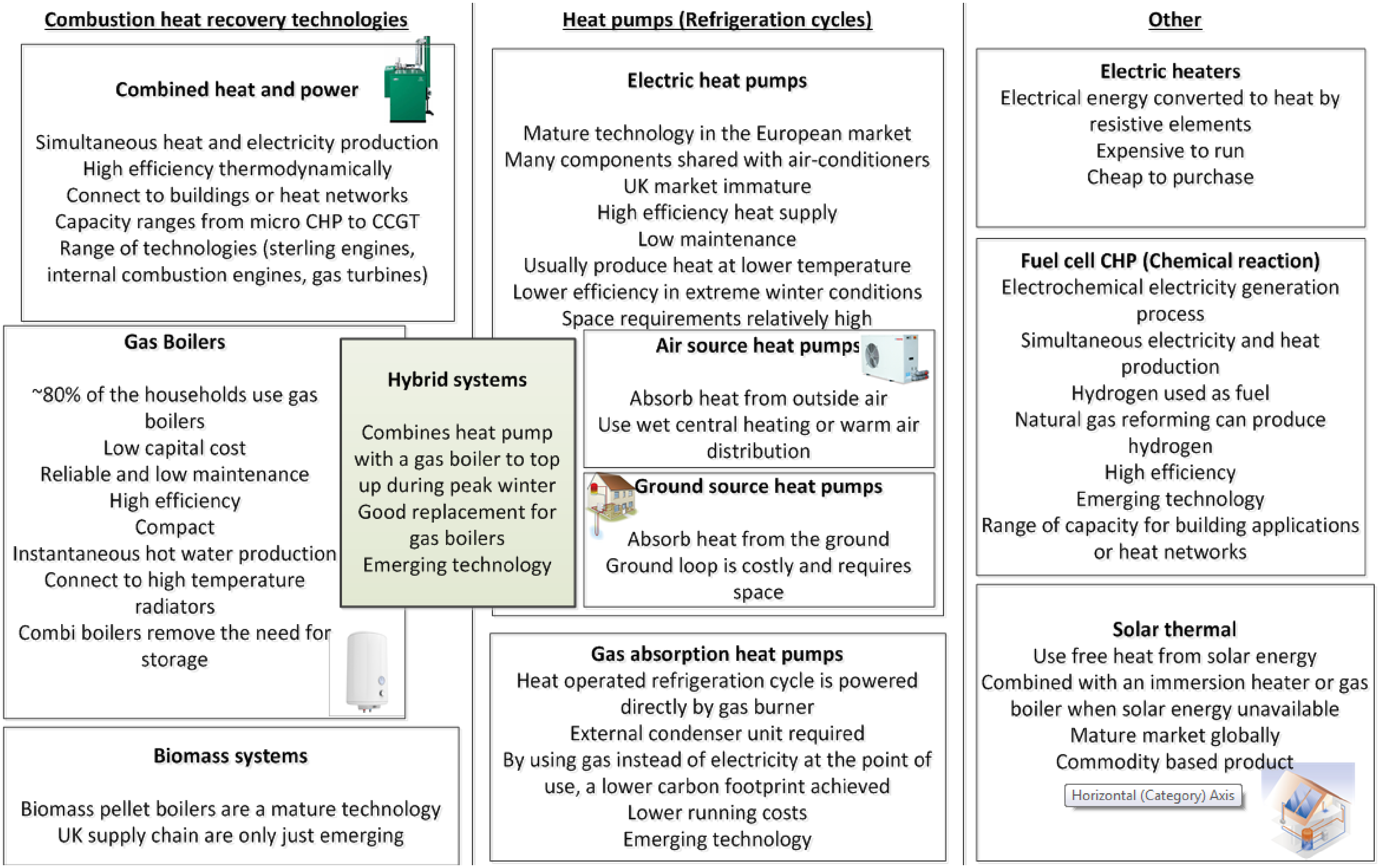
4.2 Heat supply technologies

Heat technologies can be categorized as those,

- Using combustion heat recovery (e.g. Gas boiler)
- Using thermodynamic cycles (e.g. Heat pumps)
- Other – Electric resistive heating (e.g. Storage heater), chemical reactions (Fuel cells), solar heating

Figure 4.3 shows the available heat supply technology options. Technologies used for obtaining high temperatures in industry (e.g. Blast furnace) are not considered in this study.

Heat networks, often referred to as district heating schemes are a network of pipes carrying hot water from a central heat source to homes and businesses. The fundamental idea of district heating is to use local fuel or heat resources that would otherwise be wasted, in order to satisfy local customer demands for heating. Figure 4.4 shows the most commonly used heat sources in heat networks. Though theoretically most heat supply technologies can feed heat networks the choice is restricted by economics.



Combustion heat recovery technologies

Combined heat and power

Simultaneous heat and electricity production
High efficiency thermodynamically
Connect to buildings or heat networks
Capacity ranges from micro CHP to CCGT
Range of technologies (sterling engines, internal combustion engines, gas turbines)

Gas Boilers

~80% of the households use gas boilers
Low capital cost
Reliable and low maintenance
High efficiency
Compact
Instantaneous hot water production
Connect to high temperature radiators
Combi boilers remove the need for storage

Hybrid systems

Combines heat pump with a gas boiler to top up during peak winter
Good replacement for gas boilers
Emerging technology

Biomass systems

Biomass pellet boilers are a mature technology
UK supply chain are only just emerging

Heat pumps (Refrigeration cycles)

Electric heat pumps

Mature technology in the European market
Many components shared with air-conditioners
UK market immature
High efficiency heat supply
Low maintenance
Usually produce heat at lower temperature
Lower efficiency in extreme winter conditions
Space requirements relatively high

Air source heat pumps

Absorb heat from outside air
Use wet central heating or warm air distribution

Ground source heat pumps

Absorb heat from the ground
Ground loop is costly and requires space

Gas absorption heat pumps

Heat operated refrigeration cycle is powered directly by gas burner
External condenser unit required
By using gas instead of electricity at the point of use, a lower carbon footprint achieved
Lower running costs
Emerging technology

Other

Electric heaters

Electrical energy converted to heat by resistive elements
Expensive to run
Cheap to purchase

Fuel cell CHP (Chemical reaction)

Electrochemical electricity generation process
Simultaneous electricity and heat production
Hydrogen used as fuel
Natural gas reforming can produce hydrogen
High efficiency
Emerging technology
Range of capacity for building applications or heat networks

Solar thermal

Use free heat from solar energy
Combined with an immersion heater or gas boiler when solar energy unavailable
Mature market globally
Commodity based product

Figure 4.3: Heat supply technologies

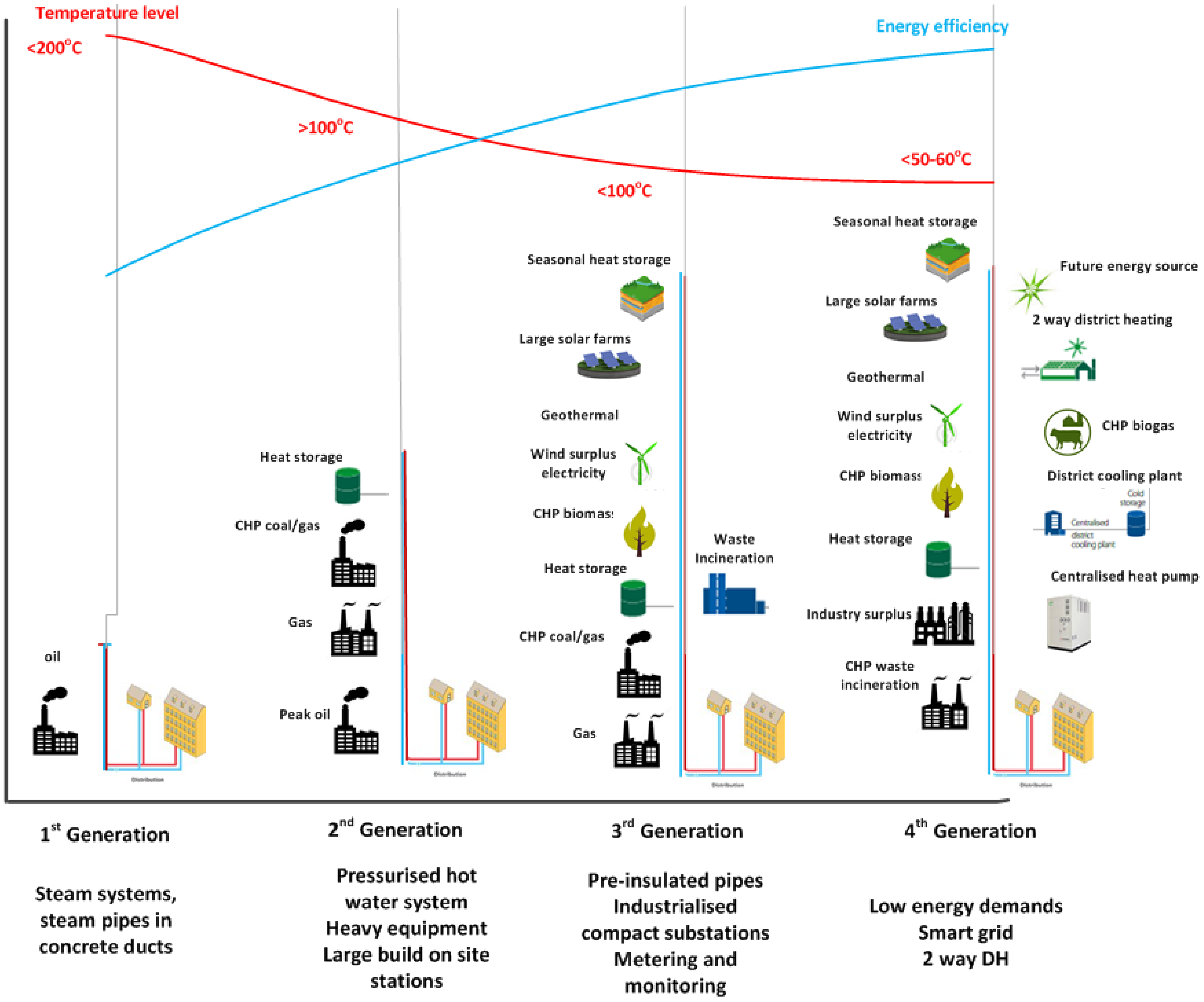


Figure 4.4: Evolution of district heat networks

Although many technologies can be considered 'mature' globally, the UK market in low-carbon heat technologies is only just emerging. This is directly connected to the dominance of the gas boiler market driven by the availability of cheap natural gas. A key barrier to overcome with regards to deployment of low-carbon heat technologies will be in developing supply chains and making customers aware of these emerging technologies. Table 4.1 presents the relative state of maturity of technologies in global and UK markets (Allen, 2008, Delta-ee, 2012).

Table 4.1: Status of maturity of technologies (Levels – 5 being the most mature and 1 being the least)

Technology	Global market maturity	UK market maturity
Air source heat pump	4	2
Ground source heat pump	4	2
Hybrid heat pump	2	1
Gas absorption heat pump	2	1
Biomass boiler	4	2
Micro CHP	2	2
CHP	4	3
District heating infrastructure	4	2
Fuel cell CHP	2	2
Solar thermal	5	4

Carbon performance of different heating appliances

The carbon intensity of heat delivered depends on the efficiency of the heat generation system and the carbon intensity of the fuel used. The electricity grid is projected to be largely decarbonised by 2030 which will improve the carbon performance of electric driven heat technologies. At a much lesser scale bio methane injection in the gas grid is expected to reduce the carbon intensity of natural gas. As markets develop and technologies improve, heat will be generated at much higher efficiencies than seen today. Due to these factors the carbon performance of technologies reported in literature varies. Figure 4.5 shows the range of uncertainty in carbon performance of the key heat supply technologies (Ricardo-AEA, 2013; AEA & Element Energy, 2012; Delta-ee, 2012; ETI, 2012; Energy Saving Trust, 2010a; World Energy Council, 2004; Paul Scherrer Institut, 2003).

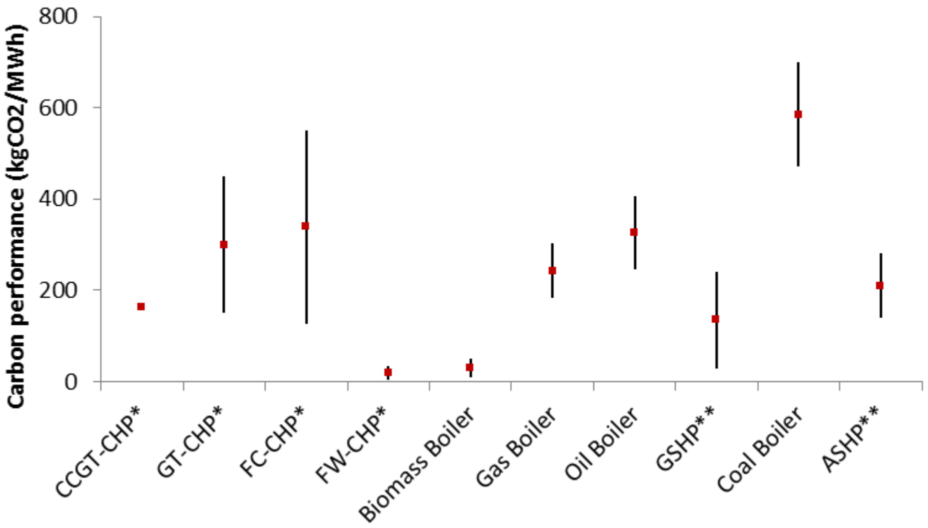


Figure 4.5: Carbon performance of heating appliances

* Only CO_2 emissions for heat supply from CHP technologies is considered.

** Based on the current value for electricity grid emissions intensity in 2012

Upfront capital cost and running cost

The upfront capital cost of low-carbon heat supply technology will be a key barrier to technology uptake. Today many novel heat technologies are priced at a considerably higher value than the conventional gas boiler. Financial support in terms of capital grants or voucher schemes can be considered to bridge the difference in upfront cost in order to drive the uptake of low-carbon heat technologies. The upfront capital cost range per unit capacity, of the set of key heat supply technologies are shown in Figure 4.6 (Element Energy, 2013; Sweett Group, 2013; AEA, 2012; AEA, 2011; NERA, 2011; Energy Saving Trust, 2010a; NERA & AEA, 2009; Poyry, 2009,).

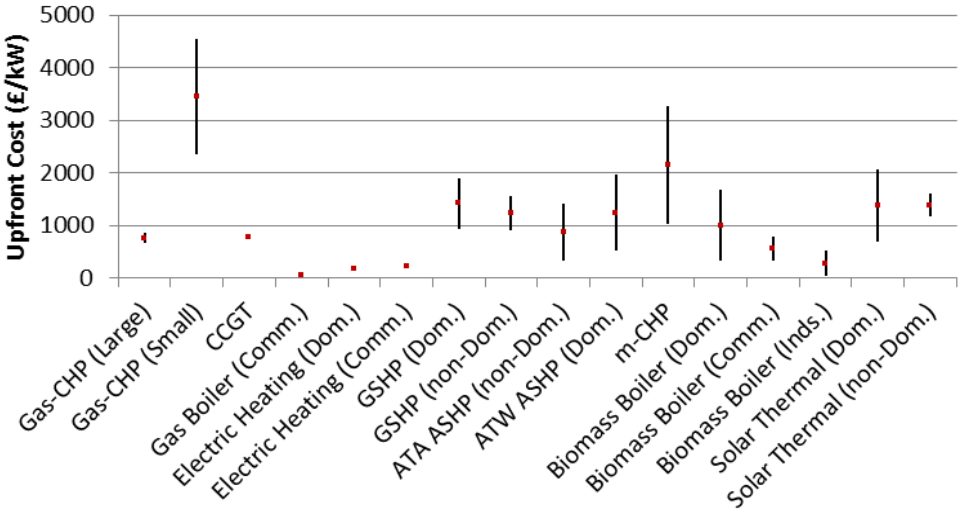


Figure 4.6: Upfront capital cost of heat technologies

The running cost of a heat supply technology depends predominantly on the cost of fuel it uses. However, there is an element of fixed costs to maintenance, labour etc. that are associated with operating a heating technology. These fixed costs of operating a heat supply technology per unit capacity installed are shown in Figure 4.7.

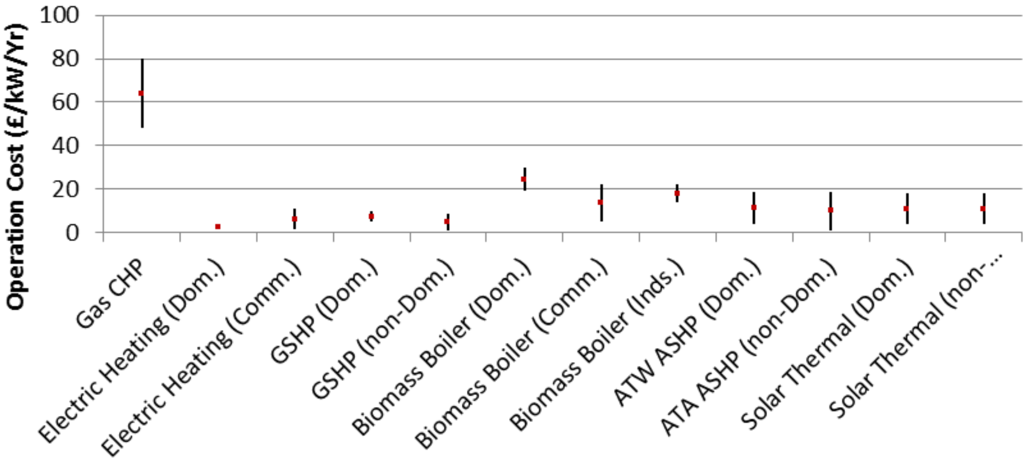


Figure 4.7: Running cost of heat supply technologies

Retrofitability

The diversity in the UK's building stock presents unique challenges in retrofitting new heat supply technologies. The considerations on technology suitability arise from space requirements, limitations of existing heat emitter and distribution systems, managing fuel supplies and planning regulations required in installing new low-carbon heating systems. The diversity of the building stock makes it impractical to generalise the aptness of a particular technology to the range of applications. Several decarbonisation scenario studies (Delta-ee, 2012; National Grid, 2012; Allen, 2008), have made additional assumptions on technology retrofitability to represent the diversity of the UK building stock. For example, the suitability/retrofitability of a ground source heat pump solution will be much higher for rural houses with greater space availability than for urban apartments.

The levelised cost of technologies and the relative cost of carbon abatements are discussed in section 7.

5 Heat decarbonisation policy landscape

Analysis of uncertainties in decarbonising heating necessitates understanding the policy direction of government. The changes in the UK's government policy over time and the financial support programmes are summarised in this section.

5.1 Policy timeline

The government's energy policy portfolio provides a strategic framework for achieving the carbon emission reduction targets.

Figure 5.1 shows the relevant policy papers (specific to heat decarbonisation) published and financial support schemes introduced since the climate change act was instated in 2008. It should be noted that decarbonising heat goes hand in hand with energy efficiency improvements and decarbonising the electricity supply. However, policy papers relevant to energy efficiency and decarbonising the electricity sector are not investigated in this study.

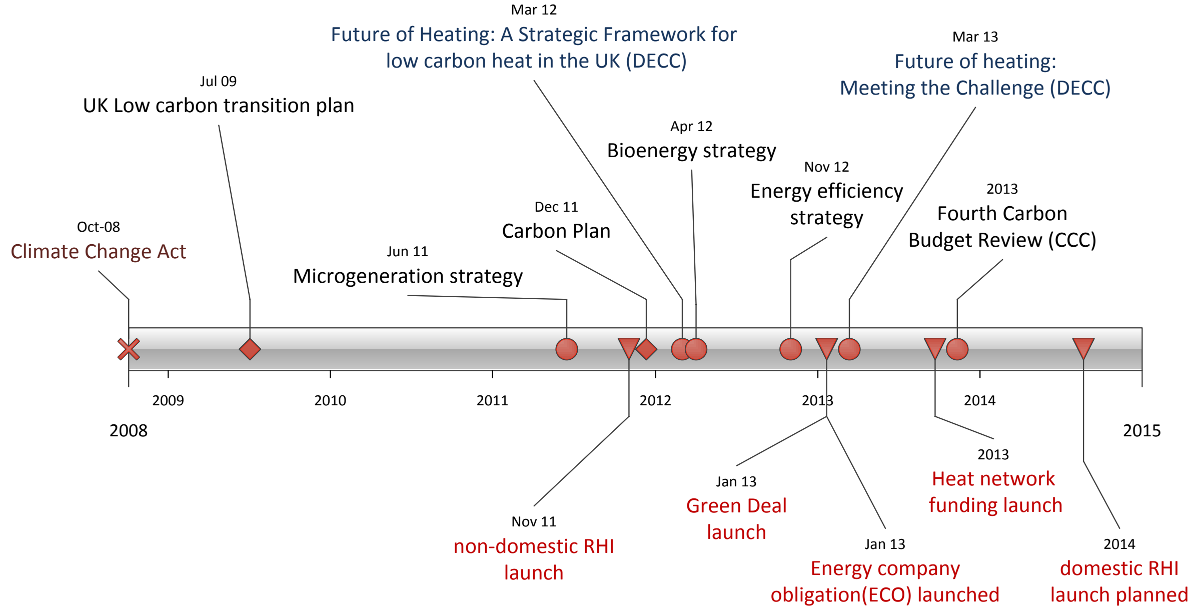


Figure 5.1: Energy policy papers published with relevance to heat decarbonisation

The 'Carbon Plan' published in December 2011, sets out the government's vision for achieving the emissions reductions it is committed to in the first 4 carbon budgets. This document supersedes the 'UK Low-carbon transition plan' which was first published in 2009 to address the first 3 carbon budgets. The fourth carbon budget, covering 2023-2027 was established in June 2011 and is due to be reviewed in 2014 following advice from the Committee on Climate Change.

The first dedicated policy paper on heat was published by DECC in 2012 to outline the government's strategic framework for low-carbon heat in the UK up to 2050. A year later, 'The Future of Heating: Meeting the challenge' was published to set out specific actions for the delivery of low-carbon heat. In the midst of these, the 'Energy efficiency strategy', 'Microgeneration strategy' and the 'UK Bioenergy Strategy' were put forward to provide clear insight to the government's ambition in each sector for setting policy in the coming decades.

5.2 Targets for heat sector emissions reductions

The CCC's fourth carbon budget review recommends specific targets to be achieved by 2030 (2023-2027) in the heat sector to remain in the cost effective path to meeting the 2050 target. The following are highlighted in Table 5.1.

Table 5.1: CCC central scenario-estimates on low-carbon heat infrastructure by 2030

Decarbonisation options	Measures	Target level by 2030 (medium abatement scenario)
Energy efficiency improvement	Building lofts and cavity walls insulation	All lofts and cavity walls where practical by 2015
	Buildings solid walls insulation	Cumulative insulation of 2.7 million walls by 2020 and 3.5 million solid walls in the residential sector (8 million existing)
Electrification of heat	Heat pumps	Penetration rate of 25% of heat demand in the residential sector and 60% in the non-residential sector (143 TWh)
District heating	-	Limited role (2% of 10 TWh)
Use of bioenergy	-	No growth in 2020's from the level recommended for 2020 in the Gallagher review (2%, 13 TWh)
New built		Zero carbon

5.3 How the targets have changed

The committee of climate change published an update for the 4th Carbon Budget recommendations in late 2013 (CCC, 2013) which presented new estimates. The targets have changed due to several reasons. These include gathering new and updated information and evidence, new energy modelling and related assumptions, etc. Table 5.2 shows a comparison between the original targets and the updated ones.

Table 5.2: Comparison of original and updated 4th carbon budget

Item	Original target	Updated target
2020 abatement potential (residential buildings)	17 MtCO$_2$e	8.1 MtCO$_2$e
2020 total abatement potential (residential and non-residential buildings)	57 MtCO$_2$e	17.2 MtCO$_2$e
2020 penetration of renewable heat	12% of total heat demand	
2030 abatement potential (residential buildings)		27 MtCO2e
2030 penetration of renewable heat	28% of total heat demand	
Total heat pumps (TWh) by 2030	160	82
District heat (TWh) by 2030	10	30
Biomass (TWh) by 2030	13	
Residential buildings emissions		2020: 72 MtCO$_2$e 2030: 61 MtCO$_2$e

5.4 Financial support schemes

Table 5.3 provides a summary of the financial support schemes introduced to promote low-carbon heat supply.

Table 5.3: Financial support schemes for promoting low-carbon heat technologies and energy efficiency

Category	Financial support scheme	Notes
Energy efficiency	Green Deal	Supports financing energy saving improvements to home or business (heating unit, insulation, drought proofing, double glazing, renewable energy generation)
	Energy Efficiency Directive	-
	Energy company obligation	Support from the energy company to improve home energy performance if on certain benefits or a low income, or for certain hard to treat properties
Deployment of low-carbon heat technologies/ infrastructure	Non-domestic Renewable heat incentive (RHI)	Supports businesses, the public sector and non-profit organizations meet the cost of installing renewable heat technologies. Biomass boilers, heat pumps (ground source and water source), geothermal, solar thermal collectors and biomethane and biogas technologies are being supported.
	Domestic Renewable heat incentive (RHI)	Supports individual households in meeting the cost of installing low-carbon heat technology (ASHP, GSHP, biomass and solar thermal are to be incentivised via a feed in tariff mechanism)
	Heat network funding	£6 million funding stream to support local authorities to develop technical proposals and financial evaluations of installing new heat networks or expanding existing ones
	Renewable heat premium payment	Financial support to installing renewable heating technologies at home. Solar thermal, heat pumps and biomass boilers are being supported.

Table 5.4 shows a list of other instruments that through decarbonisation of the overall energy sector affects heat supply.

Table 5.4: Other financial instruments

Financial instrument	Notes
EU ETS	The EU ETS works on the cap and trade principle. A cap is set on the total amount greenhouse gases that can be emitted by factories, power plants and other installations in the system. Within the cap, companies receive or buy emission allowances which they can trade with one another as needed.
The Climate Change Levy	The climate change levy (CCL) is a tax on energy delivered to non-domestic users in the United Kingdom. Its aim is to provide an incentive to increase energy efficiency and to reduce carbon emissions.
Carbon price floor	Minimum price for carbon (implemented through CCL); set at £16/ tCO_2 in 2013 increasing to £30/ tCO_2 by 2020 and £70/tCO_2 by 2030.
Carbon reduction commitment	The CRC Energy Efficiency Scheme is a mandatory carbon emissions reduction scheme that applies to large non-energy-

	intensive organisations in the public and private sectors.

6 Review of decarbonisation pathways

The UK government's vision to decarbonise heat by 2050 in different sectors including domestic buildings, (non-domestic buildings) service and industry is described in this section. In addition to the government's cost-effective pathway modelling, other parties have drawn alternative scenarios for achieving the emission targets. These alternative pathways are also described.

6.1 Government's vision

The government envisions a three stage strategy for decarbonising heat as outlined in the 'Carbon Plan'. The stages are categorised in time periods outlining actions to be taken during this decade, 2020s and 2030s and finally the 2040-2050 period.

Table 6.1 summarises the technology transformations envisioned for each sector of heat demand up to 2050. The technology pathways outlined by DECC is based on cost optimisation modelling results representing the whole UK energy system. DECC used "Redpoint energy system optimisation model" (RESOM) as its benchmark and the Energy Technology institute's "Energy System Modelling Environment" (ESME) to explore sensitivities, and to compare with RESOM in preparing the 'Heat strategy'.

Table 6.1: UK government vision for Heat decarbonisation

	Domestic buildings sector	Service (non-domestic buildings) sector	Industry sector
Heat technology transfers expected in the medium to long term	ASHP's GSHP (rural properties off the gas grid) Heat networks Hybrid systems Electric heating (Rural properties peak top up)	Heat pumps (Air source and Ground source) Heat networks **Alternate scenario** GAHP and Hydrogen boilers Biomass boilers	***High temperature process heat*** Gas boilers with CCS Hydrogen boiler Bioliquid boiler ***Low temperature process heat*** Heat networks Heat pumps Bio liquid boilers
This decade *Complete and prepare*	The easy wins and low regret options. Focus on energy efficiency improvements and prepare the market, supply chains for low-carbon heat technologies. Drive early deployment helping to bring down costs ahead of large scale roll out		
2020-2040 *Mass deployment*	Key transitional decade and progress is important to ensure a smooth and cost effective transition. Growth of low-carbon heat technologies to market levels. Governments focus will be on creating the right frameworks to support the market to bring down cost of low-carbon heat. The gas network will start winding down from 2030's. Hybrid systems[3] will be a key transitional technology for domestic buildings and will be adopted relatively quickly. The heat network penetration will accelerate to 2030 and beyond, supplying domestic and non-domestic (service sector) buildings. Late 2030's will see the industry shifting from coke and coal to hydrogen and deployment of CCS in the industry.		
2040-2050 *Finalising*	Helping business and consumers tackle the more challenging areas of decarbonisation. Supporting difficult to reach buildings and industry in the roll out of technologies.		
Remarks	Domestic buildings need to be almost fully decarbonised. ASHP and GSHP replace the role played by gas boilers today. Heat networks provide around 10% of the heat demand in 2050.Hybrid systems will be a major transitional technology. Gas networks will meet 1 in 20 winter peak demands along with storage.	Will adopt low-carbon heat technolgies very quickly. Heat networks will provide around 7% of the demand by 2030 and 9% by 2050. An alternate modelling scenario[4] shows take up of GAHP and a role for hydrogen boilers. This scenario also shows a role for biomass boilers as a transitional technology.	Continued role for gas out to 2050 for high temperature applications. For low temperature processes heat networks supplied by gas CHP is used. A significant role for hydrogen in the industry. Along with fuel switching take up of CCS. A 60-70% reduction in emissions by 2050.

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[3] Hybrid systems are where gas boilers are used in conjunction with heat pumps. These systems will enable the gas to meet the peak Demands (1 in 20 winter peak)

[4] ESME Modelling scenario

6.1.1 Domestic and non-domestic (services sector) buildings

The government envisions a predominantly electrified heat demand in the domestic and service (non-domestic) sector by 2050 (DECC, 2013c) (Figure 6.1). Heat will be delivered through a mix of ASHP and GSHP consuming electricity that is largely decarbonised. The gas network will play a minor role in 2050, and this will be through either highly efficient gas appliances such as 'gas absorption heat pumps' (GAHP) or through 'hybrid heat pump' systems in meeting the winter peak demands. Heat networks will grow to provide around 10% of the heat demand to domestic and non-domestic buildings by 2050.

The 'UK Bioenergy strategy' highlights the low lock-in risks offered by bioenergy systems in a number of different heat applications. However within the wider options for decarbonising the heat sector, bioenergy is only expected to play a marginal role. The use of bioenergy will be key in meeting the heat demands of vital segments that could be hard to decarbonise such as high temperature industrial process and in situations in domestic and non-domestic (service) buildings where other technologies are not suitable or as cost effective. Biogas is expected to be used in space heating in the short to medium term and in high temperature process heating in the longer term. A key use identified for bioenergy, will be to generate net negative emissions through CCS. These negative emissions will be used to balance out emissions in hard to decarbonise sectors.

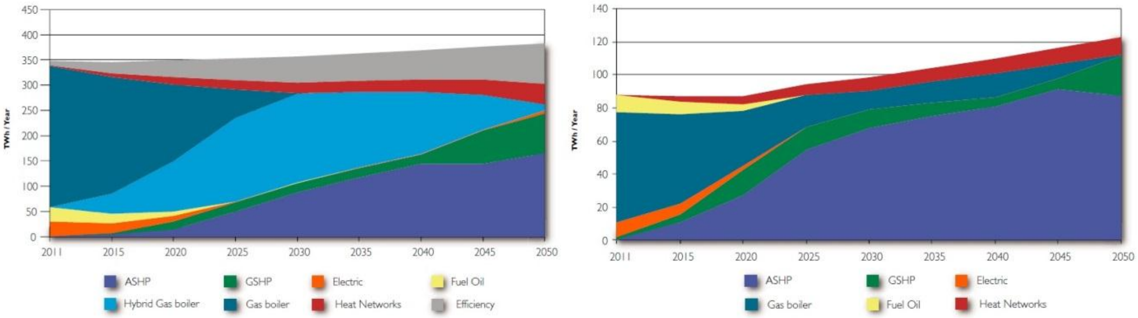

Figure 6.1: Technology pathways for building heat decarbonisation a) domestic buildings b) non domestic buildings (DECC, 2013c)

6.1.2 Industry

Gas will remain the main fuel in industry supplying high temperature process heat. The industry will take up 'carbon capture and storage' (CCS) for its gas use starting in the 2030s. The use of coke and coal will be substituted by hydrogen in high temperature process heat applications. The low temperature process heat will switch to heat networks and biomass boilers are expected to play a transitional role up to 2030 (DECC, 2013c) (Figure 6.2).

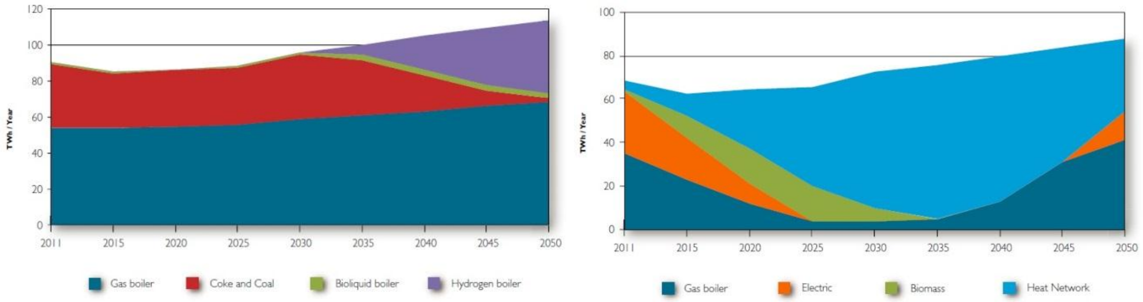

Figure 6.2: Technology pathways for Industrial heat decarbonisation a) high temperature b) low temperature process heat (DECC, 2013c)

The UK has a legally binding commitment, agreed in the climate change act to reduce greenhouse gas emissions by 80% relative to 1990 levels. The CCC recommends a 50% cut in emissions by 2025 relative to 1990 levels (32% on 2012 levels). Achieving these targets require investment in each of energy efficiency improvement, fuel efficiency improvement, power sector decarbonisation, decarbonisation of transport and heat and use of sustainable bioenergy.

Government policy papers have outlined specific objectives to be achieved in the heat sector in order to meet the overall carbon budgets. The carbon plan sets a penetration level of 12% and 35% of renewable heat by 2020 and 2030 respectively. By 2050 the emissions from buildings are required to be nearly zero and a 70% reduction of emissions in industry (from 1990 levels) (DECC, 2013b).

6.2 Alternative pathways

A plethora of scenarios of the energy system have been developed describing different paths towards achieving an 80% reduction in emissions by 2050. A majority of these scenarios investigate both the carbon emissions and cost impacts of this transition. Publications from different stakeholders have brought about new analysis and views on the optimal pathway for decarbonising heat and the robustness of these scenarios under varied assumptions. Table 6.2 provides a high level overview of the key stakeholder publications and diverse pathways presented in their analyses.

Table 6.2: Review of different stakeholder views on pathways for decarbonising heat

stakeholder	Publication title	Author	Model used	Pathways modelled	Emerging messages
Government	2050 Pathways analysis (HM Govt,2010)	HM Government	2050 Calculator	A total of 6 different pathways were modelled and analysed with respect to varied electrification levels, a primary non-electric fuel scenario (biogas, biomass, power station heat, mix) and a pathway with less action on energy efficiency.	• Ambitious per capita energy demand reduction needed. • A substantial level of electrification of heating • Electricity supply may need to double and will need to be decarbonised • Sustainable bioenergy a vital part of decarbonising high-grade heating processes
	Future of heating: Meeting the challenge (DECC, 2013b)	DECC	RESOM and ESME	A run for the RESOM model was used to provide benchmark pathways for domestic, non-domestic buildings and industry heat decarbonisation. The model was run for sensitivities and compared with ESME modelling.	• A radical decarbonisation of heat for buildings and 60-70% reduction in emissions for industry required • Heat pumps and heat networks needed to achieve emissions reduction target • Role for gas in 2050, either in GAHP or in hybrid systems • Potential role for hydrogen to provide heat in industry and buildings
Utilities	Pathways for decarbonising heat (National grid, 2012a)	Nationalgrid/ Redpoint	RESOM	Cost optimal pathways for decarbonising heat in a scenario where: • UK can purchase international emission credits (Abatement cost cap scenario) • and where the UK effectively has to meet the emission target from abatement action only within UK are modelled and analysed	• Electrification of heat in buildings, facilitated by heat pumps is a critical component of decarbonising heat • Widespread and early decarbonisation of the electricity system required • Both peak and annual electricity demand rise rapidly from 2030 onwards, requiring timely reinforcements • Energy efficiency has a crucial role to play • To tackle the seasonal and diurnal swings in demand use of hybrid electric/gas heating and heat storage strategies important • A low risk way to achieve managing the swings in demand is by maintaining significantly reduced flows of gas in buildings or to make extensive use of heat networks • In sensitivities where gas forced out of buildings by 2050, costs for home heat and power rise by 10-15% • Key transition points in 2030s with rapid growth of electricity demand and roll-out of CCS, followed by wide scale use of hydrogen use in 2040's

Consultancies	Decarbonising heat: Low-carbon heat scenarios for the 2020's (NERA & AEA, 2010)	Report for CCC by NERA and AEA	Modelling framework developed by NERA and AEA	Benchmarking on a central scenario several alternative scenarios are modelled and analysed. • An electrification strategy • a bioenergy strategy • a district heating strategy are explored. The scenarios are tested for sensitivities to discount rate, fossil fuel price, biomass availability and energy efficiency.	• Low-carbon sources could reduce emission from heat by one third by 2030 • Significant emission abatement could be provided at low or even negative cost • Attractiveness of heat pumps depend on improvements in the technology over the next two decades • Heat pumps are an attractive option for decarbonisation of space heating, complemented by bioenergy for high temperature heat • District heating route would require significant co-ordination and potentially changes to market arrangements • Failure to promote energy efficiency a significant risk
	Decarbonising heat in buildings: 2030-2050: Domestic and non-domestic (service sector) buildings (Element energy & AEA, 2012)	Report for CCC by element energy and AEA	Scenario modelling	Starting from the CCC Central scenario prediction for 2030 the modelling establishes a baseline scenario for evaluation. • A scenario where the existing policies are assumed to continue beyond 2030 • a scenario of high DH uptake • and a scenario where uptake of building level renewable heat is restricted are modelled.	• With continued growth in the UK's building stock the potential for reductions in overall thermal demand relative to today is limited • Projected total UK buildings heat demands in 2050 range from 416TWh/yr (high efficiency) to 532 TWh/yr (low efficiency) • Complete shift in the heating market to renewable heating technologies • An order of magnitude drop in the carbon intensity of grid electricity relative to today's values • Abundant supply of ultra-low-carbon electricity • Most robust low-carbon heat pathway will involve a mix of technologies (electrification, district heating , biomass) • Around 80% of thermal demand is technically suited to DH • A maximum of 28% if thermal demand could be supplied by existing power stations • A maximum of 9% of non-industrial heating demand supplied by biomass boilers • Electricity demand for heating reach 100TWh/yr under the policy extension scenario. • Peak heat demand estimated to be around 65GW in the same scenario • Failure to decarbonise electricity supply and lack of suitability for renewable heat are the highest risks • Continued availability of relatively cheap gas could hinder the uptake of renewable heating technologies

Pathways to 2050 – Detailed Analysis (MARKAL model review and scenarios for DECC's 4th Carbon Budget Evidence Base) (AEA, 2011a)	AEA	MARKAL	MARKAL core run	• During the 4th budget period emissions intensity of the grid electricity would halve • Mass adaptation of heat pumps • Mass uptake of all cost-effective conservation measures • Notable component of demand response, is well underway in the 4th carbon budget period • All new installations of heating systems over the period from 2020 to 2035 • In the 4th budget period gas heating is still dominant
2050 Pathways for domestic heat (Domestic heat) (Delta-ee,2012)	DELTA Energy & Environment	Residential heat model developed by Delta-ee	Three potential pathways for low-carbon heat in domestic buildings are modelled. • Customer choice scenario where customers are allowed to choose their heating system based on upfront and running costs and physical fit • a electrification and heat network scenario where virtually all homes use either electric heating or heat networks • a balanced transition scenario where equal contribution from heat networks, low-carbon gas appliances and electric heating is seen.	• Customer choice scenario fails to meet the 2050 carbon targets. Gas boilers continue to be used in 19 million homes. Carbon emissions fall by 46% only. • Use of high electrification and heat networks can achieve 96% reductions in carbon emissions from domestic buildings • Balanced transition can achieve with less government intervention 90% carbon reductions • Keeping a variety of options open gives lower risks and potentially a lower cost path • Balanced transition avoids 12 million homes completely moving away from gas • Additional peak generation demand grows to 24GW in balanced transition, rather than 48GW (in the elec & DH) • Costs to re-inforce the electricity distribution network are €8bn lower • Both scenarios require significant reduction in thermal demand, wide-spread expansion of heat networks, market maturity, decarbonisation of electricity grid, major distribution system upgrades and additional generation capacity • Balanced transition is relatively robust to sensitivities examined
HHIC Pathways for domestic heat (Domestic heat) (HHIC, 2012)	HHIC & DELTA Energy		Three pathways are modelled. • An all-electric scenario • a low-carbon gas hybrid technology scenario • a balanced mix of technologies for different house types are modelled and analysed.	• Government support required to bridge the gap for upfront cost of renewable heating technologies • Building investor confidence will be critical • Heat pumps and a suit of low-carbon gas technologies make up the majority of the market by 2027 • By 2027 60% of homes will be condensing gas boilers, 5% of homes with district heating, 20% of homes with heat pumps and less than 2% on oil heating

UKERC	Comparing low-carbon resilient energy scenarios for the UK energy system in 2050 (UKERC, 2013b)	UKERC	MARKAL/TIMES		• Greater increased efficiency and conservation • Residential heating by 2050 uses almost no natural gas • Heat pumps makes a major contribution to heating in all scenarios, supplemented by biomass and solar thermal • Electricity system needs to be decarbonised by 2030 by at least 80% • Active management of the electricity grid required to prevent high peak demands
Trade Organizations	Building a roadmap for heat: 2050 scenarios and heat delivery in the UK (CHPA, 2010)	CHPA	Review study	Examines the energy system scenarios to 2050 that have contributed to current government energy policy and develops an integrated scenario which seeks to utilise waste heat efficiently and diversify the means by which heat is provided to end users.	• All electric future is low-carbon but associated with continued reliance of fossil fuels and large losses of energy at the power generation stage • Challenges related to managing power flows, demand peaks and end-user adaptation of insulation, heat pumps and other measures • Use of CHP and DHN will assist a number of power flow and electric network issues

7 Analysis of the key uncertainties in UK heat infrastructure development

It is evident that meeting the carbon budgets and longer-term (2050) greenhouse gas emission target will require a transformation in the way heat is provided today. Due to a range of technical, economic and market challenges combined with customer scepticism and alternate market investment strategies mean that large scale deployment of key classes of low-carbon heat technologies are plagued with uncertainties. Figure 7.1 is a diagram showing the complex inter-dependent relationships of different uncertainty elements in the energy sector that impact the development of low-carbon heat infrastructure.

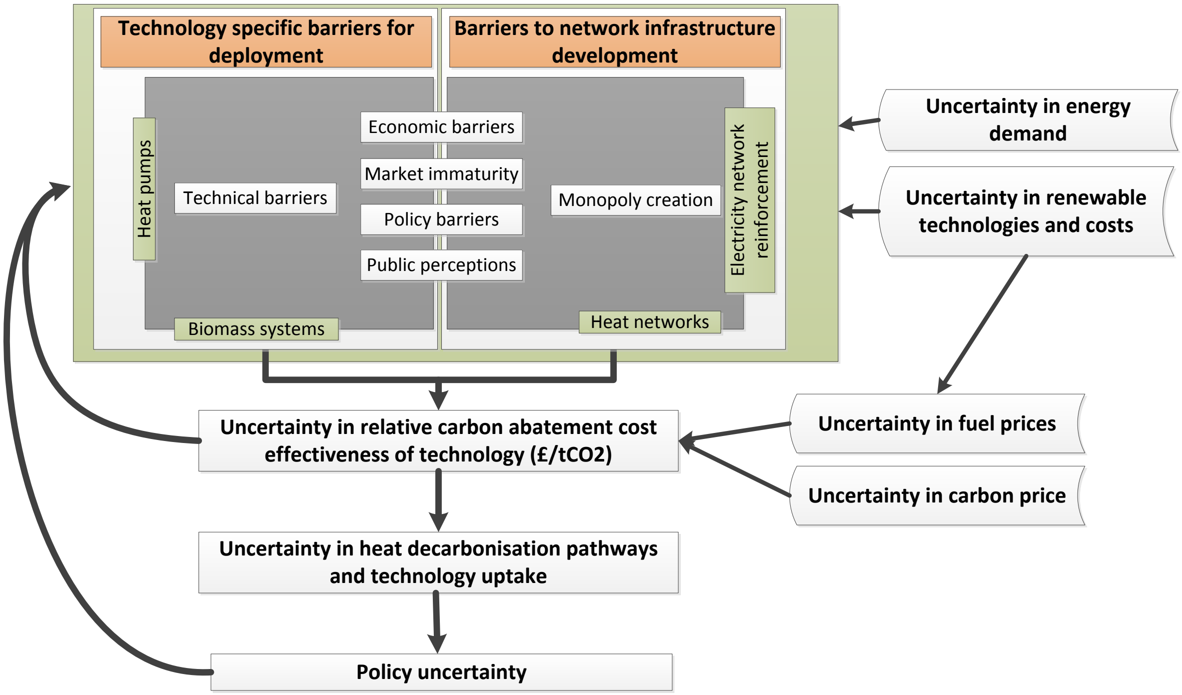

Figure 7.1: Diagram of the inter-related nature of uncertainties in UK heat infrastructure developments

Due to the relative immaturity of low-carbon heat technologies in the UK market, each technology is met with a unique set of barriers for large scale deployment. These barriers are amplified by the uncertainties in policy direction, external factors such as fuel prices in the global market and uncertainties in achieving key decarbonisation goals in other parts of the energy sector (e.g. electricity sector decarbonisation without significant increase in price).

A review of evidence on the set of barriers and uncertainties effecting the deployment of two key low-carbon heat technologies, heat pumps and district heating schemes and their impact on technology uptake is presented in section 7.1 and 7.2. In section 7.3 various uncertainty elements such as capital costs, fuel prices, electricity grid emission intensity and heat demand are analysed with respect to their impact on overall costs and carbon abatement. Finally section 7.4 outlines ways to manage the impact of uncertainties with a focus on the deployment of heat pumps and heat networks.

7.1 Uncertainties in heat pump deployment

Heat pumps (HP) are recognized as a key technology for decarbonising the hot water and space heating demands of domestic and non-domestic buildings (service sector). Comparatively higher efficiencies (Seasonal performance factor on average around 2.5 in ASHP and 3.0 in GSHP systems) and the potential decarbonisation of the electricity supply make them highly attractive in the choice to replace gas boilers.

Even though heat pumps are a mature technology for heat supply in other parts of Europe, it is still a relatively new technology in the UK (20,000 installations per year in 2012 compared to 1.6 million gas boilers) (Frontier Economics & Element Energy, 2013). For example, in Sweden and Switzerland, heat pumps have achieved a significant market share in recent decades due to policy incentives and market growth (Figure 7.3).

The various modelling results on the uptake of heat pumps in the UK vary. Figure 7.2 shows the varying levels of heat pump[5] uptake by 2030 estimated in a set of key energy scenarios.

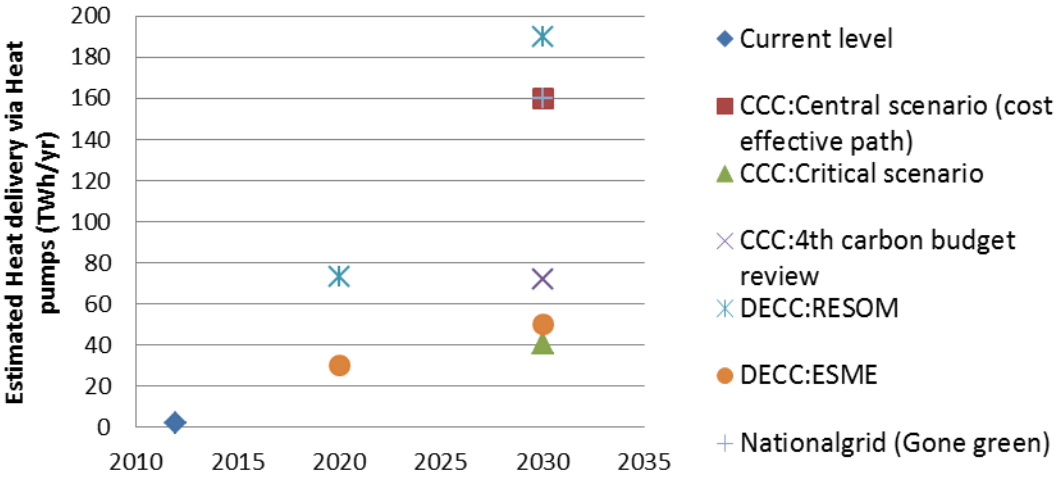

Figure 7.2: Heat pump uptake levels projected by different energy scenario publications

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[5] Heat pumps here refer to both ASHP and GSHP unless stated otherwise. Hybrid heat pumps are not included.

The CCC's initial assessment of the cost effective path (Central scenario) to 2050 (CCC, 2010), estimated a requirement of 143 TWh/yr of thermal energy delivered via HP by 2030, increasing to 365 TWh/yr by 2050 (31 million domestic installations; 80 % of properties) (CCC, 2013). Due to greater financial barriers (Frontier Economics & Element Energy, 2013) as a result of higher capital costs, lower performance and shorter lifetimes, the Committee of Climate Change pulled back its initial estimates of higher heat pump uptake levels. The '*Fourth carbon budget review'* (CCC, 2013) published in late 2013, dropped the initial estimate down to 72 TWh/yr (50% reduction) by 2030. The heat pump deployment levels estimated in domestic and non-domestic buildings, in a set of key scenario publications is shown in Table 7.1.

Table 7.1: Modelled uptake of heat pumps in domestic and non-domestic buildings

Scenario	Model/Study	Total heat delivered by 2030	No of installations by 2030		Heat delivered by 2030 (TWh/yr)	
		TWh/yr	Domestic	Service (non-domestic)	Domestic	Service (non-domestic)
Current policy uptake	Frontier Economics & Element energy	12.3	0.66m	0.04m	4.3	8
Critical pathway to meet 2050 target	Frontier Economics & Element energy	41	2.5m	0.1m	30	11
4th carbon budget target	CCC	72	4m		45	27
Cost optimal	CCC-Central scenario	143	7m		81	62
	DECC (RESOM)	190			110	80
	DECC (ESME)	50				
(Gone Green)	National Grid		8.5m			

A consensus can be observed from the published evidence of modelling outputs, that a significant penetration of heat pumps is assumed in domestic and non-domestic buildings by 2030 to reach the 2050 emission target cost effectively (Redpoint, 2012). The CCC commissioned Frontier Economics and Element Energy to analyse the actions required in the near and medium term to ensure sufficient heat pump uptake by 2030 (Frontier Economics & Element Energy, 2013) is achieved. Under this study, a heat technology uptake model developed by *Element energy* estimated that only 13 TWh/yr of heat can be expected by 2030 from the uptake of heat pump installations, under the current policy landscape. It is less than 10% of the estimate under the 'central scenario' and 15% of the estimate in the '4th carbon budget review'. These uptake levels were also below that identified as the '*critical path*[6]' to meet the decarbonisation targets by 2050 (41 TWh/yr). Nevertheless, the study concludes that the 'cost effective' CCC scenario is achievable with the introduction of major policy changes.

The RHI for domestic customers (DECC, 2013a) to be introduced in spring 2014, is expected to incentivise off gas grid households (but not limited to) to take up heat pump systems. The response to this financial support scheme is difficult to predict. Significant financial and non-financial barriers remain to be overcome in achieving the required levels of heat pump uptake. A number of technology challenges are yet to be addressed. Also, the repercussions on the electricity distribution network from a high rate of heat pump uptake will need to be carefully managed.

7.1.1 Barriers to heat pump uptake

A review of the barriers to heat pump uptake was undertaken and is presented below.

- **Technical uncertainties**

There are numerous technical issues relating to heat pump installations that are yet to be addressed in the UK.

System design considerations

Heat pump systems are usually undersized relative to the peak demand of the property to reduce capital cost and increase utilisation. It is therefore supplied with a backup heater to provide the required heating on the coldest days of the winter. Some models (older ones) are not able to provide heat above 60^{0}C and therefore use the backup heater to pasteurise hot water to reduce legionella health risks (Staffell, 2012). Electric immersion heaters are often used as the back-up auxiliary heater. Regular use of the immersion heaters can substantially increase running costs and reduce the seasonal performance factor of installations. The impact from a large number of heat pumps running immersion heaters concurrently could have substantial consequences on the electricity network.

The output of a heat pump reduces with decreasing outdoor temperatures. Below -15^{0}C to -25^{0}C the auxiliary heater must solely be used to meet the heating demand. Only ASHP suffer from this in practical use, as ground temperatures are usually higher and more consistent than air temperature between seasons. Freezing of the outdoor unit is also a disadvantage for ASHP operation as ice begins to form on the external heat exchanger below around 5^{0}C. These factors could significantly impact the performance of the heat pump system.

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[6] A critical path was defined in the study undertaken by Frontier Economics and Element energy, as the minimum level of heat pump uptake required by 2030, for the 2050 target to be achievable, given very difficult constraints on uptake.

a) Domestic hot water provision

As the insulation levels of the UK's building stock increases, the relative fraction of the domestic hot water demand (washing, showering etc.) compared to the space heating demand will increase. Even though low temperature emitter systems (under floor heating) can make room heating very efficient through heat pumps, with domestic hot water (DHW), there is little opportunity to reduce the working temperatures; therefore when producing DHW the heat pump outlet temperature needs to increase to approximately 50^{0}C. This will further impact the overall efficiency of the system. It should also be noted that heat pumps are not suitable for instantaneous hot water provision unlike gas boilers. Energy saving trust (Energy Saving Trust, 2014) recommends using solar water heating to provide hot water to help keep the heat pump efficiency higher.

b) Storage requirement

Most heat pump installations necessitate hot water storage for efficient operation. This would require space from buildings for installation of an accurately sized storage tank. It was discussed during the heat workshop that increasingly many customers are replacing gas boilers with combi boiler units which removes the need for water storage freeing up valuable space. It will be challenging to persuade customers to return to a system that require additional space to that of the existing system.

Performance of heat pumps

An independent field trial monitoring heat pump performance in customer homes in the UK was undertaken by the Energy Savings Trust (Energy Saving Trust, 2010b, 2013). Phase 1 of the field trial monitored technical performance and customer behaviour at 84 sites across the UK in a year-long study. It identified that heat pump performance was below expectations in many of the sites with a mean system efficiency of 1.82 for Air to Water Systems (22 units, range of 1.2 to 2.2), and 2.39 for ground source heat pump systems (49 units, range of 1.55 to 3.37). A number of issues were identified as contributors to the poor performance, including:

1. under-sizing of the heat pump, the hot-water cylinder and, in the case of ground source heat pumps, the boreholes /ground loop;
2. flow temperatures too high both in radiator and underfloor emitter systems;
3. poorly designed ground loop; and
4. inadequate controls, over-use of circulation pumps and reliance on immersion heaters for hot water.

A second phase of the heat pump trial (between 2010-2013) (Energy Saving Trust, 2013) was undertaken to address the technical issues identified at a number of the phase 1 installations and to monitor the performance of the system to identify any improvement. The range of recovery work undertaken included major work such as replacing of heat pumps to minor changes such as changing the heat pump control strategy. An improvement in system performance was reported compared to Phase 1. However, a significant proportion of the air source systems heat pumps (6 out of 15) had not achieved the performance levels required to be considered ‘renewable’ under the EU Renewable Energy Sources Directive[7]. This will have further implications as the domestic RHI policy (DECC, 2013a) is expected to pay ASHP systems based on a significantly higher deemed SPF to that recorded in the EST field trials.

Lifetime assumptions

The evidence on the lifetime of heat pumps is weak and estimates for ASHP are on average 15–20 years. The technology uptake model (Frontier Economics & Element Energy, 2013) estimates are highly sensitive to lifetime assumptions.

Noise and size of the outdoor unit

Noise, particularly from the external fan and compressor unit of an air source heat pump is a potential barrier for heat pump uptake. This is of special concern in urban areas. The current regulation requires; “The noise level should not exceed 42dB at 1m from the window of a habitable room in the façade of any neighbouring dwelling.” A study by the Building Performance Centre measured noise levels from a range of ASHP installations and found to be in the range of 50–60db at 1m distance[8] (Frontier Economics & Element Energy, 2013). Worryingly, these levels were broadly agreeable with the manufacturer’s specifications. Most of the units achieved the 42db level in the range of 10–20 meters from the outdoor unit.

The regulation on outdoor unit size imposes an additional barrier for the uptake of larger systems (above $9kW_{th}$) as the permitted size of the outdoor unit is constrained to $0.6m^3$.

Suitability of the UK building stock

There are several uncertainties surrounding the suitability of the UK’s building stock to be serviced by heat pumps.

1. The energy performance of the building. Heat pumps have a lower output rating than a typical gas boiler. As a consequence they are better suited to well insulated buildings which are less susceptible to changes in heat demand.
2. The space availability to accommodate components parts of a heat pump installation
    a. ASHP – Outdoor compressor and fan unit and indoor heat storage tank
    b. GSHP – Ground loop/ bore hole and internal storage tank
3. Compatibility with existing heat emitter and distribution systems (due to the comparatively low flow temperatures of heat pump systems)

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[7] A minimum SPF of 2.5 is required for air source heat pumps to be considered renewable

[8] Noise levels were measured in line with the fan.

The suitability of different building types for a heat pump varies with relation to above factors. EST Heat pump trials have further highlighted each installation to have its unique design considerations.

The early markets for heat pumps are driven by new build and, for retrofitting buildings which are not connected to the gas system.

Impact from a change in European refrigeration standards

There are on-going discussions for a change in European refrigerant standards to phase out or ban HFC refrigerants. Changing of refrigerants may have implications both on the performance as well as the cost. This topic has not been dealt with in detail in literature and requires further work to be better understood.

Impact on the electricity network

There is considerable impact on the electricity network by a mass up take of heat pumps. Under all pathways examined both the peak and annual electricity demand rise significantly and require timely reinforcement. Therefore the impact of a high rate of heat pump uptake needs to be carefully managed in order to avoid undesirable effects on the electricity network.

Economic uncertainties

A study by Frontier Economic and AEA (Frontier Economics & Element Energy, 2013) evaluated levelised cost of heating technologies with the carbon price factored in. The cases of on and off gas grid installations were considered. In off-gas rural houses ASHP offers a lower levelised cost of energy (LCOE) to the main alternatives which are oil fired boilers and electric storage heating. In on-gas suburban houses however, even by 2030 heat pumps have higher LCOE than gas boiler systems.

There is limited opportunity for cost reduction in heat pump manufacture. The majority of components such as compressors are already produced in large numbers and therefore significant economies of scale are unlikely. However, there is potential to reduce the installation costs of heat pump units. The supply chain, in particular the demand side is yet to develop, and the increased maturity of the market and future competition will drive down installation costs. In particular GSHP systems can benefit from a mature installer base. For example, the cost of a bore hole (£3000-£4000 for a 3 bed semi-detached) which accounts for the over 50% of the heat pump installation cost can significantly reduce with a developed industry.

Therefore it is clear a major contribution from capital grants and incentives will be required to drive heat pump uptake and development. Policy confidence will play a crucial role in helping to establish a heat pump market.

Market readiness

There are bottlenecks that can occur in the downstream supply chain, due to the lack of capacity of the installers and specific skills in heat pump installations. It is reported that with policy uncertainty and weak demand, companies have not invested in the training of installers (Frontier Economics & Element Energy, 2013). The UK manufacturing base (e.g. Mitsuibishi factory, Kensa, Dimplex) has deferred investment due to policy uncertainty. A cause for concern is that the incentives planned for the heat pump sector could attract non-specialists from other industries to diversify into the heat pump market. This will have implications on delivering properly designed systems which will create a negative perception of the technology with the public.

7.2 Uncertainties in the deployment of district heating

District heating has been deployed in the UK since the 1950's. However, it has achieved a relatively low market penetration and provides less than 2% of the UK heat demand today. This is in stark contrast to countries such as Sweden, Finland and Denmark which showed market shares for district heating grow considerably during the recent decades. The growth in these countries has mainly replaced the use of fossil fuels in local boilers for heating (Figure 7.3) (Frederiksen, 2013).

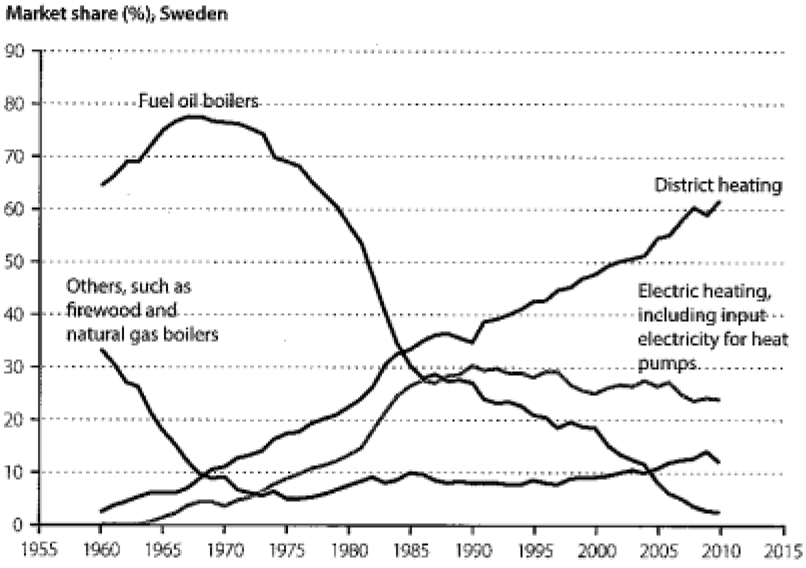

Figure 7.3: Market shares of heat supply technology in Sweden (Market share in accordance with net heat demands) (Frederiksen *et.al*, 2013)

A DECC study that catalogued heat networks in the UK (DECC, 2013e) identified 1765 individual district heating networks, of which three quarters were classified as small with an average of 35 residential dwellings and no non-domestic buildings on the network. 75 networks were classified as large with an average of 1035 dwellings and 15 non-domestic buildings connected to the network. 85% of the small networks and 70% of the large networks were recognized as built before 1990. The statistics showed that 85% of the networks were not supplied by heat of a combined heat and power (CHP) system. This fraction varied with the size of the network, where a higher percentage (65%) of large networks involved a CHP system.

Recently, there is an increased interest in the potential of district heating to contribute to meeting the carbon budget targets. At the time of the first 4th carbon budget advice by CCC in 2010 (CCC, 2010), the estimated deployment of heat networks was quite low. The level of heat delivered via heat networks was expected at 10TWh/yr by 2030 out of a total estimated potential of 90TWh/yr. However, in the 4th carbon budget review in 2013 (CCC, 2013) this estimate was raised threefold to reach 30TWh/yr by 2030 (6% of the total heat demand). A study done by AEA and Element energy (Element energy, 2012) for the 4th carbon budget review identified a greater potential for district heating deployment, at 160 TWh/year by 2050. The evidence base on the potential for district heating has strengthened over the past few years and a greater roll-out to 2030 is envisaged. Table 7.2 shows the diversity of assumed heat network deployments by 2030 in a set of key scenario modelling studies.

Table 7.2: Range of assumed heat network deployments in a set of key scenario modelling studies

Scenario	Model/study	Total heat delivered via heat networks by 2030 (TWh/yr)	Deployment in residential dwellings	Deployment in commercial buildings	Industrial process heat applications
Current policy uptake	POYRY		70,000 properties	14%	
4th carbon budget review		30 TWh/yr			
Cost-optimal	DECC-RESOM	90 TWh/yr	20 TWh/yr	10 TWh/yr	60 TWh/yr
	DECC-ESME	25 TWh/yr			
	National grid-Pathways to heat				Focused on industry
Balanced transition	Delta EE-Pathways for domestic heat		~3.5 million properties		
Gone green	National grid	1-2 TWh/yr			

➢ Barriers to heat network uptake in the UK

The uptake of district heating faces a set of unique barriers in the UK. These barriers create uncertainty in the amount of heat that can be expected to be delivered via district heating schemes in the future. DECC commissioned a study to identify barriers to the deployment of district heating networks in suitable locations (BRE, 2013). A variety of barrier issues arising at various stages of project development were recognized.

District heating schemes developed in the UK are mainly instigated by (BRE, 2013):
a) Local authorities – initially developed to serve existing buildings associated to the local authority (e.g. Social housing, council buildings), but where a strategic aim exists to expand the scheme in the future.
b) Property developers– designed to serve new buildings in a property development scheme, but which allow connection to larger, area wide networks in the future.
Evidence from literature on barriers of which some are common and some unique to each sector are presented in the next section.

Economic barriers for district heating scheme deployments

According to a study done for DECC (BRE, 2013), district heating scheme developers in the UK are facing significant economic barriers in all stages of project development. These are presented in the sub-sections below.

Obtaining money for initial feasibility funding and independent legal advice (for local authorities):

It was recognized (BRE, 2013) that many local authorities found it difficult to obtain the money required for starting feasibility work and obtaining independent legal advice. These were indicated as a barrier that would potentially stop the project from being realised. In response, DECC has established a 'Heat network delivery unit' and made funding available to support local authorities in overcoming early stage barriers to developing heat networks (DECC, 2013d). Successful grant funding applications received £1.94 million in 26 local authorities in England and Wales to meet 67% of the estimated costs of carrying out feasibility work.

Capital cost and cost of capital:

Funding the large upfront capital cost of laying a network of hot water pipes was identified as a key economic barrier in district heating scheme deployments (BRE, 2013). Due to the perceived risk in a relatively immature technology, combined with market immaturity the investments require a higher rate of return. A study by POYRY (POYRY, 2009), suggested that the diverse mix of the housing stock in the UK compared to, for example Finland where there is a higher proportion of flats and apartments, the unit cost of building a network can be higher. In the DECC interviews (BRE, 2013), not having sufficient funds to carry out the procurement process was identified as a main reason local authority schemes failed. But also supply chain immaturity may raise the cost of procurement and employing civil contractors. The difficulties in arriving at an agreement with energy service providers, including a contribution to the capital cost was also recognised as barrier for heat network deployments in the UK.

Revenue and operational cost uncertainties:
The interviews carried out by DECC (BRE, 2013) identified that both local authorities and property developers face uncertainties surrounding the longevity and reliability of heat demands, for example lack of heat demand in the new build sector that may affect the business case for laying a large network of pipes in the ground. This creates difficulty in forecasting the revenue potential of a district heating scheme and consequently difficulty in accessing risk and loan capital. There were also uncertainties identified on accessing the full revenue potential from the operation of CHP systems because of the incentives in current distribution charging methodologies to pursue the private wires approach (POYRY, 2009). Heat networks will need to compete with the already sunk costs of the gas distribution network and the electricity network on economic grounds to achieve significant penetration levels. The risk of potential redundancy of the network in a scenario where alternative technologies were to become more competitive is very much real. In addition significant marketing costs will need to be incurred if sufficient volume commitments are to be agreed upfront.

Accommodating the extra costs involved in sizing the initial scheme to allow future expansion without the guarantee of additional revenue:
A significant barrier to both the local authority and property developer led schemes were in meeting the additional cost of allowing capacity for future expansion, in the initial scheme design. These additional costs are incurred, for example in oversizing pipes and building in additional space in the energy centres. These investments were identified as difficult to defend in the absence of guaranteed additional revenues. However, there were cases in the DECC interviews (BRE, 2013) which depended on realising future expansion capacity over the longer term to construct the business case for investment. This barrier also relates to the lack of clarity in policy direction and targets, resulting in more uncertainty for the scheme developer.

Market immaturity and lack of resources

The district heating market in the UK is relatively immature. This is in contrast to some of the European countries such as Sweden and Finland, where district heating accounts for a large fraction of the heat market. As a result the uptake of potential district heating schemes are delayed facing numerous difficulties. The following can be highlighted (BRE, 2013; Poyry, 2009):

- local authorities have difficulty identifying internal resources to instigate scheme and overcome lack of knowledge
- Identifying and selecting suitably qualified consultants remain difficult

- Correctly interpreting reports prepared by consultants remain difficult due to lack of awareness
- Lack of generally accepted contract mechanisms between stakeholders
- Inconsistent pricing of heating due to lack of standardisation in contract structures

These challenges faced at different stages of project development create anxiety for project developers and investors alike. This will impact the cost of capital reflecting the risk of investing in the project.

Public perceptions

District heating schemes offer customers a simple, reliable form of direct heat delivery without major customer investments. Less floor space and lower capital investments for the customers own heating equipment is required compared to conventional heat supply systems. However due to the natural monopoly created in a district heating scheme individual customers are unable to negotiate prices and delivery conditions. Also the lack of internal competition can reduce future system efficiency improvements. High switching costs and practical difficulties for leaving the systems will capture customers' concern (Frederiksen, 2013). There is also a significant lack of familiarity amongst consumers on district heating. This creates uncertainty in the level of uptake of district heating schemes as local authorities and property developers may find it difficult to persuade building occupants to accept district heat.

Carbon abatement cost effectiveness

The cost of a unit of heat supplied via a heat network varies depending on:

a) The cost of heat sourcing (Example– waste heat from incinerator, CHP)
b) The size of the network/size of the heat demand per unit area

Even in the current market and regulatory environment, there are some combinations of fuel sources and built areas that can offer a competitive value proposition. For example where the district heating scheme (Poyry, 2009):

- uses waste heat from conveniently sited power stations
- replaces resistive heating systems
- supplies commercial premises and high rise flats in high heat density areas

The real benefit of heat networks is the whole system efficiency improvement and the subsequent carbon savings they can deliver. The relative 'carbon savings' of district heating schemes are dependent on the carbon intensity of centralised electricity production and therefore compete with a promise of a decarbonised electricity supply. The uncertainties surrounding the decarbonisation of the electricity network effects investments in district heating schemes as the 'carbon savings' are not guaranteed. Furthermore, under current policies, the benefit of carbon savings is not yet fully rewarded. Nevertheless, a study undertaken by POYRY Energy Consulting (POYRY, 2009), concludes even if the price of carbon is factored in the price proposition is unchanged. Figure 7.4 is an assessment from the POYRY study of the average cost of carbon abatement for a range of district heating options and stand-alone renewable technologies compared to a composite benchmark dwelling.

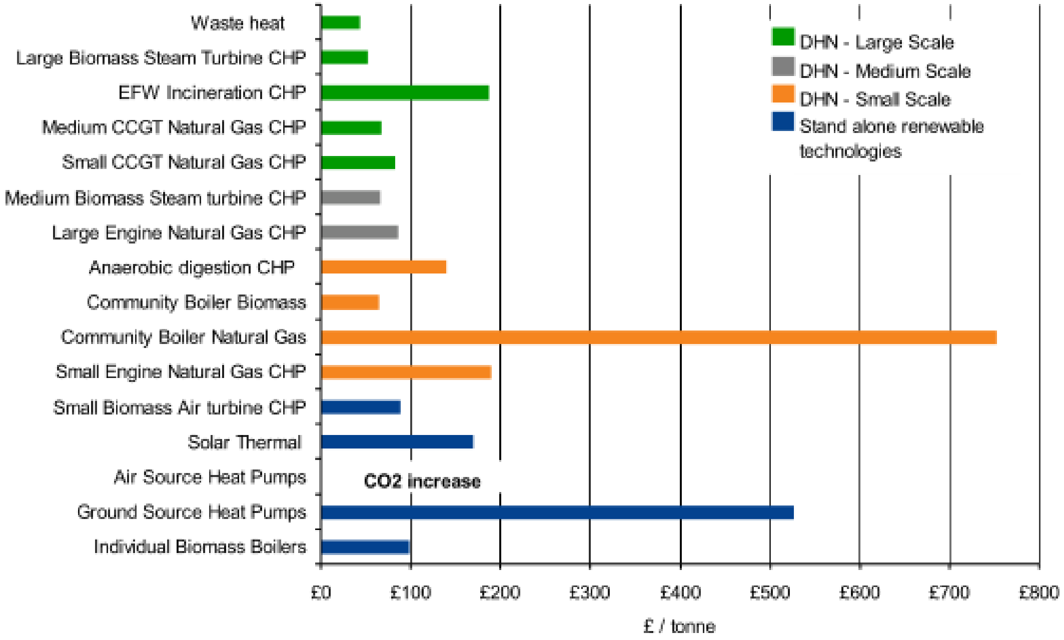

Figure 7.4: Carbon abatement cost relative to the composite benchmark dwelling (Poyry,2009)

In the POYRY study (POYRY, 2009), district heating networks emerged the most cost effective carbon abatement solution where a high penetration (in the region of 80%) in a build-up area can be achieved. It also concludes that district heating remains the cost effective carbon abatement solution in built up areas unless electricity can be decarbonised to a level below 0.15 tCO_2/MWh (uses 0.43 tCO_2/MWh in the study) and without raising the wholesale price of electricity above £45/MWh.

However the carbon abatement competitiveness of district heating is uncertain if,

a) the cost of capital are higher due to perceived risk in investments
b) penetration of network is lower
c) carbon intensity of grid electricity falls without a consequent increase in the price of electricity-which may then favour heat pumps

- **Interdependencies between barriers to heat network deployment and their impact**

The barriers to heat network deployment encountered at different stages of the project can have a varying degree of impact on its progress. Figure 7.5 shows the key barriers to heat network deployment identified, their relative impact (where evidence is available), and inter-dependencies between internal and external uncertainties. The DECC study on the barriers to heat network deployment (14) recognized the relative impact of key barriers as indicated by the interviewees. In the same study, the prevalence of each issue among interviewees was also identified.

The same characterisation in the study is used in Figure 7.5 using a colour code for the level of impact and a marker for the prevalence of the issue. The barriers identified from other reports (CCC, 2013, DECC, 2013b, DECC, 2013e, Poyry, 2009) with evidence on the level of impact and its prevalence are also included.

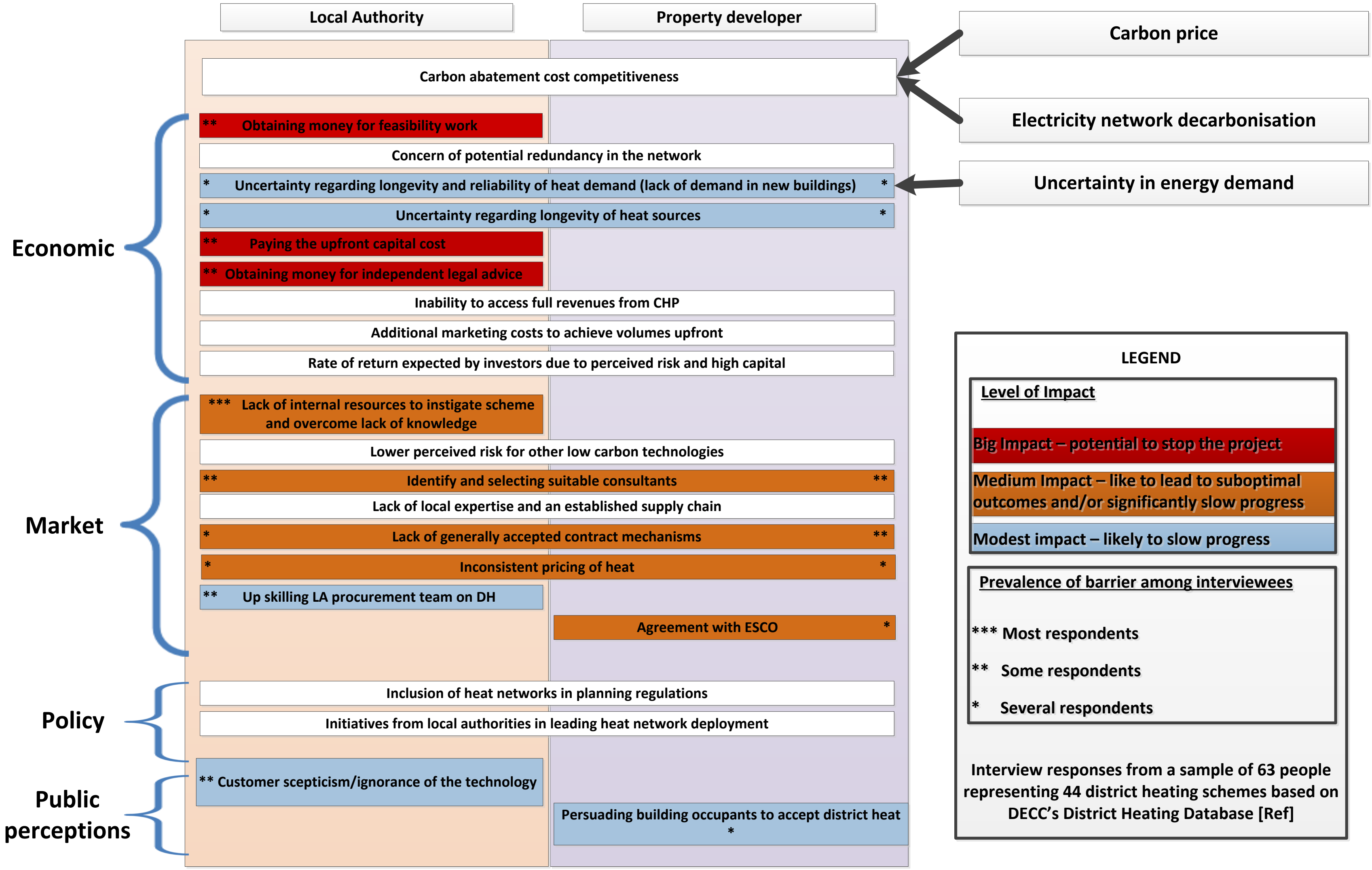

Figure 7.5: Barriers to heat network uptake

7.3 Impact of key uncertainties on costs and carbon abatement

There is a great deal of uncertainty with the cost and carbon abatement potential of heating technologies. CO_2 emissions will depend primarily on the degree of decarbonisation of the electricity system, fossil fuels burned, demand reduction and technology performance (efficiencies). Heat technology cost uncertainties are across a range of components such as capital and fixed costs and fuel prices. The impact of fuel price uncertainty is given greater significance the lower the efficiency of heat technologies.

Fossil fuel prices, directly or indirectly account for a large percentage of overall running costs for a number of heat technologies. This will to a degree remain the case if the electricity sector continues to be fuelled by fossil fuels (CCS etc.) but less so if renewables command a large share of electricity generation. Network reinforcements, especially on the electricity system will have an upward trend in order to facilitate the decarbonisation of heat.

The impact of key uncertainties on indictors such as levelised energy costs, carbon cost of abatement and carbon emissions is explored using an input-output model of key heat technology characteristics in 2030. Figure 7.6 illustrates the projected range of gas and electricity wholesale prices out to 2030 that are used in the analysis (CCC, 2013).

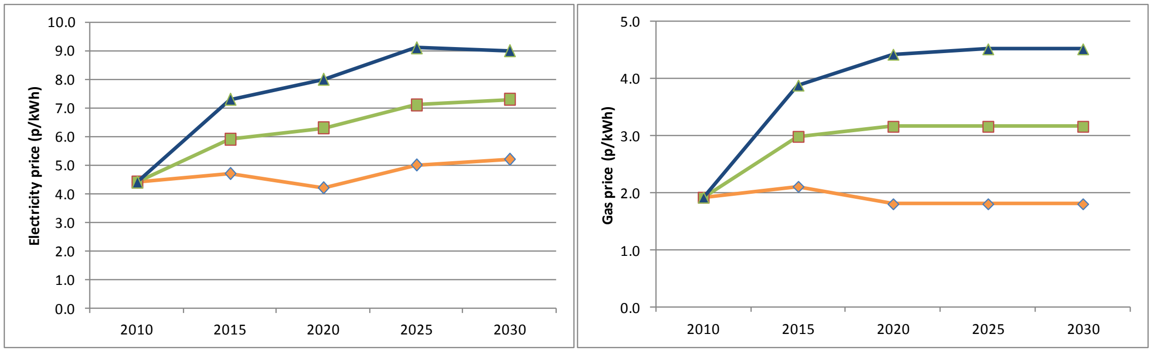

Figure 7.6: range of wholesale gas and electricity prices

The summary of heat technology characteristics in 2030 is shown in Table 7.3.

Table 7.3: Summary of heat technology characteristics in 2030*

Technology	Efficiency	Fixed operational costs (£/kW)	Capital costs (£/kW)
GSHP	1.5 – 5 (SPF) ~ Central: 2.5	5 – 10	940 – 1899
ASHP	1.2 – 4 (SPF) ~ Central: 2.5	4 – 19	513 – 1963
GT-CHP	40 – 50 % (Heat)	48 – 80	Small: 2363 – 4545 large: 657 –864
Gas Boiler	90 –95 %	–	45 –70
Biomass Boiler	90 – 95 %	19 – 30	330 – 1667

*** Central capital and fixed costs are used for the reference case in 2030**

7.3.1 CCC 4th carbon budget reference case (2030)

Technology uptake projections from the fourth carbon budget review were used to establish a benchmark for exploring the impact of key uncertainties. The levelised cost of energy (assumed carbon price of £70 CO_2/kWh by 2030; no other incentives were modelled in the reference case) and the relative carbon abatement cost for key low-carbon technologies for 2030 (electricity grid emissions intensity: 50 g CO_2/kWh) were calculated as shown in Figure 7.7[9].

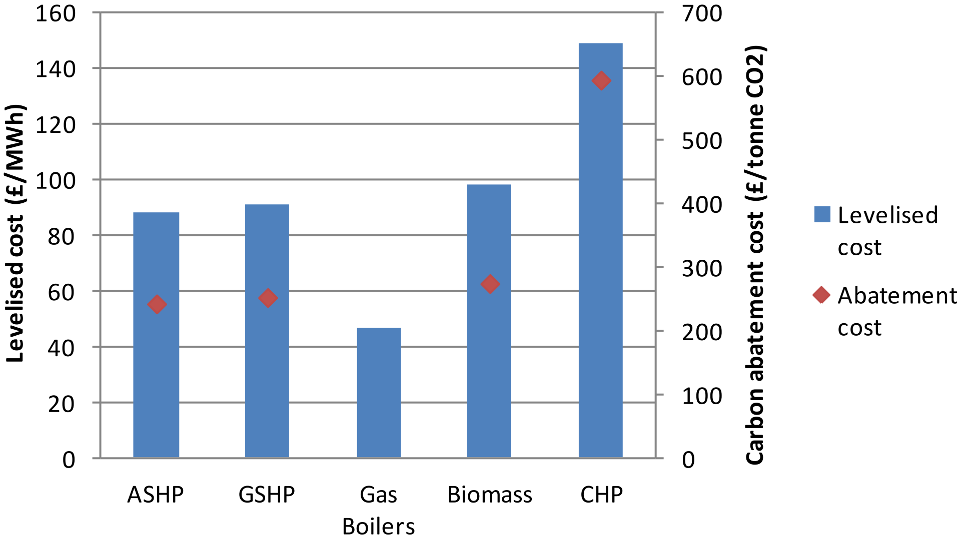

Figure 7.7: CCC 4th carbon budget levelised and abatement costs in 2030 (derived from modelling)

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[9] Levelised cost of energy and carbon abatement costs will differ from official CCC estimates as different capital and fixed costs and efficiencies were assumed (central values from table 7.3 were used). The reference case (2030) is intended to serve as a base to analyse the impact of variation in elements such as capital costs, fuel prices and efficiencies of heat technologies.

The calculated CO_2 emissions in the residential & commercial and industrial sectors are 64 and 65 $MtCO_2$.

7.3.2 Analysis of key uncertainties

➢ Uncertainties in fuel costs

Wholesale fuel costs contribute to a large percentage of the final cost of many heat technologies. Uncertainties in fuel costs as shown in Figure 7.6 could lead to heat technologies going from being cost effective to being less attractive technology choices.

Table 7.4: Impact of fuel price variations on levelised cost of energy (£/MWh)*

Scenario	ASHP	GSHP	Gas Boiler	CHP
Low Gas price	–	–	-14.3	-28.1
High Gas price	–	–	+14	+25.9
Low electricity price	-7.8	-8.4	–	–
High electricity price	+7.4	+6.8	–	–

*In comparison with reference levelised heat technology costs

Table 7.4 illustrates that heat pumps are better insulated to fuel price uncertainty compared with gas boilers and CHP (gas) technologies. This is mainly due to high heat pump efficiencies (SPF).

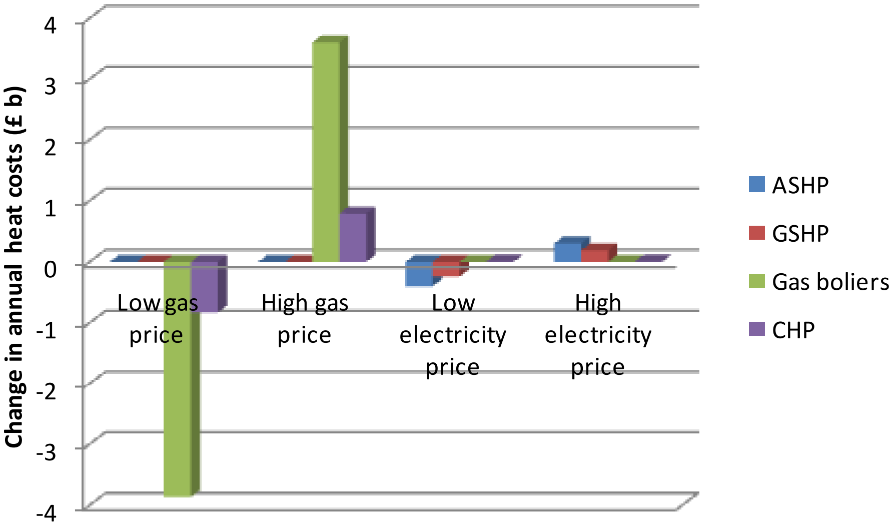

Figure 7.8: Impact of fuel price changes on annual heat costs*

*In comparison with reference levelised heat technology costs

The impact of gas price uncertainty on annual (2030) heat costs is large, running into the billions of pounds (Figure 7.8). Electricity price variation has much lower impact on overall heat costs, again mainly due the relatively high efficiency of heat pumps.

The uncertainties in fuel and electricity prices are due to a mix of exogenous and partially controllable factors such as the possibility of successful UK shale gas exploitation that could stabilise peak gas prices and the prospect of large amounts of renewables connected to the electricity system offering somewhat stable electricity prices.

➢ Uncertainties in capital costs

The estimated capital costs of low-carbon heat technologies vary widely (Table 7.3). Capital costs for heat technologies such as ASHP/GSHP have a large impact on the levelised cost of energy especially in comparison to changes in the price of electricity (see Figure 7.9). The reverse is true for gas boilers and gas based CHP technologies (fuel prices dominate).

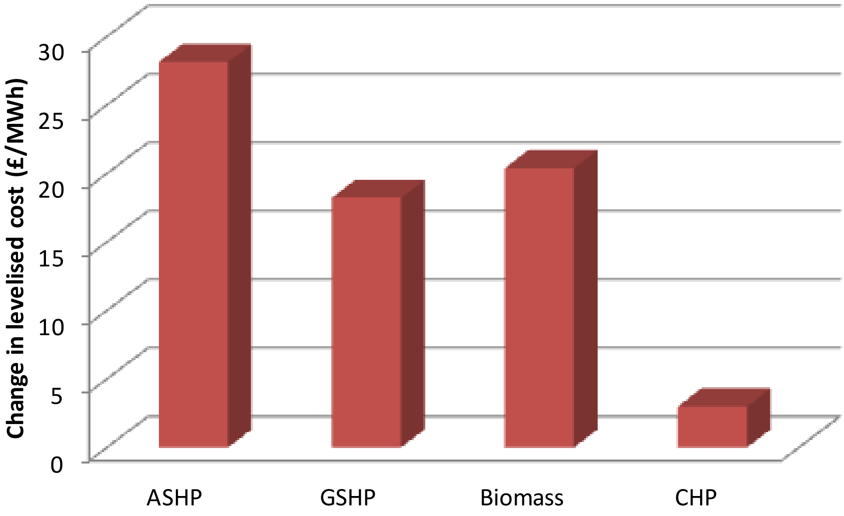

Figure 7.9: Impact of high capital costs on levelised heat technology costs*

***In comparison with reference levelised heat technology costs**

The reduction in capital costs for heat pumps could have an impact of approximately £1.7 billion per annum of total heat supply costs by 2030. With respect to biomass boilers modest saving can be expected with a reduction in capital costs of around £0.3 billion this is mainly due to the low uptake of these in the 4th carbon budget review.

➢ Impact of carbon price uncertainties

Table 7.5 illustrates that heat technologies dependant on fossil fuels suffer as the carbon price increases and gain the most as it drops. There is minimal change in levelised energy cost of heat pump technologies mainly due the virtual decarbonisation of the electricity sector (50 g CO_2/kWh by 2030).

Table 7.5: Impact of carbon price floor on levelised heat technology costs (£/MWh)*

Technology	£50/tCO$_2$	£100/tCO$_2$
ASHP	-0.4	+0.6
GSHP	-0.39	+0.61
Gas Boiler	-3.4	+6.07
Biomass	-0.3	+0.55
CHP	-7.3	+10.7

*In comparison with carbon price of £70/tCO2

The annual cost of heat supply decreases by almost £2.5 billion as a result of a decrease in the price of carbon to £50/tonne CO$_2$ in 2030 to an increase of £3.8 billion if the carbon price increases to £100/tonne CO$_2$.

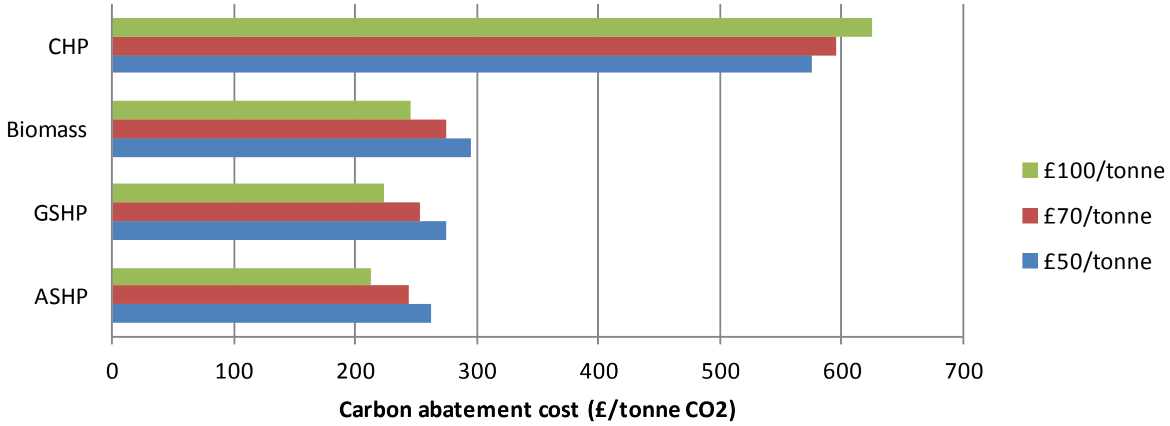

Figure 7.10: Carbon abatement cost of heat technologies*

*Gas boiler is used as counterfactual

The carbon abatement cost of a technology depends on many factors such as the engineering characteristics of the technology itself and of the electricity grid to which the new technology will be connected. The carbon abatement costs shown in Figure 7.10 use gas boilers as the counterfactual technology.

The analysis shows that the cost of carbon abatement of all low-carbon heat technologies (heat pumps and biomass) decrease as the carbon price increases, but values of between 200-250 £/ tonne CO$_2$ remain quite high.

➢ Heat demand uncertainties

The 4th carbon budget assumes a host of energy efficiency and demand reduction measures to be delivered by 2030. The realisation of these targets is difficult to predict. Table 7.6 shows the impact of a 20% increase in total heat demand in 2030 compared with the reference 4th carbon budget review case. The results show CO$_2$ emissions rising by approximately 14%. This places a large burden on the efficiency and demand reduction measures to live up to expectations.

Table 7.6: Impact of heat demand increase on CO_2 emissions $MtCO_2$ *

Sector	Change in CO_2 emissions
Residential & Commercial	+10
Industrial	+8.2

*In comparison with heat pump CCC 4th carbon budget review reference case

➢ Heat technology uncertainties

a) Heat pumps

i) SPF uncertainties

Heat pump SPFs have a large impact on the levelised energy and annual heat pump running costs as shown in Table 7.7. If a heating system is considered to be in operation for 15-20 years then even a modest efficiency improvement can have a significant impact on energy bill savings to consumers; for example an improvement in average ground source and air source heat pump seasonal performance factors (SPF) to the upper values in the analysis could each result in a saving to consumers of approximately £500 million annually given the uptake assumed in the 4th carbon budget review.

Table 7.7: Impact of SPF on levelised costs and annual heat pump costs*

Technology		Levelised cost (£/MWh)	Annual Heat pump running costs (£bn)
ASHP	SPF:1.2	+33	+1.45
	SPF:4	-10.9	-0.51
GSHP	SPF:1.5	+20.1	+0.57
	SPF:5	-15.3	-0.429

*In comparison with heat pump SPF: 2.5

The impact of SPF on carbon abatement costs is quite profound (Figure 7.11). A high SPF pushes heat pump technology into the 130-150 £/tonne CO_2 range. This is quite competitive and could be even lower if capital costs and fuel costs are reduced.

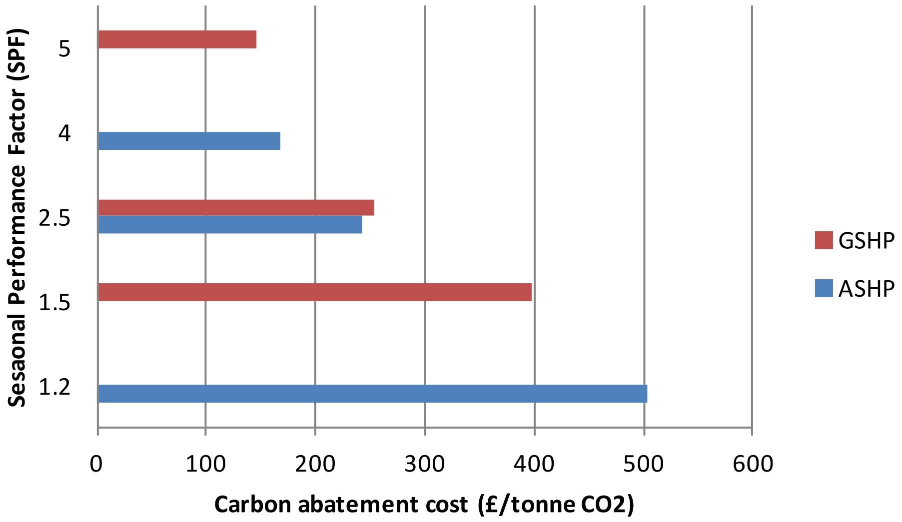

Figure 7.11: Carbon abatement cost of heat technologies with respect to SPF

Additionally the modelling shows SPF values lower than 2.5 could increase emissions by ~2 $MtCO_2$ (given the uptake assumed in the 4th carbon budget review) and this impact would be greater if the electricity grid does not decarbonise to an intensity of 50 g CO_2/kWh by 2030.

ii) Heat pump uptake

The impact of increasing heat pump uptake in the residential and commercial sector by 50% in 2030 compared to the 4th carbon budget review is a 10% decrease in CO_2 emissions. Alongside this heat pump running costs would increase by over £3 billion annually by 2030.

Table 7.8: Impact of heat pump uptake on CO_2 emissions and annual costs*

Technology	Heat pump uptake increase (TWh)	CO2 emissions ($MtCO_2$)	Annual Heat pump running costs (£bn)
ASHP	+22	-7	+3.2
GSHP	+14		
	Total :+36		
	Total :+36		

*In comparison with heat pump CCC 4th carbon budget review reference case

b) Biomass boilers

The Impact of increasing biomass boiler uptake in the residential, commercial and industrial sectors by 50% in 2030 compared with the 4th carbon budget review results in a 10% decrease in CO_2 emissions across all the sectors. There is a decrease in the heat supply running costs this is mainly attributable to lower costs in the industrial sector by use of very efficient biomass boilers (replace gas CHP units that have a heat efficiency of between 30-50%).

Table 7.9: Impact of biomass uptake on CO_2 emissions and annual heat supply costs*

Sector	Biomass uptake increase (TWh)	CO_2 emissions ($MtCO_2$)	Annual heat supply running costs (£bn)
Residential & Commercial	+7.5	-12.9	-0.8
Industrial	+20		
	Total :+27.5		

*In comparison with Biomass CCC 4th carbon budget review reference case

➢ Uncertainty of role of gas and electricity networks

Both gas and especially electricity transmission and distribution systems will have a key part in helping to move to a decarbonised heat sector.

Impacts on the electricity system

Several factors affect the future demand for electricity in meeting the heat demand in residential, services and industrial sectors as shown in Table 7.10.

Table 7.10: Factors affecting future demand on the electricity network in decarbonising heat

Technical
• Decarbonisation of electricity network • Meeting the heat demand during peak winter periods • Rate of uptake of heat pumps • Future role of the gas network • Development of heat networks • Energy efficiency in buildings and industry • Smart grid realisation
Economic
• Electricity network reinforcement • Costs of electrical high temperature process heat • Future gas / electricity prices • Carbon price

Electricity grid carbon intensity

The impact on carbon emissions as the carbon intensity of the grid increases from 50g CO_2/Kwh is minimal (see Table 7.11). This somewhat surprising result is mainly due to low level of heat pump uptake assumed in the 4th carbon budget review, heat demand reduction and relatively high values for heat pump SPFs.

An electricity system with a carbon intensity of 100g CO_2/kWh results in a small increase in the levelised energy cost of heat pumps of approximately £2/MWh. This is mainly due to electricity system carbon intensity and therefore carbon costs having less of an impact compared with the relatively high efficiency of heat pumps (SPF values). But at the same time the carbon abatement costs increase by a larger amount especially for heat pumps. The results also show a small increase in overall heat system costs

(<2%). Overall CO_2 emissions increase by ~+2.5 $MtCO_2$ compared with the 4th carbon budget review reference case.

Table 7.11: Impact of electricity system carbon intensity on carbon emissions ($MtCO_2$)*

Sector	100 g CO2/kWh	200 g CO2/kWh
Residential & Commercial	+1.5	+4.4
Industrial	+1	+3.1

*In comparison with electricity carbon intensity 50 g CO_2/kWh

The impacts of a 50% higher heat pump uptake on electrical energy demand are shown in Table 7.12. In terms of additional generation capacity required to be connected to the grid (with respect to no heat pump uptake) could be between 10 – 15 GW.

Table 7.12: Electricity demand due to increase in heat pump uptake*

Heat pump demand in domestic and commercial buildings sector (TWh)	Electricity demand (TWh)
72 (4th carbon budget review)	28.8
108	43.2

*assuming SPF of 2.5

The majority of scenarios and pathways for reducing overall CO_2 emissions assume a decarbonised electricity grid (50 g CO_2/kWh) which will allow the heat sector to be decarbonised through large scale adoption of heat pumps out to 2050. The analysis in this report does not disagree with this longer term aim.

What the analysis challenges is the notion that the UK must without fail decarbonise the electricity sector by 2030 for heat decarbonisation. The analysis does not support this given what could be called a drastic “reassessment” of heat pump penetration levels from the original CCC 4th carbon budget (143TWh to 72TWh in the residential and commercial sectors with the slack taken up by heat networks that are not unduly impacted by electricity system decarbonisation). On the other hand if heat pump uptake is much higher than envisaged in the CCC 4th carbon review then the impact of electricity decarbonisation on heat related emissions is greater.

These results are firmly based on heat pump efficiencies being at 2.5 SPF. Higher SPF efficiencies in 2030 will show a larger impact on CO_2 emissions due to variation of electricity grid emission intensities (and vice versa). It can be noted that the total impact of uptake of heat pumps on demand from the electricity network is relatively small in comparison to the total electricity demand expected by 2030. Therefore this level (4th carbon budget review) of heat pump uptake has a relatively low impact on overall electricity system reinforcements as summarised in Table 7.13.

Table 7.13: Impact of heat pump uptake on the wider energy system

Heat pump uptake level by 2030	Electricity network reinforcement	CO_2 reduction	Costs
(60< & 120> TWh/yr)		~15MtCO$_2$ by 2030 if 100 TWh/yr heat delivered (CCC, 2013)	Costs of electricity distribution infrastructure around £350million in 2030 (CCC, 2013)
(>120TWh/yr)	Upto 4 TWh/yr increase in electricity demand by 2030 (NationalGrid, 2012)	~30MtCO$_2$ by 2030 if 160 TWh/yr heat delivered (CCC, 2013)	

Impacts on the gas system

The gas network will continue to play a key role by 2030 according to the 4th carbon budget review. Gas will play a vital role in helping to balance the electricity system with large amounts of renewables connected to the grid. Gas boilers are expected to continue alongside heat pumps in the form of hybrid systems to potentially meet the peak heat demand.

Currently the heat demand met by the gas network is ~540 TWh. This will reduce to approximately 300 TWh/yr (4th carbon budget review) and to 250 TWh/yr if there is a 50% increase in heat pump uptake by 2030. There are several factors that affect the role of the gas network and the extent to which it is going to be used; these are highlighted in Table 7.14.

Table 7.14: Factors affecting future role of gas network

Technical
• Meeting the peak heat demand • Uptake of heat pumps • Developing heat networks • Energy efficiency in buildings and industry • Security of supply of alternative fuels
Economic
• Decommissioning • Future gas / electricity prices • Carbon price • Iron Mains Replacement Programme
Market
• Gas exports and imports • Shale gas • Power generation demand

7.4 Managing Uncertainty

7.4.1 Heat pump uptake

Significant barriers remain in achieving the required levels of heat pump uptake by 2030. Nevertheless, a study by Frontier economics and element energy for CCC suggests the estimated uptake in the cost effective scenario is achievable by means of a range of policy measures and market maturity. Managing the uptake of heat pumps will require the government to use both 'carrots and sticks' type policy measures. Figure 7.12 shows the classification of measures that can encourage uptake and thus help manage the uncertainty in heat pump uptake levels. These measures can be categorised as:

- **Enabling measures**: Measures that tackle behavioural barriers to uptake such as awareness and confidence
- **Incentivising measures (carrots)**: Measures that provide financial stimulus
- **Mandating measures (sticks)**: Regulatory requirements

Figure 7.12: Measures to encourage heat pump uptake (Frontier Economics & Element Energy,2013)

Enabling measures can be put in place to manage uncertainties related to behavioural barriers in heat pump performance and awareness. Enhanced heat pump certification schemes mandating installers and consumer to obtain training can help delivering high standards in the design and installations of heat pump systems. This would improve the performance and thereby the confidence and awareness in technology. 'Enabling' type measures have proven to be effective in other countries with successful heat pump markets.

The RHI is expected to drive the market for heat pump uptake up to 2020. Gas prices are expected to remain relatively unchanged by 2030 and therefore the counterfactual technology (gas boiler) will remain cost competitive in most building installations.

Extending the RHI subsidy beyond 2020 might be required to maintain sustained growth in the heat pump market if the consumers are to make savings by adopting heat pump systems. Capital grants in terms of voucher schemes or Renewable heat premium payment type payments or those under energy supplier obligations (CERT, ECO) are able to provide support to customers in meeting the gap in upfront capital cost difference with the traditional systems. In many European countries it is reported that capital subsidy schemes are more common than RHI style subsidies. Another method of incentivising is to provide loan guarantees as those provided via the ‘Green deal’ scheme.

By linking the green deal scheme to heat pump uptake policies it can be ensured that the installations take place at cost effective sites. A higher carbon price will also encourage the uptake of heat pumps by making gas and oil relatively more expensive. It is a good idea to initially focus on the off-gas market where the savings will be higher and replace the most carbon intensive heating systems. National grid studies show that the uptake of heat pumps in the off-gas sector will have a reducing effect on the electricity demand as these will replace energy intensive electric heating systems.

Mandating measures can be established via regulation to initially drive the new build sector to consider heat pumps as a preferred option. Tightening the carbon emissions standard on the new build sector and also on heating system replacement are two of the possible regulation options to drive the heat pump market while allowing consumers the flexibility to choose the most cost effective solutions.

In the case of a high rate of uptake of heat pumps, the repercussions on the electricity network will need to be managed carefully.

7.4.2 Heat network uptake

Uncertainties related to the deployment of district heating schemes can be managed by addressing issues with market immaturity and up-scaling local authority skills and capabilities in the UK. Trade organizations such as UK District energy association and the Combined Heat and Power Association are already addressing many issues related to preparing standards for industry practices. The following were identified as potential solutions to deal with inconsistencies in the industry.

- Develop a model customer charter/code of conduct which would include standard forms of payment, service standards, treatment of bad debt and disconnection procedures etc.
- Improve transparency in pricing of heat
- Making available standard contract documentation
- Making available a generic technical requirement specification

Furthermore to deal with the skills gap, provision of an independent advisory service was proposed by DECC. Genuine expertise in district heating project development, unbiased commercial interests and the availability to work systematically with the developer should be key characteristics in a potential advisory service.

Local authorities are key instigators of district heating schemes and should be better equipped to understand the potential benefits of heat network development and work with numerous stakeholders. Therefore the local authority skills and capabilities in managing district heating project should be up-scaled. It would be beneficial to mandate local authorities to consider potential for district heating in local planning. The ability to share information of experience in project development can be a key enabler to drive schemes forward.

Financial support for district heating from the government is important in unlocking the potential for district heating scheme deployments. Also a type of RHI payment for heat networks will enable developers to build a stronger business case for projects. Reducing the commercial risk of district heating scheme is key to project initiation. This could be managed by government putting in place mechanisms to underwrite risks to the developer.

Combined heat and power generation are central in district heating scheme development. Tightening the power station consents policy to mandate CHP and insisting on co-location of generation plant with heat loads could support the case for building heat networks.

7.4.3 Modelling Policy measures

The RHI is the government incentive to encourage a switch to renewable heating systems for domestic and non-domestic buildings. Payments for the domestic RHI are based on meter readings of your heating systems annual heat use multiplied by the appropriate tariff (Table 7.15). These payments are for a maximum of seven years for domestic RHI and 20 years for non-domestic RHI. The tariffs are initial values and will be reduced as the overall budget for each scheme is approached. The budget for the RHI as whole is set at £430 million for 2015/16.

Table 7.15: Summary of domestic RHI tariffs

Technology	Domestic RHI (p/kWh)
GSHP	18.8
ASHP	7.3
Biomass boiler	12.2

The RHI removes the barrier of additional heat technology costs, helping to create a level playing field between renewable and conventional heating technologies and widen the choice of heating options. It is expected that over time, the cost of renewable heating technologies will fall as technologies enter the mainstream and the benefits from economies of scale become more evident. But the renewable heat deployment levels in the 4th carbon budget review are relatively ambitious (even though they have been downgraded since the original 4th carbon budget announcement) given that heat pump and biomass boilers do not compete with gas boilers in domestic buildings even if favourable conditions occur such as low capital and electricity prices. Figure 7.13 shows the levelised energy cost of technologies in domestic buildings.

Two policies for encouraging uptake of renewable heat technologies were assessed. Firstly carbon prices were increased from £70 to £100 per tonne CO_2 (+£30 t/CO_2). This had a marginal impact on levelised energy costs of heat pumps and biomass boilers. The impact on gas boilers were appreciable but not enough by itself to lead to further investment in renewable heat technologies.

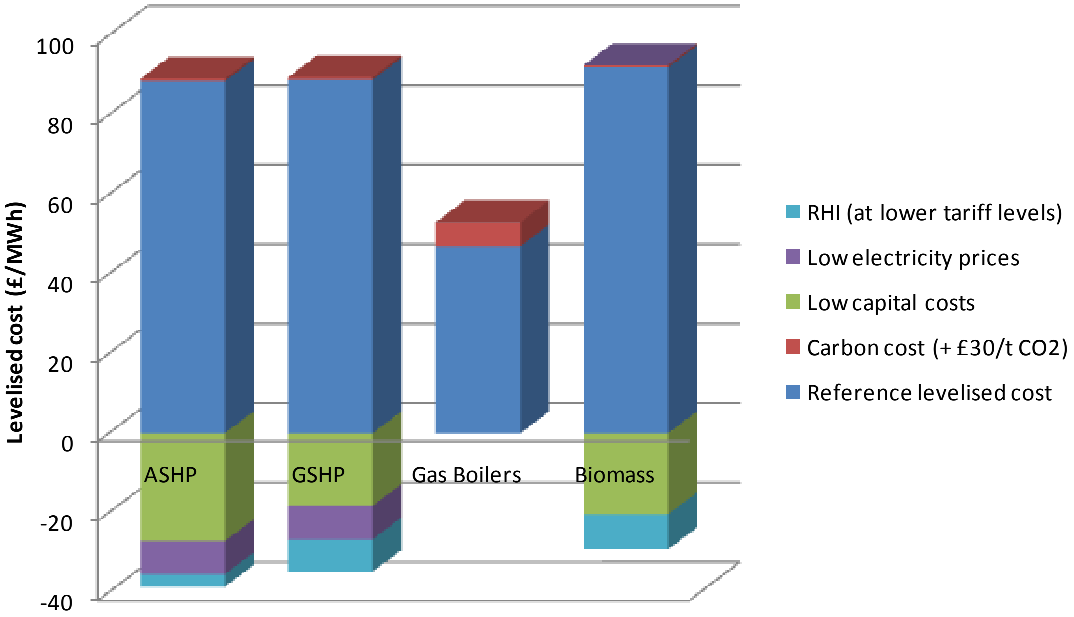

Figure 7.13: Impact of policies and costs on levelised energy cost of heat technologies

The second policy modelled was a continuation of the RHI through to 2030 by keeping the budget at 500 million per year (the budget is spread over a larger installed capacity of low-carbon heat technologies therefore reducing the overall p/kWh RHI tariff) and at 4th carbon levels of heat pump and biomass uptake. This in itself narrows the gap between the levelised energy costs of air source heat pumps and gas boilers to near identical levels. With extra carbon price support (+£30 t/CO_2) GSHPs are also within touching distance with gas boiler levelised energy costs.

Under these favourable conditions, carbon abatement costs drop to in the region of £150 –175 /tonne of CO_2 across all low-carbon heat technologies. With technology learning especially with heat pump technologies (SPF improvements; lower capital costs) the carbon abatement costs will drop to below £100/tonne CO_2.

8 Summary and conclusions

The UK's climate strategy, through implementation of a series of carbon budgets will set the UK on a path to decarbonise the whole economy and meet the 2050 carbon targets. The 4th carbon budget review attaches great importance to reductions in carbon emissions in the heat sector in the 2020s and therefore laying out the foundations to further reductions by 2050.

The aim of this project is to explore the risks and uncertainties associated with the transition to a low-carbon heat system in the UK out to 2030 and investigate the potential impact of these uncertainties in the development of the heat supply infrastructure.

In 2012, direct buildings CO_2 emissions accounted for 91 $MtCO_2$ with gas supplying the majority of the energy supply. Industry accounted for 116 $MtCO_2$ of direct CO_2 emissions. The 4th carbon budget aims to reduce these CO_2 emissions to approximately 64 and 65 $MtCO_2$ in domestic/commercial buildings and industrial sectors by 2030.

The 4th carbon budget review ascribes prominent roles to demand reduction, efficiency improvements and to the deployment of heat pumps in efforts to reduce CO_2 emissions by 2030. The cost effective path assumes heat pump deployment of 72 and 10 TWh in the domestic/commercial buildings and industrial sectors. Other technologies such as heat networks and biomass boilers will also play key roles in helping to decarbonise the heat sector.

There is a great deal of uncertainty regarding the achievement of low-carbon heat technology deployment levels and ultimately CO_2 emissions by 2030.

- **Uncertainties of heat pump deployments**

  The performance of heat pumps is of paramount importance. The assumption is that most if not all types of heat pumps will have a SPF of at least 2.5. The reviews and modelling showed that lower SPF values could increase emissions by 2 $MtCO_2$ (at uptake levels assumed by the 4th carbon budget review) and the impact would be greater if the electricity grid does not decarbonise to an intensity of 50 gCO_2/kWh by 2030. So there is a great emphasis on improving the performance of heat pumps through the period to 2020 and beyond. This can only be done if the uptake of heat pumps is relatively steady now and increases so technological learning can take place.

  Currently the levelised energy cost of heat pumps is high when compared with gas boilers. This will most likely still be true by 2030. This is a major barrier for deployment of heat pumps and other technologies such as biomass boilers. Most of these technologies have high upfront capital costs that make a very large contribution to their levelised energy costs in comparison with incumbent technologies such as gas boilers. This issue is one that will only resolve itself with technological learning (cost reductions and efficiency improvements) and experience gained by installers to efficiently design heat based systems.

- **Electricity grid decarbonisation uncertainties**
  The analysis showed that given the deployment of heat pumps (main consumer of electricity in 2030 for heating in domestic buildings) in the 4th carbon budget review the impact of not meeting the 50 gCO_2/kWh target by 2030 is not catastrophic for CO_2 emissions. But if heat pump uptake is larger than envisaged in the 4th carbon budget review and or efficiencies do not improve CO_2 emission reductions will not meet expectations. The aim is to reduce uncertainties by making sure that the power system is decarbonised so that performance and cost based uncertainties have a lower impact given potential pessimistic outcomes. In the longer term out to 2050 the heat system decarbonisation agenda very much rests on the shoulders of decarbonising the electricity grid to meet the 2050 CO_2 emissions target.

- **Heat network deployment uncertainties**
  The 4th carbon budget review provided a boost to heat network deployment levels from 10 to 30 TWh by 2030. This is a significant increase. Firstly there are significant economic barriers, mainly focussed around digging, laying of hot water pipes and high upfront capital costs for potential customers. Secondly, issues with public perception. There is a distinct lack of knowledge about heat networks (heating capabilities) including the charging methodology and awareness of services offered.

  A review of heat networks showed that in terms of carbon abatement costs they are an effective solution in built up areas. But this was dependant on the electricity system being decarbonised to a carbon intensity of no less than 150 gCO_2/kWh. Uncertainties also exist in the penetration level of heat networks.

- **Managing uncertainty**
  Enabling measures can be put in place to manage uncertainties related to public perception for technologies such as heat pumps and heat networks. For heat pumps, performance could be highlighted and awareness of both heat pump and heat networks could be increased by government and industry via exemplars. Confidence in these technologies could be further enhanced by ensuring that

installers abide by high standards in the design and installations of heat pump and heat networks.

Extending the RHI subsidy beyond 2020 might be required to maintain sustained growth in the heat pump market if consumers are to make savings by adopting heat pump systems. The modelling showed an extended RHI scheme could make heat pumps more competitive with the incumbent gas boiler but only if capital costs are consistently reduced to the low end of uncertainty range. This will need a steady uptake of heat pumps over the period to 2020 and beyond to allow learning to take place. This will most likely only occur if RHI support is maintained.

One can take this argument further and extend it to heat networks, it would be inconsistent for the government to continue to support the RHI for standalone technologies without offering a similar level of support for heat network development so that costs and risks through learning can be reduced and best practice in the system design process can improve over time.

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