elementenergy

An evidence based strategy for delivering zero carbon heat in Bristol

A report for

Bristol City Council

October 2018

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Version control

Version	Date	Comments
1.0	21/05/2018	First version for client review
2.0	18/07/2018	Second version for client review
3.0	05/10/2018	Final version

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1 Executive summary

1.1 Summary of context, objectives and methodology

Bristol has made a commitment to become carbon neutral and to be run entirely on clean energy by 2050. Meeting this goal will require the complete or near-complete decarbonisation of energy use in Bristol, including the energy used for heating, transport and electricity. This study examines the potential pathways to complete or near-complete decarbonisation of heat for space heating and hot water, which accounts for approximately one-third of Bristol's carbon emissions today[1].

The objectives of this work are to:

- Determine the potential of low carbon heating technologies to contribute to Bristol's ambition of being carbon neutral by 2050;
- Compare the possible pathways to deep decarbonisation of heat in Bristol, in terms of the associated cost, risk and level of uncertainty;
- Identify low regrets actions common to most or all pathways in the short and medium term;
- Highlight policy 'gaps' in relation to low carbon heating technology deployment, where existing policy measures do not meet the required level of ambition;
- Identify key decision points in time on the pathway to deep decarbonisation;
- Develop criteria to define zones with potential for the development of heat networks in Bristol.

At a high-level, our approach to achieve these objectives has been a bottom-up assessment of the potential for a variety of low carbon technologies to drive decarbonisation of heat in Bristol, an estimate of the likely level of decarbonisation achieved and cost incurred to 2050, and an analysis of the policy and technology conditions required for the stated level of decarbonisation to be realised. We have used the best-available data sources, wherever possible using sources specific to Bristol.

1.2 Summary of results and key findings

We have developed a series of scenarios representing a possible pathway for Bristol's heat sector to 2050. A headline description of the scenarios studied is provided in the box below, with an accompanying high-level description of the level of deployment of various technologies in each scenario in Table 1-1. We present in Figure 1-1 a profile of the heat demand met by the various technology options in 2050. Further detail on the scenarios is found in section 5.

[1] Our analysis finds current annual carbon emissions from heating (space heating and hot water, excluding industrial process heating) of 659 $ktCO_2$. This represents approximately one-third of the annual economy-wide emissions for Bristol in 2013 of 2.0 $MtCO_2$ as presented in Bristol City Council's 2015 study: *Our Resilient Future: A Framework for Climate and Energy Security.*

Baseline: Reflects current policy ambition regarding the uptake of heating technologies. It assumes low uptake of most technologies beyond 2025 in the absence of new policies, incentives and regulations.

High HNs (heat networks): Ambitious policy to develop decentralised energy in Bristol is implemented, led at the local level. In addition to the extensive development of heat networks served by low carbon heat sources, the gas grid is partially decarbonised using biomethane and bio-synthetic natural gas (bio-SNG).

High HPs (heat pumps): Heating is dominated by heat pumps, including hybrid gas-electric heating in the medium term, as a result of ambitious policy to electrify heating and decarbonise the electricity grid. No policy effort to decarbonise the gas grid, which serves no heat demand in buildings by 2050.

Decarbonised gas: Bristol's gas grid is repurposed to deliver 100% low carbon hydrogen from 2040, following a national decision to convert large parts of the UK's gas grid. Medium level of heat networks served by low carbon sources including hydrogen. Medium level of deployment of heat pumps in near term, mainly in off-gas grid areas unsuitable for heat networks.

High HNs and High HPs: Aiming to achieve the deepest level of decarbonisation possible through the deployment of proven technologies, rollout of heat networks is pushed to the same level as in the High HNs case, with heat pumps meeting almost all the remaining heat demand.

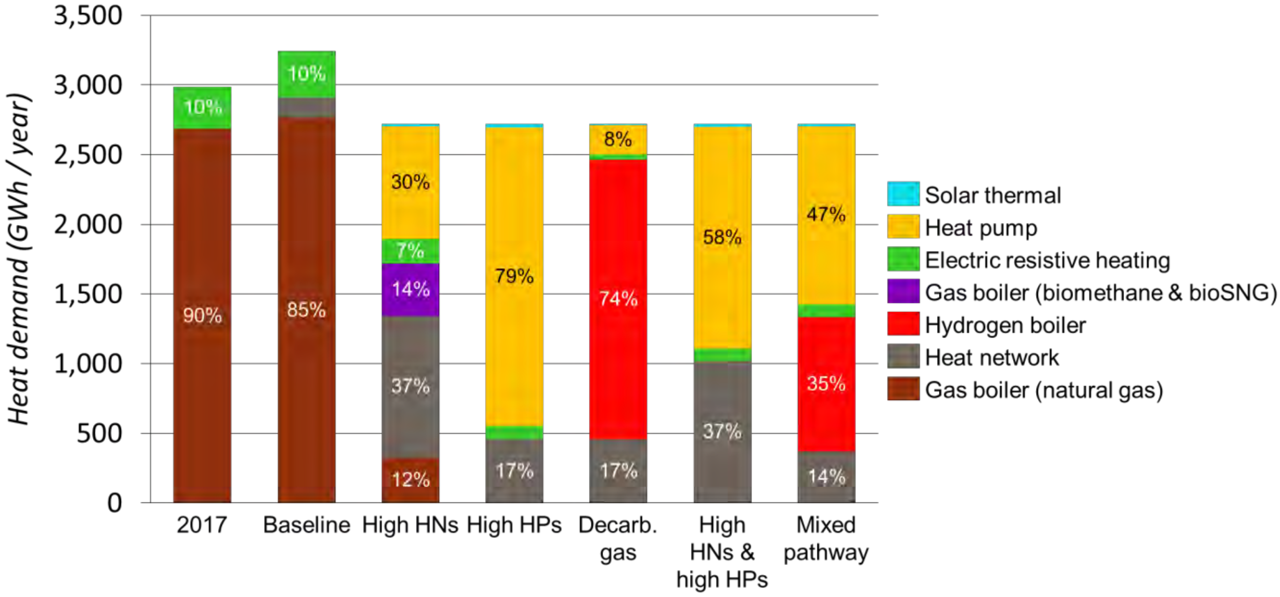
Mixed pathway: To mitigate the risk that hydrogen heating will not prove to be viable, heat pumps and heat networks are deployed widely into the 2030s. Following the viability of hydrogen heating being proven, gas grid is converted to 100% hydrogen to serve the remaining gas customers. By 2050, the hydrogen grid serves around half the number of customers served by the gas grid today.

Table 1-1: High level description of the technology deployment level in each scenario[2]

	Baseline	High heat networks	High heat pumps	Decarbonised gas	High heat networks & high heat pumps	Mixed pathway
Energy efficiency	Low energy efficiency	High energy efficiency	High energy efficiency	High energy efficiency	High energy efficiency	High energy efficiency
Heat networks (HN)	Low HN deployment	High HN deployment	Medium HN deployment	Medium HN deployment	High HN deployment	Medium HN deployment until 2040
Heat pumps (HPs)	No HPs	Medium HPs & hybrid HPs	Widespread HP roll-out	Low HPs & hybrid HPs	Widespread HP roll-out	Widespread HP rollout to 2040
Green gas	No green gas	Maximum green gas deployment	No green gas	No green gas	Some green gas deployment	No green gas
Hydrogen (H_2) gas	No H_2	No H_2	No H_2	Full H_2 conversion in 2040s	No H_2	Full H_2 conversion in 2040s
Grid decarbonisation	National Grid FES Steady state	HMT Green Book	HMT Green Book	HMT Green Book	HMT Green Book	HMT Green Book

[2] Note: a summary of the descriptors for uptake by technology type can be found in section 0, Appendix D

Figure 1-1: Heat demand met by each technology in 2050 in the six scenarios. NB: segment labels added only for values larger than 5%



The resulting carbon emissions trajectory of the heat sector in each scenario is presented in Figure 1-2, where the upper chart shows the annual emissions and the lower chart shows the cumulative emissions. In addition, the 'low regrets' measures, which are the measures installed under the 'low regrets' actions (defined as actions should be acted on urgently in order to keep pace with the required level of emissions reduction) are also shown in Figure 1-2.

The low carbon heating options studied here are able to achieve very low levels of carbon emissions, but no scenario reaches the target of 'carbon neutral' heating in 2050. This is due to the modelling assumption that all scenarios rely either on electricity consumption from a grid that is not fully decarbonised (since we have used the HMT Green Book scenario carbon intensity projection[3]), or on hydrogen produced using Steam Methane Reformation (SMR) and Carbon Capture and Storage (CCS)[4] for which the CO_2 cannot be completely captured, or both. These emissions are therefore related to factors which may be largely outside Bristol's control.

We note that all scenarios are consistent with zero carbon emissions, under certain circumstances. In the case of electrification of heat, this could be achieved through full decarbonisation of the electricity grid using renewable sources. In the case of decarbonised gas, this could be achieved through the use of hydrogen produced through electrolysis using renewable electricity. An alternative approach to achieving carbon neutrality involves a continued reliance on heating technologies that emit some carbon, whilst also using 'negative emissions technologies' to achieve zero *net* emissions[5]. In this study,

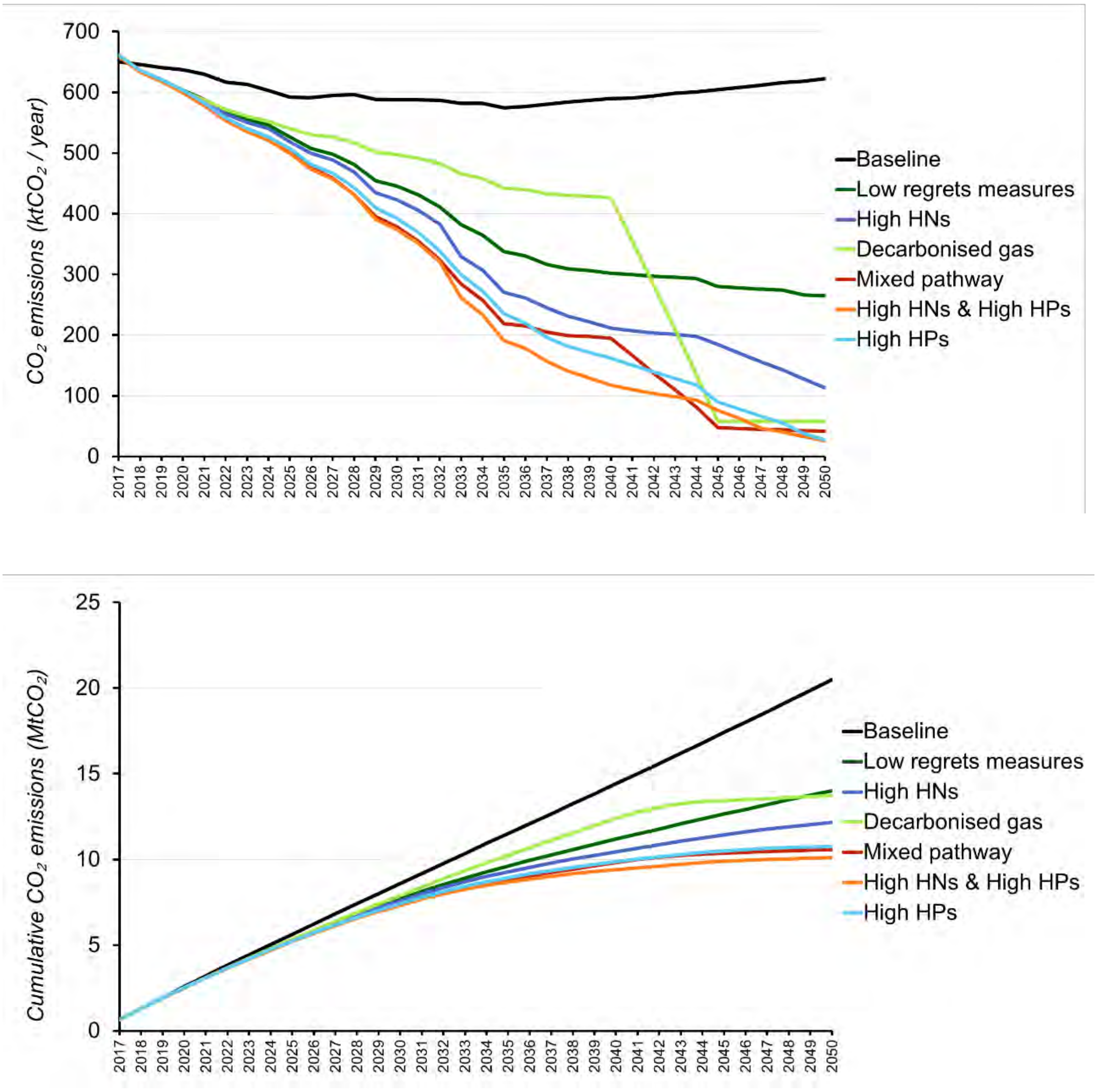
[3] HM Treasury Green Book supplementary appraisal guidance, Table 1 (December 2017)

[4] SMR with CCS is likely to be the most cost-effective source of bulk low carbon hydrogen. SMR uses a natural gas feedstock, reacted with steam under high pressure, to produce hydrogen. During the SMR process that can be used to produce hydrogen, there are carbon emissions, however, the emitted carbon is in a form that can be captured relatively easily, and then stored in offshore CO_2 storage sites.

[5] Negative emissions technologies encompass a wide variety of technologies or processes, some of which are already available (e.g. CO_2 capture through soil, afforestation and reforestation) but many of which are at an early stage of technological development (e.g. the combustion of bioenergy combined with carbon capture and storage (CCS), direct air capture and enhanced weathering). A detailed assessment of these technologies is outside the scope of this study. It is important to note, however, that negative emissions technologies have a limited potential to offset carbon emissions, and it would be highly risky to consider them an alternative to deep reductions in direct carbon emissions. However, negative emissions could have a useful role to play in offsetting a small remaining amount of emissions following a deep, but not complete, reduction in direct emissions.

we therefore consider options which achieve a deep level of decarbonisation, but we do not limit the analysis only to options that result in zero 'direct' emissions. However, it is crucial to keep in mind that for pathways in which direct emissions are not reduced to zero, achieving carbon neutrality will be reliant on negative emissions technology of some form. This can be considered as an additional risk of such pathways.

Figure 1-2: Emissions results for the six scenarios, annual (top) and cumulative to 2050 (bottom)



The key energy and emissions findings from the results presented are summarised below:

- All low carbon scenarios, apart from the High HNs scenario, achieve annual carbon emissions of less than 60 ktCO$_2$ / year in 2050, which represents a more than 90% reduction versus current levels.
- The High HNs scenario is limited by the feasible level of deployment of heat networks, which is determined by the share of heat demand located in sufficiently densely populated areas and in new build developments.

- The Decarbonised gas scenario reaches deep decarbonisation by 2050. However, the cumulative emissions to 2050 in this scenario are higher than for all other scenarios except the Baseline. It is unlikely that hydrogen deployment at scale could occur much earlier than 2040, due to the time required for the component technologies, including CCS, to become commercially viable. Therefore, carbon emissions in this scenario remain above 400 ktCO_2 / year to 2040.
- The three scenarios that achieve the lowest cumulative emissions to 2050 are the Mixed Pathway, High HNs & high HPs and High HPs. These all rely on high levels of heat pump uptake – continuing until 2050 for High HPs and High HPs & high HNs, or until 2040 for the Mixed pathway, prior to conversion of the gas grid to hydrogen.
- There is, however, substantial uncertainty over the achievable levels of decarbonisation using the low carbon heating options presented. The key risks associated with the different technology options are presented in section 6, along with an indication of the risk bearer, the type of risk and potential actions to mitigate the risk.

Cost comparison

Table 1-2 provides a cost comparison between the scenarios alongside the carbon emissions results, including estimated high and low sensitivities on the cost. The costs are segmented into building-level, infrastructure and fuel costs, to indicate where the investment is required in each case and how this differs between the scenarios. The key cost findings are summarised below:

- The comparison of total cumulative undiscounted cost to 2050 across all decarbonisation scenarios (i.e. excluding the Baseline) suggests that the range of uncertainty in the cost is of the same order as the difference between scenarios. This suggests that there is no clear least cost scenario at this stage.
- All decarbonisation scenarios are likely to be more costly than the Baseline scenario.
- The Decarbonised gas scenario carries the greatest uncertainty in cost, mainly relating to the uncertainty in the cost of hydrogen production.
- We note that under the Central cost sensitivity, the lowest cumulative fuel cost is found for the Decarbonised gas scenario. This, however, is not reflective of the fuel costs associated with hydrogen heating, but of the continued use of natural gas heating until 2040.
- The investment required to achieve decarbonisation of heat is distributed in different ‘types’ of investment across the scenarios. Large infrastructure costs are highest in the scenarios with the greatest deployment of heat networks. The building-level costs are highest in the cases with high deployment of heat pumps. A range of different types of financing will be required to raise these different types of investment.
- While the infrastructure costs associated with converting the gas grid to enable hydrogen heating, or of reinforcing the electricity grid to allow widespread deployment of heat pumps, are substantial, they represent a relatively small share of the overall cost of heating, which is dominated by the fuel and building-level costs.

Table 1-2: Summary of scenario emissions and discounted cumulative scenario investment results to 2050 with central, low and high cost sensitivites

		Baseline scenario	High HNs	High HPs	Decarb. gas	High HNs & high HPs	Mixed pathway
Annual emissions in 2050 ($ktCO_2$)		**623**	**118**	**27**	**58**	**26**	**42**
Cumulative emissions to 2050 ($MtCO_2$)		**20.5**	**12.1**	**10.8**	**13.7**	**10.1**	**10.6**
Cumulative undiscounted cost to 2050 (£ bn)	Low	7.9	11.1	10.9	9.1	11.9	10.3
	Central	**9.1**	**12.5**	**12.1**	**10.3**	**13.3**	**11.6**
	High	9.8	13.5	12.8	11.6	14.3	12.4
Building level costs (£ bn)	Low	2.3	4.1	5.0	3.7	4.9	4.5
	Central	2.3	4.2	5.3	3.7	5.2	4.7
	High	2.3	4.3	5.5	3.8	5.3	4.8
Infrastructure costs (£ bn)	Low	0.4	2.4	1.2	0.9	2.4	1.0
	Central	0.4	2.5	1.3	1.1	2.6	1.2
	High	0.4	2.6	1.3	1.1	2.7	1.3
Fuel costs (£ bn)	Low	5.2	4.6	4.7	4.5	4.6	4.7
	Central	6.3	5.8	5.6	5.5	5.7	5.7
	High	7.0	6.6	6.0	6.7	6.4	6.4

1.3 Recommendations

Low regrets actions

Some or all of the decarbonisation scenarios, and all scenarios that reach the lowest levels of cumulative emissions to 2050, have several commonalities in the short term. We have identified these commonalities as ‘low regrets’ actions, which should be acted on urgently in order to keep pace with the required level of emissions reduction.

- ***Low regrets action 1: retrofit Bristol’s building stock to the level described in the ‘high energy efficiency’ target. This involves the retrofit of the majority of existing buildings to EPC C by 2030 and all remaining energy efficiency measures wherever practical by 2040.***

This will involve targeting the estimated 36,000 cavity walls, 10,000 lofts, 56,000 solid walls, and 130,000 floors that remain uninsulated, or insufficiently insulated, in Bristol. This action will help to ensure lower energy bills for consumers irrespective of the long-term pathway. High levels of energy efficiency are also a pre-requisite for deep electrification of heat using heat pumps.

The rate at which energy efficiency measures are currently being installed in Bristol falls well short of the rate required to achieve this action. While a substantial increase in energy efficiency retrofit rate will likely be reliant on a renewal of national policy in this area, Bristol can and should take action to promote the deployment of energy efficiency in the local area in various ways. As such, we recommend the continued support of existing initiatives that address this action, such as *Warm-up Bristol*, and a consideration of the ways in which such schemes could be extended and expanded. Key actions to support uptake of energy efficiency include raising awareness of the benefits of energy efficiency to residents and businesses; actively identifying households eligible for national schemes (such as the Energy Company Obligation); and developing or facilitating new ways to bring together lenders, local suppliers and installers and customers to provide low cost finance for energy efficiency, while making use of national schemes. Bristol could also join with other local authorities (or through the mayoralty of the West of England) to lobby the national government to raise the level of ambition for energy efficiency policy, providing an evidence base to demonstrate the need for increased ambition.

- ***Low regrets action 2: promote the extensive development of low carbon heat networks in Bristol including the Strategic Heat Main***

We recommend strong planning policy and financial support for the rollout of heat networks in new and existing buildings, at least to the extent set out in the 'Medium HN' level of deployment. This includes the completion of Temple & Redcliffe, City Centre Phase 1 and 2, and construction of the Strategic Heat Mainly to allow the supply of low carbon waste heat from Avonmouth to the city centre. We recommend that these networks be constructed as soon as possible, entailing the connection of approximately 3,300 new buildings and 6,700 existing buildings by 2030, representing 26% of new build heat demand and 8% of existing building heat demand by that date. We include this as a low regrets action since heat networks can provide benefits within all long-term heat decarbonisation pathways, being supplied by a range of sources including heat pumps and waste or environmental heat and, potentially, green gas or hydrogen, whilst offering economies of scale for these technologies. They can also bring additional flexibility to the energy system.

Development of heat networks is an area where Bristol City Council is able to have a strong influence. The development of the Strategic Heat Main will require a coordination from the local authority, potentially with a direct role for the local authority in the investment in and/or operation of the heat networks, as well as a key role in setting planning and connection policy. Our recommended action relating to planning policy is set out in Low regrets action 3 below.

In order to promote the delivery of cost-effective, reliable and low carbon heat in Bristol, the City Council intends to define zones in which heat networks should be developed. We have proposed a set of criteria that the City Council could use to define these zones, and we have outlined a potential connection policy framework that could be applied within these zones. Our recommendation is to adopt a system under which existing or planned heat network schemes could become 'classified' networks where a range of conditions are met relating to the cost of heat to consumers, carbon intensity and service quality. An outline of a possible formulation of the classification system is presented in section 7.

There are also important barriers to development of heat networks relating to the high upfront cost and relatively long payback periods (or equivalently, moderate to low rate of return). In order to address this, it may be important, at least in some cases, for the local authority to be an investor and/or delivery partner in heat network development. Bristol City Council already has experience of delivering and operating existing heat networks in the city, and should consider whether this could be extended to the level of heat network deployment envisaged in the scenarios presented.

- ***Low regrets action 3: strengthen new building planning policy to ensure all new buildings are served by low carbon heat networks or heat pumps, or equivalent low carbon options***

Bristol's adopted Core Strategy requires developers to demonstrate that heating systems have been selected according to the heat hierarchy, which strongly encourages connection to existing, or new, renewable or otherwise gas-fired CHP distribution networks. This policy has been challenged by some developers, who have argued in favour of direct (resistive) electric heating as alternative to either connection to a heat network or renewable electric heat (i.e. heat pumps).

We do not recommend that direct electric heating is promoted or supported in new buildings, wherever a more efficient, lower carbon option is viable. Our view is that direct (resistive) electric heating should not be regarded as an alternative to decarbonised heat delivered via heat networks or renewable electric heat (i.e. from heat pumps) for the reasons set out in section 11, Appendix E. Rather, we recommend that Bristol's planning policy is updated to ensure that, wherever possible, all new buildings are served either by low carbon heat networks or heat pumps with a lower carbon intensity than direct electric heating. Furthermore, the policy should promote heat networks ahead of heat pumps only in cases where either the carbon intensity of the heat supplied is equivalent to or lower than that for heat pump heating, or where a credible strategy can be presented for the heat network to achieve this following replacement of the current heat source(s) at the end of its life. The system of heat network 'classification' described above, and the associated connection policy, offers an approach through which this can be implemented.

To some extent, this low regrets action can be achieved through Bristol's own planning policy. However, there appear to be limits to the application of this policy at a local level based on the draft revised National Planning Policy Framework[61]. Our reading of the draft framework is that it appears to be more supportive of the ability to drive connection of new development to heat networks ('decentralised energy') through planning policy than of the ability to drive deployment of other low carbon heating technologies such as heat pumps in new buildings. The level of uptake of heat pumps in new buildings suggested in this low regrets action is unlikely to be supported by the national planning policy framework in its current draft form[61], as this does not appear to support planning policy which can force developers to go beyond the national building regulations by, for example, mandating the installation of heat pumps in appropriate cases. Stronger support for heat pumps in new buildings would require national building regulations either to tighten carbon emissions requirements such that gas and direct electric heating are unlikely to be compliant, or through a direct requirement to use low carbon alternatives such as heat pumps wherever feasible. Bristol could lobby the national government on this topic.

A potentially powerful approach that we would recommend is the construction of demonstration or 'exemplar' developments to stricter levels of carbon emissions than existing regulations, supplied by heat networks and/or heat pumps, which can be used to show the viability of this solution and to better understand consumer experience of these options.

- ***Low regrets action 4: promote extensive deployment of heat pumps in existing buildings and off-gas grid buildings in particular***

We recommend strong policy support for rollout of heat pumps in existing buildings (as well as new buildings), including deployment of in the region of 18,000 heat pumps by 2030 in the existing domestic building stock. This should be directed initially (but not necessarily exclusively) towards decarbonising heating in the roughly 19,000 off-gas grid households in Bristol, where the cost of heating is currently higher, and where there are fewer long-term low carbon options.

To achieve the target of 18,000 new heat pump installations by 2030, uptake of heat pumps in Bristol would need to increase from approximately 70 installations per year at present to 1,500 installations per year. The deployment of heat pumps in existing buildings is less easy for Bristol to influence than the rollout of heat networks and planning policy for new development. This level of uptake will be reliant on national legislation and is highly likely to require the formulation of a policy incentive substantially more attractive to consumers than the current Renewable Heat Incentive (RHI). There is currently uncertainty about what will follow the current RHI, which extends to 2020/21. However, Bristol could consider the implementation of a local scheme to promote heat pumps. This could aim to bring residents and businesses together with local developers to raise awareness of heat pumps and their benefits, as well as the awareness of the RHI. The scheme could also aim to address some of the remaining barriers to uptake of heat pumps under the RHI such as the high initial investment required, for example with investors (potentially including the local authority itself) offering low-interest loans or with third parties providing the upfront capital cost for the works. Approaches such as the *Energiesprong* model offer inspiration for how such schemes could be implemented.

The substantially increased rate of deployment of heat pumps, at more than a thousand installations per year in Bristol, will enable early assessment of consumer acceptance and other practical issues, to help inform the decision on Bristol's long-term heat decarbonisation pathway. The extent of cost reduction achieved through the associated expansion of the local supply chain, and through manufacturing economies of scale, will also allow a more accurate assessment of the long-term cost trajectory for heat pumps, providing important evidence towards the longer term decision.

Achieving carbon neutrality – the need to go beyond 'low regrets' actions

Our analysis estimates that the low regrets actions described above would achieve substantial reductions in carbon emissions in the short and medium term, down from 660 ktCO_2 / year in 2017 to 338 ktCO_2 / year in 2030 (a 48% reduction from today). However, these measures would fall well short of Bristol's goal of becoming carbon neutral by 2050, due to a high remaining share of gas heating. Bristol's heat policy, supported at the national level, must therefore be substantially more ambitious than the low regrets measures to achieve the target of carbon neutrality by 2050.

No scenario presented in this work reaches full carbon neutrality by 2050, for the reasons discussed in section 2.2. However, the scenarios that achieve the deepest decarbonisation over the period 2017-2050, with emissions falling below 50 ktCO_2 / year in 2050 and hence representing a greater than 90% reduction versus today, are the High HPs, High HNs & high HPs and Mixed pathway scenarios. In each of these scenarios, a very high level of deployment of at least one heating technology is required, going substantially beyond the low regrets actions.

Another key decision must therefore be made regarding the long term pathway to achieve complete or near-complete decarbonisation by 2050. The scenarios presented above suggest that in order to meet the 2050 target, a decision on the long term pathway is likely to be required during the period 2025-2030 at the latest, following which the possible pathways diverge more clearly.

Uncertainty over the cost and viability of the technology options to deliver the pathway to 2050 means this decision cannot be made today. This relates in particular to the uncertainty surrounding the commercial viability of low carbon hydrogen deployment, but also to the uncertainty surrounding the cost and viability of the highest levels of deployment of heat pumps (where deployment is contingent on consumer acceptance of the technology and very high levels of energy efficiency retrofit) and heat networks (where deployment is contingent on high levels of local authority planning and coordination, sufficient low carbon heat source availability and consumer acceptance).

Our recommendation at this stage is therefore for Bristol to implement (or help to implement) the low regrets actions and to learn from this experience, building a stronger evidence base on the cost and other implications of deployment of each technology option. This will help to ensure that the technology supply chains for the technologies develop to a point where they are able to deliver the level of deployment required in the long term, or it becomes clear that they cannot. While the low regrets actions entail substantial levels of deployment of energy efficiency, heat pumps and heat networks to develop this evidence base, in the case of hydrogen heating they do not. For this technology, it will be necessary for the component technologies – including hydrogen production, CCS and delivery of hydrogen to buildings – to be demonstrated in a more targeted way in order to reduce uncertainty and inform a (likely national) decision on the viability of this option.

2 Introduction

2.1 Context and objectives

Bristol has made a commitment to become 'carbon neutral' and to be 'run entirely on clean energy' by 2050 following the UN Framework Convention on Climate Change (COP21) in Paris in 2015. Meeting these goals and the aspirations of the Paris Agreement will require the complete or near-complete decarbonisation of energy use, including the energy used for heating, transport and electricity.

This study examines how Bristol can do this by considering potential pathways to decarbonise heat for space heating and hot water, which accounts for approximately one-third of Bristol's carbon emissions today[6]. The objective of this work is to develop an evidence based strategy for delivering zero carbon heat in Bristol.

We have studied a wide range of technology options for decarbonising heat in Bristol, including electrification (heat pumps) using low carbon electricity, decarbonisation of gas (hydrogen networks, biomethane) and hybrid gas-electric approaches, supported by the deployment of energy efficiency, heat networks and biomass combustion. We have shown that each option has benefits and drawbacks, risks and uncertainties, and requires a distinct set of ambitious local and/or national policy interventions to be successfully deployed. The study examines how the various options relate specifically to Bristol, and also where they rely on change that is largely out of Bristol's control.

The objectives of this work are to:

- Determine the potential of low carbon heating technologies to contribute to Bristol's ambition of being carbon neutral by 2050;
- Compare the possible pathways to deep decarbonisation of heat in Bristol, in terms of the associated cost, risk and level of uncertainty;
- Identify low regrets actions that are common to most or all pathways in the short term or are required to help make an informed decision on the long-term pathway;
- Highlight policy 'gaps' in relation to low carbon heating technology deployment, where existing policy measures do not meet the required level of ambition;
- Identify key decision points in time on the pathway to deep decarbonisation.
- Develop criteria to define zones with potential for the development of heat networks in Bristol.

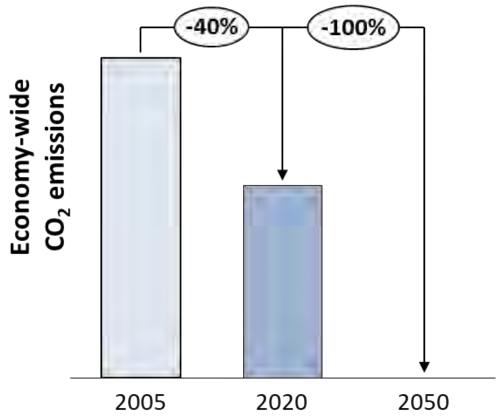
2.2 Bristol's carbon targets and implications of the ambition for carbon neutrality

In addition to the target of 'carbon neutrality' by 2050, Bristol has an interim carbon target, aiming to reduce carbon emissions in the city (relative to 2005 levels) by 40% by 2020. The economy-wide carbon targets to 2050 are illustrated schematically in Figure 2-1.

There are no specific carbon reduction targets for the heat sector. However, given that heating accounts for roughly one-third of Bristol's carbon emissions today, it is clear that deep decarbonisation of heat will be a necessary component of meeting the economy-wide target.

[6] Our analysis finds current annual carbon emissions from heating (space heating and hot water, excluding industrial process heating) of 659 ktCO_2. This represents approximately one-third of the annual economy-wide emissions for Bristol in 2013 of 2.0 MtCO_2 as presented in Bristol City Council's 2015 study: *Our Resilient Future: A Framework for Climate and Energy Security.*

Figure 2-1: Economy-wide emissions reduction targets in Bristol



In this study we investigate the low carbon heating options able to achieve very low levels of carbon emissions. Achieving very low levels of carbon emissions is challenging and will require a rate of uptake of low carbon heating technologies much higher than current rates (i.e. through current building regulations and policies including the Renewable Heat Incentive). Achieving complete decarbonisation is even more challenging, as this requires the total elimination of CO_2 emissions in the production of the fuels used, whether electricity or hydrogen, which restricts the potential production methods and has an impact on cost.

An alternative approach to achieving carbon neutrality involves a continued reliance on heating technologies that emit some carbon, whilst also using 'negative emissions technologies' to achieve zero *net* emissions[7]. In this study, we therefore consider options which achieve a deep level of decarbonisation, but we do not limit the analysis only to options that result in zero 'direct' emissions. However, it is crucial to keep in mind that for pathways in which emissions cannot be reduced to zero, achieving carbon neutrality will be reliant on negative emissions technology of some form. This can be considered as an additional risk of such pathways.

2.3 Approach

We present a high-level summary of our approach to achieve the objectives of this study in Table 2-1. We base our approach on a bottom-up assessment of the potential for a variety of low carbon technologies to drive decarbonisation of heat in Bristol, an estimate of the likely level of decarbonisation achieved and cost incurred to 2050, and an analysis of the policy and technology conditions required for the stated level of decarbonisation to be realised. Our assessment makes use of the best-available data sources, wherever possible using sources specific to Bristol.

[7] Negative emissions technologies encompass a wide variety of technologies or processes, some of which are already available but many of which are at an early stage of technological development. Afforestation and reforestation are well-understood approaches to absorbing CO_2 from the atmosphere, as are land management techniques to improve the capture of CO_2 in soils. High profile alternatives include the combustion of bioenergy combined with carbon capture and storage (CCS), direct air capture and enhanced weathering. A detailed assessment of these technologies is outside the scope of this study. It is important to note, however, that negative emissions technologies have a limited potential to offset carbon emissions, and it would be highly risky to consider them an alternative to deep reductions in direct carbon emissions. However, negative emissions could have a useful role to play in offsetting a small remaining amount of emissions following a deep, but not complete, reduction in direct emissions.

Table 2-1: Key aspects of project methodology and outputs

Process	Key aspects	Key outputs
Develop model of building stock and current heat demand in Bristol	• Construct stock model of existing buildings in Bristol using best available data sources • Segment building stock by building type, tenure, energy efficiency level, sector (for non-domestic buildings) • Derive current heat demand for each building type (calibrated to best available data)	• Number of buildings of each type in Bristol • Heating fuel type for each building • Annual heat demand for space heating and hot water for each typical building type in Bristol
Develop heat demand projection to 2050	• Develop projections for new build for domestic and non-domestic buildings • Apply assumed new building energy efficiency regulations to estimate heat demand to 2050	• Heat demand profile to 2050 for Bristol under the 'status quo' i.e. no change in heating technology mix and no further energy efficiency improvements
Determine technical and economic energy savings potential	• Identify the technical remaining potential for energy efficiency measures using Bristol-specific data sources where possible • Estimate cost-effectiveness of energy efficiency measures	• Number of homes in Bristol to which various energy efficiency measures can be applied • Heat demand savings, fuel savings and carbon reductions from the implementation of these measures
Determine potential deployment of low carbon heating options	• Identify viable level uptake of low carbon heating options in view of constraints specific to Bristol's building stock • Develop scenarios (typically low, medium and high) for each option reflecting varying levels of ambition	• Set of potential deployment scenarios for each low carbon heating option in Bristol • Conditions for viability of each scenario (e.g. policy measures, technological progress) and associated risks and uncertainties
Construct heat decarbonisation scenarios for Bristol and compare impacts	• Construct heat decarbonisation scenarios deploying various carbon heating options and energy efficiency measures to 2050 • Estimate the carbon emissions reduction achieved and costs incurred	• Heat demand and carbon emissions profiles to 2050 for each scenario • Building-level, infrastructure and fuel cost curves to 2050 for each scenario
Identify low regrets options, policy gaps and key decision points to inform Bristol's zero carbon heat strategy	• Evaluate risks and uncertainties associated with each scenario • Identify commonalities between scenarios • Identify divergence points between scenarios • Compare current policy with that required in each scenario	• Low regrets options • Key gaps between current policy and that required to achieve low regrets options and deeper decarbonisation • Decision points in time at which policy action is required to follow various decarbonisation pathways

3 Assessment of local and national policy on heat decarbonisation relevant to Bristol

3.1 National and local climate change agreements

In 2008, the Climate Change Act established a legally-binding requirement for the UK to reduce CO_2 emissions by at least 80% by 2050 compared to 1990 levels. To meet the carbon budgets, the Government sees a growing role for local authorities and local enterprise partnerships, as presented in its recent Clean Growth Strategy[8] and Industrial Strategy[9]. Bristol has been even more ambitious in its carbon emission reduction targets than the national commitments. Following the UN Framework Convention on Climate Change (COP21) in Paris in December 2015, BCC made a commitment to make Bristol 'carbon neutral' by 2050 and to be on course to be run entirely on clean energy by 2050[10]. Between now and 2050 Bristol has made the interim commitment to reduce carbon emissions by 40% by 2020 from a 2005 baseline.

Although these are economy-wide emissions targets, emissions associated with heating make up approximately one-third of the total in Bristol, and the targets cannot be met without a deep decarbonisation of heat. As noted in the Government's Clean Growth Strategy, "*decarbonising heat is our most difficult policy and technology challenge to meet our carbon targets*". This is evidenced by the lack of progress in this sector to date. In this section, we provide a brief overview of current policy relevant to heat decarbonisation in the UK and Bristol.

3.2 Energy efficiency

The Government recognises the potential for cost-effective energy saving measures in the Industrial and Commercial sector and plans to encourage investment through a new scheme proposed in their recent Industrial Strategy. Businesses are already incentivised to take up energy efficiency measures through the Enhanced Capital Allowance scheme. This scheme allows businesses to write off the entire cost of any energy-saving product included on the list against taxable profits.

Driving the uptake of energy efficiency in the domestic sector has proven difficult and the Government has launched a call for evidence on additional measures to build a market for energy efficiency among homeowners. The 'Next steps for UK heat policy' report[11], published by the Committee on Climate Change, identifies that the implementation of energy efficiency measures across the existing building stock is a necessary action, and that it must be carried out now. Specifically, this includes the insulation of 7 million walls and lofts in homes. The report identifies the benefits of energy efficiency to consumers, including reduced energy bills, lower levels of fuel poverty and improved health and wellbeing[12]. Currently, large energy suppliers are obligated to fund energy efficiency measures in UK households through the Energy Company Obligation (ECO) to help reduce carbon emissions and alleviate fuel poverty. The Green Deal, a Government scheme to provide low-cost loans to homeowners and landlords to invest in renewable energy or energy efficiency products, received very little uptake and as a result was closed in July 2015. Alternative financing options are now being considered to stimulate uptake of energy efficiency in homes.

Bristol's social housing stock includes more than 34,000 dwellings. Data provided by Bristol City Council suggests that while very few (<3%) of these have the lowest energy efficiency ratings of EPC F and G, more than 8,000 (29%) are EPC D or E, offering substantial scope for improvement of these buildings to at least EPC C. We understand that the majority of the low cost efficiency measures, such as cavity wall and loft insulation, have been installed in these properties. A substantial share of the solid wall properties in Bristol's social housing stock have also been insulated, but around 4,000 solid walls remain

[8] HM Government, The Clean Growth Strategy: Leading the way to a low carbon future (October 2017)
[9] HM Government, Industrial Strategy Building a Britain fit for the future (November 2017)
[10] Bristol City Council's Corporate Strategy (2017-2022)
[11] Committee on Climate Change, Next steps for UK heat policy (October 2016)
[12] Committee on Climate Change, Next steps for UK heat policy (October 2016)

uninsulated. This presents significant potential to further improve the energy efficiency of the social housing stock, to reduce bills and achieve additional decarbonisation of heating.

3.3 New build regulation

In the domestic sector, Bristol's Local Plan[13] includes the provision of 35,500 new homes to 2036 from a 2016 base. In the non-domestic sector, Bristol's Local Plan includes a provision of 236,000 m^2 net additional floor space from 2006 to 2026[14]. In order for Bristol to accommodate its new housing requirements and economic growth targets whilst delivering on its carbon emissions reduction targets, new buildings must be constructed to be substantially more energy efficient than the existing building stock.

Nationally, new housing requirements have been prioritised over increased regulation for energy efficiency in new buildings: the planned Zero Carbon Homes legislation was dropped in 2015 to reduce regulation on housebuilders, and no replacement to update building regulations has yet been implemented.

In this study, the new build energy efficiency standards assumed are based on the level determined to be the cost-optimal level in work undertaken in 2013 for the UK Government[15], which is close to the current new build regulations. The cost-optimal level for a given house type is defined as "the energy performance level which leads to the lowest cost during the estimated economic lifecycle"[16]. Higher energy efficiency standards, such as those required for the Passivhaus certification, could be introduced either nationally or, potentially, as a result of local planning policy in Bristol.

One of the implications of Bristol being on course to be run entirely on clean energy by 2050 is a shift away from natural gas to very low or zero carbon heat sources. However, under the current building regulations, there is no requirement for buildings to be heated by a lower-carbon alternative than a gas boiler. The regulations imply a limit on the overall carbon emissions intensity of the building, but this can usually be achieved using a gas boiler in combination with a sufficiently high level of energy efficiency, often with solar PV or solar thermal. The majority of new buildings are currently installed with a gas boiler. Bristol's adopted Core Strategy requires developers to demonstrate that heating systems have been selected according to the heat hierarchy, which strongly encourages connection to existing, or new, renewable or otherwise gas-fired CHP distribution networks. However, this policy has been questioned by some developers, who have argued that direct (resistive) electric heating should be allowable given reductions in the carbon intensity of mains (grid) electricity. Our view is that direct (resistive) electric heating should not be regarded as an alternative to decarbonised heat delivered via heat networks or renewable electric heat (i.e. from heat pumps) for the reasons set out in section 11, Appendix E. New building regulations are likely to have an important role in driving greater deployment of low carbon heating systems such as heat pumps whether through increased carbon emissions requirements or a direct requirement to use alternatives to gas heating where feasible.

3.4 Heat pumps

Heat pumps are a heating technology that extract heat from the environment, typically the air or ground, and in some cases water sources, and transfer this heat to where it is needed. The heat transferred from the environment is considered to be renewable, because for every unit of energy required to operate the pump 2 to 5 units[17] of useful heat can be extracted from the air, ground or water, and that heat is replenished naturally by solar energy. A heat pump requires energy to achieve this heat transfer, usually in the form of electricity. Heat pumps are several times more efficient than traditional direct

[13] Bristol Local Plan, 2011 (and updates from BCC)
[14] These figures are under development and are subject to change.
[15] Department for Communities and Local Government (DCLG), Cost optimal calculations: UK report for the European Commission (2013)
[16] European Union Energy Performance of Buildings Directive, Article 2.14
[17] Hybrid heat pumps study, a report by Element Energy for BEIS, 2017.

electric or storage heaters (where efficiency is defined as useful heat delivered per unit of electrical energy input[18]). If the electricity grid is decarbonised, heat pumps can provide low carbon heat, and have the potential to provide zero carbon heating if the electricity supply is fully decarbonised.

The main policy measure in place to increase the uptake of heat pumps in existing buildings is the Renewable Heat Incentive (RHI). The RHI is a subsidy paid for each unit (kWh) of renewable heat produced (usually based on deemed heat usage for domestic buildings). The RHI is currently in place until 2020/21. Across the UK, approximately 10,300 ground and air source heat pumps were accredited per year, on average, through the RHI between its inception in April 2014 and April 2018. Alternative forms of financial incentive such as capital grants and low-interest loans for heat pumps could be applied, but are not currently part of national policy. It is unclear at this stage what incentives may be put in place, if any, to replace the RHI once it comes to an end.

Other forms of financial incentives, if designed to be more attractive to consumers, could lead to higher levels of uptake of heat pumps than has been achieved to date. However, the number of consumers who would avail themselves of such incentives voluntarily may be limited. In order to reach the highest levels of uptake of heat pumps in existing buildings, it may in the future be necessary to regulate the replacement of heating systems, effectively removing the option to install a gas boiler where a lower carbon option is feasible. Currently however, this policy is not, being considered for implementation in the UK in the near future..

There is significant potential to roll out heat pumps in dwellings owned by Bristol City Council, with 88% of the Council's housing stock being served by gas boilers and gas-based communal heating. Heat pumps could also replace electric storage heating, helping to reduce fuel bills and improve thermal comfort.

3.5 Biomass

Biomass heating, including biomass boilers and combined heat and power (CHP), is also eligible under the RHI. Biomass has accounted for the majority of heating systems installed under the RHI, accounting for 78% of the heat paid for under the under the Non-domestic RHI and 53% of the heat paid under the Domestic RHI.

Bristol City Council took action to reduce carbon emissions from heating across its own building stock by installing ten biomass boilers from 2008 to 2015, and more than 4 MW_{th} of biomass boiler capacity is currently in place. However, the Council's agenda regarding biomass has shifted in recent years for two main reasons. Firstly, there are growing concerns around the air quality impacts of biomass, particularly in Bristol's urban environment, as combustion of biomass releases higher levels of particulate matter and nitrogen oxides than gas heating. Secondly, there have been operational issues with some of the systems linked to fuel quality, fuel cost versus gas and also surrounding the decommissioning, repair and replacement of biomass boilers. As a result, the deployment of further biomass heating is not a key focus of this report. It is worth noting, however, that there may be a role for biomass boilers as one of a number of sources of low carbon heat in areas of the city where boilers can be sited away from housing. Larger installations, such as those supplying heat networks, could be attractive in areas such as Avonmouth, where population densities are lower and where there is sufficient operational capacity to ensure the system can be well-operated and properly maintained.

3.6 Heat networks

Heat networks can facilitate carbon emissions reduction by enabling the use of low carbon heat sources that are not easily accessible at an individual building level, such as waste heat, geothermal and water sources and energy from waste. Heat networks also have potential to improve overall energy efficiency, reduce consumer energy bills and form part of local regeneration. The Government is supporting the

[18] Electrical resistive heating is 100% efficient. Heat pumps usually have a seasonal efficiency approximately in the range 200% to 500%. For each unit of energy (usually electricity) required to drive the heat pump 2.5 to 4 units of useful heat are produced.

development of district heating and cooling networks in the UK through the Heat Network Delivery Unit (HNDU), which provides grant funding and guidance for local authorities to determine the feasibility of heat networks, and the Heat Networks Investment Project (HNIP), which provides capital grants and loans to support the delivery of heat network projects.

Development of heat networks in Europe

Planning policy to encourage or require new buildings, particularly large new developments, to connect to heat networks is instrumental in initiating their deployment, as the guarantee of demand for heat reduces the risk to developers and investors. In cities that already have extensive heat networks, such as Copenhagen, Gothenburg, Amsterdam and Seoul, city planning or heat zoning has commonly played an effective role in creating efficient heat networks with high connection rates. Within heat network zones, connection policy can ensure that the majority of consumers connect to the heat network in the long run. Connection policy is most easily applied to new development, but for the heat network to expand more substantially, the policy often extends to existing buildings including domestic properties. In Paris, for example, heat network zones are defined within which all new buildings must connect, and all existing buildings must connect within a certain timeframe, unless deemed to be economically unfeasible.

In Bristol, the aim for the deployment of heat networks is to provide affordable, secure low or zero carbon heat to users. It is therefore critical that heat supplied to the heat networks is sourced from a low carbon heat source, or that there is a viable and low risk opportunity to transition to a low carbon heat source in the near future. Another important consideration is the natural monopoly characteristics of a heat network which can mean that customers connected to a network have no option to switch supplier. Accordingly, it will be crucial to ensure value and quality of service for customers, most likely through some form of oversight or regulation.

In France, to address these issues, a heat network 'classification' framework is in place that means heat networks are only able to take advantage of the type of mandatory connection policy described above if they meet the following criteria:

- The network is supplied by at least 50% renewable or recovered energy sources and will be able to retain this proportion as demand increases;
- There are no constraints to growth of the network in terms of infrastructure capacity;
- The network will supply heat at a 'reasonably cost effective' price;
- There is a system to record the amount of heat delivered at each 'node'.

Development of heat networks in Bristol

The system of heat network classification described above allows a local authority to promote only networks capable of delivering cost-effective, low carbon heat to heat users. A similar classification framework could be implemented in Bristol in order drive extensive deployment of heat networks through strong planning and connection policy, whilst ensuring value and quality of service to customers.

It is important to consider that different heat load types and different areas within the Council are not all equivalent, and so connection rules and zones must be set out. We propose a 'HN connection policy' framework that includes policy for both new development and existing buildings, and takes into consideration not only existing heat network schemes but also planned and proposed schemes. We present this framework in Section 7.

Previous studies commissioned by Bristol City and South Gloucestershire Local Councils identify several potential low carbon Energy-from-Waste (EfW) facilities that could supply heat to heat networks. EfW facilities are a type of power station, generating electricity from various sources of waste including municipal solid waste and refuse derived fuel and, like all thermal power stations, produce a large amount of 'waste' heat. EfW plants that capture and use this heat (or deliver it elsewhere for a useful purpose), thereby acting as a combined heat and power (CHP) plant, may be eligible to receive additional revenue through a Contract for Difference (CfD). Six CfDs have been awarded to EfW projects across England and Wales as of September 2017.

A low carbon heat network in Bristol could be supplied by other sources, either in combination with waste heat from EfW or industry, or as an alternative. There is a high level of interest in the use of water-source heat pumps (WSHPs) using water from the floating harbour. Other possible low carbon sources include air-source and ground-source heat pumps, deep geothermal, solar thermal, biomass boilers and CHP and biogas combustion, all of which are eligible for revenue payments under the current RHI.

4 Technology options for heat decarbonisation in Bristol

In order to evaluate the potential to decarbonise heat for space heating and hot water in Bristol, we segmented the current building stock into its component parts – such as households, commercial and public buildings, and different building types with different heat demand characteristics within those sectors – and we created a heat demand stock model. Throughout our analysis, we used Bristol-specific data sources where available.

We used the stock model to develop scenarios for the change in Bristol's heat demand to 2050. We also used it to evaluate the suitability of various low carbon heating technologies in Bristol. Our analysis considers all low carbon technology options deemed to have the potential to have a large impact on Bristol's heat sector to 2050, including:

- Energy efficiency measures;
- Heat networks, including the use of waste heat[19] and environmental heat[20];
- Heat pumps;
- Hybrid heat pumps (hybrid heat pumps are systems integrating a heat pump with a boiler, usually gas);
- 'Green gas', including biomethane and bio-synthetic natural gas (bioSNG);
- Hydrogen boilers;
- Solar thermal.

We then developed a set of scenarios with varying levels of deployment of these low carbon technologies to 2050. The level of uptake of these technologies in each scenario was based on the following factors:

- Technology suitability to Bristol's building stock
- Level of local policy ambition towards each technology assumed in the scenario
- National policy assumed in each scenario

We then compared these scenarios in terms of carbon emissions reduction to 2050, the cost over that period and the level of associated risk or uncertainty in the scenario being achieved. This allows us to address the key objectives of this work, including an assessment of which technologies have the potential to contribute to Bristol's ambition of being carbon neutral by 2050. We can then also identify the actions we consider to be 'low or no regrets' in the shorter term, where local and national policy gaps exist with regards to driving the necessary decarbonisation, and we are able to identify at which stages key decision points exist regarding the preferred decarbonisation pathway.

[19] in this context, waste heat refers to high- or low-grade heat produced as a byproduct of an industrial process or power generation
[20] in this context, environmental heat refers to heat from the ambient air or ground, or body of water such as a river or estuary, which can be used as a heat source for heat pumps to feed heat to a heat network

4.1 Stock model of Bristol's heat demand

We developed two building stock models to assess the heat demand in Bristol, one for the Domestic sector and one for the Non-domestic sector[21]. The domestic stock was segmented by house tenure, type, age of construction and energy efficiency level, where data was available. The heat demand in the non-domestic stock was segmented by sub-sector, shown in Figure 4-2. Table 4-1 describes the various sources used to develop the stock model. The Private Sector Housing Condition Survey for Bristol containing data on Bristol's building stock was used where possible to ensure local relevance in the owner occupied and privately rented segments, while BCC's own data was used for the social housing stock. Where the required data was not available in a Bristol specific source, national sources were used as described and adjusted appropriately.

Table 4-1: The building stock model - process methodology and description of sources

Key aspects	Key data and tools	Description
• Existing building stock model construction • Building archetype generation • Building stock segmentation by building type, tenure, energy consumption, sector, sub-sector where possible	**Domestic**	
	Private Sector Housing Stock Condition survey, ORS for BCC, 2011	Number of buildings by type, tenure, age
	National Energy Efficiency Database (NEED), 2016	Annual gas demand by building type, tenure, age
	Social housing data from BCC, 2017	Number of buildings by SAP band and type
	Energy Consumption in the UK (ECUK) tables, 2016	Share of the domestic energy demand by end-use and fuel type
	Valuation Office Agency (VOA), 2017	Number of dwellings, published annually
	Non-Domestic	
	Building Energy Efficiency Survey (BEES), 2016	Share of the non-domestic energy demand by end-use and fuel type
	National Heat Map, Bristol region, 2011	Split of heat demand between sub-sector

[21] The Domestic sector covers all households. The Non-domestic sector covers both Commercial buildings and Public sector buildings.

Figure 4-1: Heat demand in the domestic sector in 2017

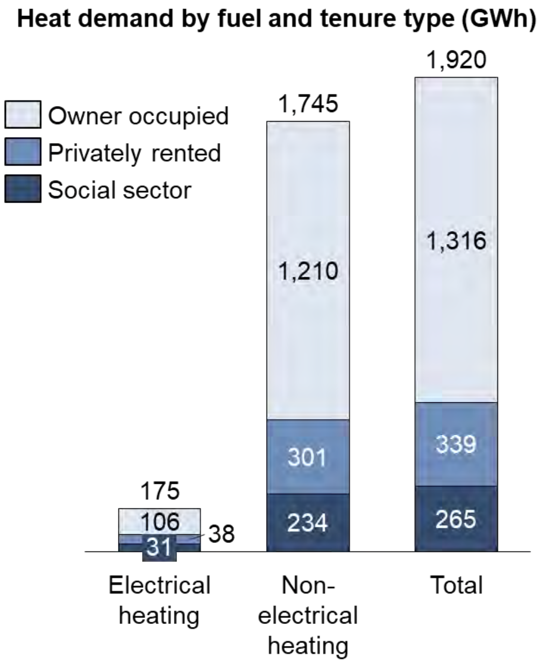
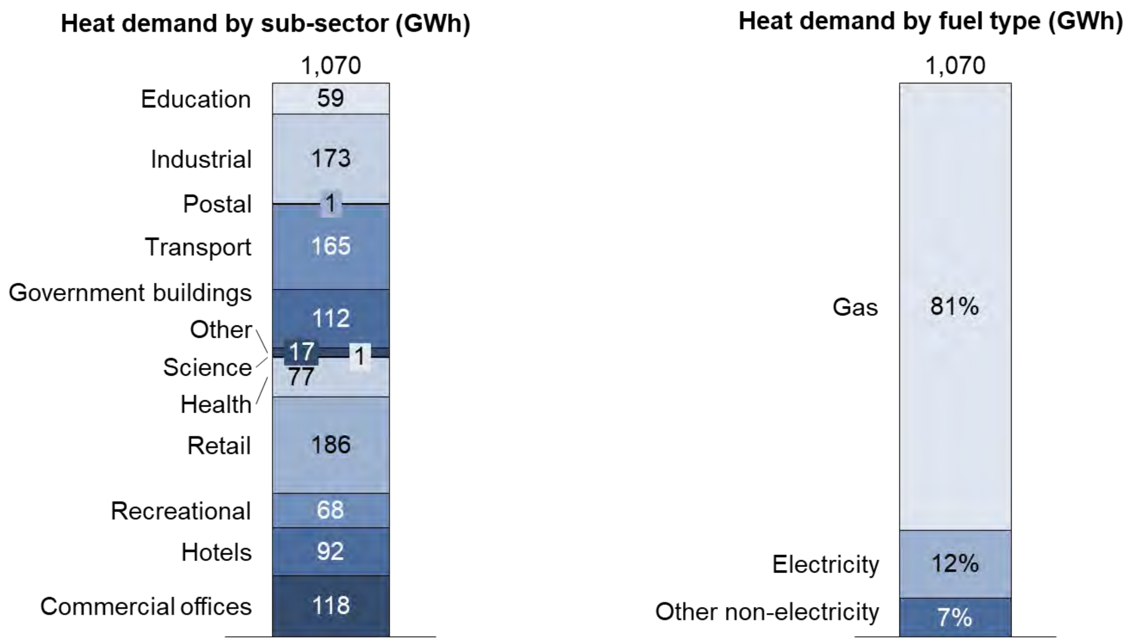


Figure 4-2: Heat demand in the non-domestic sector in 2017



According to the stock model, there is 1,920 GWh of domestic heat demand in Bristol in 2017. Around 90% of this is supplied by non-electrical heating, as displayed in Figure 4-1. According to the stock model, there is 1,070 GWh of heat demand in the non-domestic sector (excluding industrial process heating), and more than 80% of this is supplied by gas, illustrated in Figure 4-2.

We then estimated the number of buildings in Bristol's domestic stock to 2050, and we performed the equivalent calculation for the non-domestic sector (based on floor space). By using average heating and hot water consumption data for each building archetype, we used the stock model to project the heat demand in Bristol to 2050, in the first instance assuming no energy efficiency improvements. The approach and datasets used to develop the projection are outlined in Table 4-2. It is assumed in this analysis that the heat demand for all new buildings is consistent with current building regulations. The construction and demolition rates assumed throughout this report are defined in Table 4-3.

Table 4-2: Bristol's heat demand profile to 2050 – process methodology and sources used

Key aspects	Key data and tools	Description
New build stock model generation	**Domestic**	
	BCC Local plan (& updates), 2011	Spatial projections of domestic buildings to 2036
Baseline heat demand (for hot water and space heating) projection to 2050	Cost optimal calculations: UK report for the European Commission, 2013	Energy consumption of new buildings by type, floor area of new builds by type
	Non-Domestic	
	Element Energy for the CCC, Research on DH and localized approaches to heat decarbonisation, 2015	Build rate of 1.6% and demolition rate of 0.6% by floor area in each sub-sector (EE assumptions)
	Cost optimal calculations: UK report for the European Commission, 2013	Energy consumption of new non-domestic buildings
	BEIS, Building Energy Efficiency Survey	Median sub sector heat consumption (kWh / m^2) to estimate current floor area of each sub-sector

Table 4-3: New build construction rates and existing building demolition rates

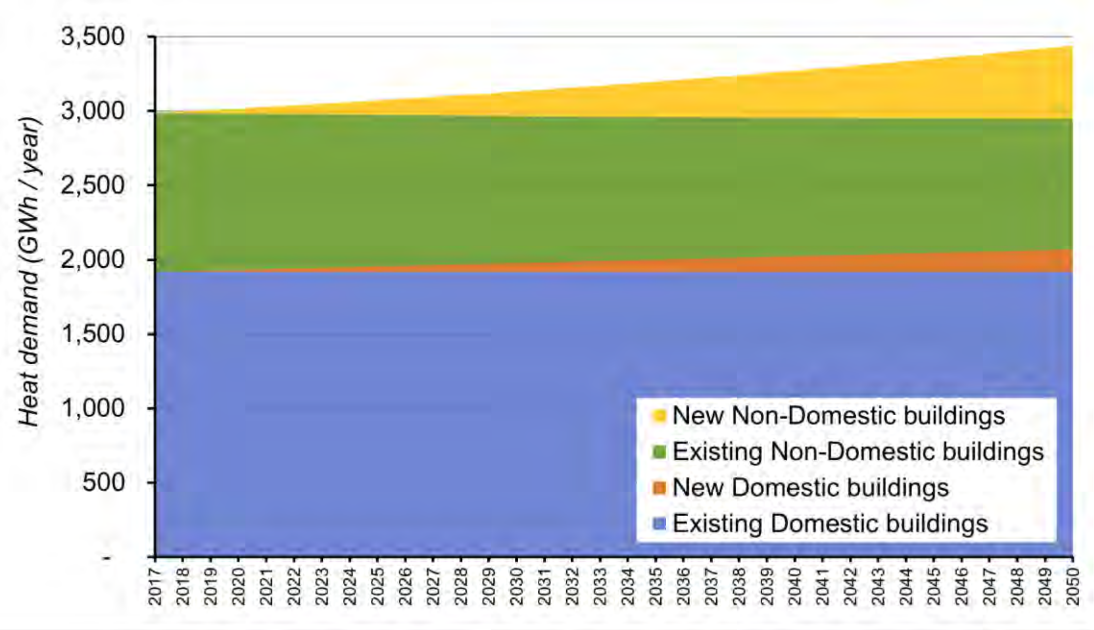
	Construction rate / year	Demolition rate / year	Data source
Domestic	990 new homes	None	BCC Local plan (& updates), 2011
Non-domestic	1.6% new floor space	0.6% floor space	Element Energy for the CCC, Research on district heating and localised approaches to heat decarbonisation, 2015 BCC Employment Land Study, 2009

Figure 4-3 presents Bristol's heat demand profile to 2050, segmented by building type and tenure, assuming no energy efficiency improvements. This suggests that the majority of the heat demand in 2050 will come from existing domestic buildings assuming no reduction in demand from energy efficiency measures.

In 2050 the total heat demand is projected to be 3,450 GWh with 2,800 GWh coming from existing buildings and 650 GWh from new buildings built between 2018 and 2050. This suggests that there is significant potential to reduce Bristol's heat demand up to 2050 by implementing efficiency measures in the existing stock.

Figure 4-3 has been calculated assuming that energy demand in new build buildings is consistent with current building regulations. If the standards set out in these regulations were not achieved, the heat demand in 2050 would be higher. The possible benefits of higher efficiency, e.g. Passivhaus, are described in section 3.3.

Figure 4-3: Projection of Bristol's heat demand to 2050 when no energy efficiency measures are applied. 'Existing' represents the existing building stock in 2017.



4.2 Energy efficiency uptake scenarios

Retrofit of the existing building stock, through the application of energy efficiency measures such as wall and loft insulation, more efficient glazing and others, is an effective means of reducing heat demand and therefore carbon emissions, whilst also lowering heating bills and in some cases improving thermal comfort.

We have constructed four scenarios to reflect the rollout of different energy efficiency measures at varying levels, including three scenarios with increasing levels of rollout and a scenario with no further rollout. The trajectories of Bristol's heat demand under the four different scenarios are shown in Figure 4-4. The estimated number of remaining uninsulated cavity walls, lofts, solid walls and floors in Bristol's domestic stock that would need to be retrofitted under the high energy efficiency target are displayed in Table 4-4.

Figure 4-4: Projection of Bristol's heat demand to 2050 with varying levels of energy efficiency applied

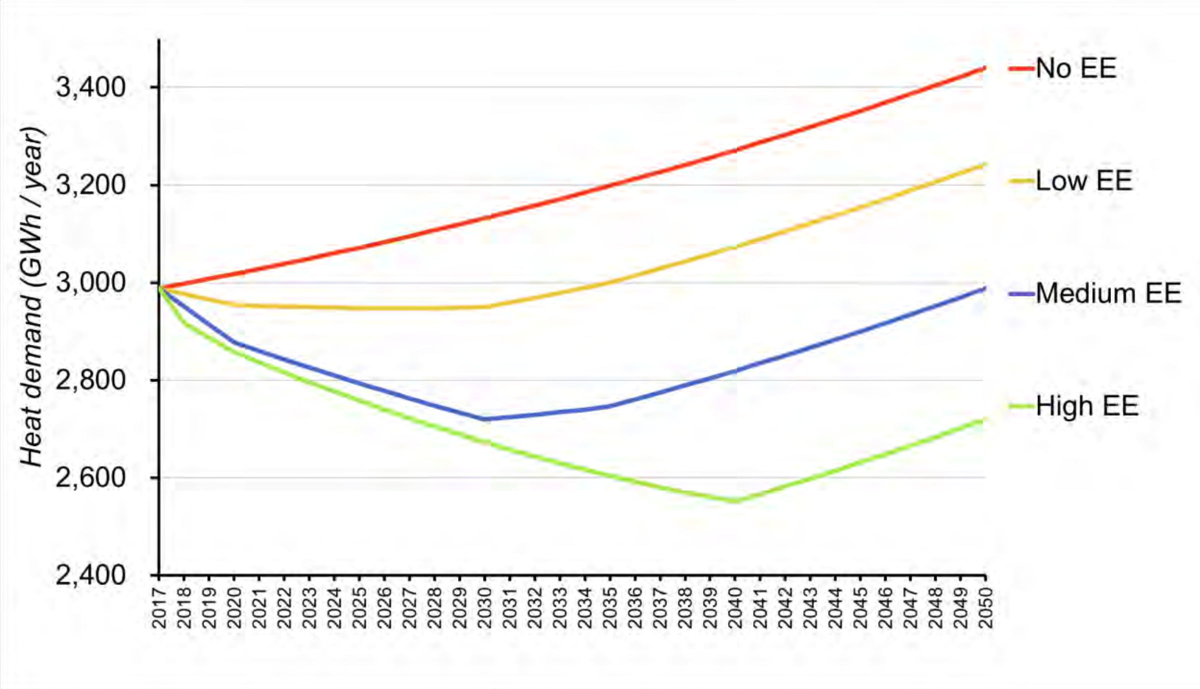


Table 4-4: Estimated number of retrofits required by 2040 to reach the high energy efficiency target in Bristol's domestic stock

Insulation type	Estimated number of retrofits by 2040 under the high energy efficiency target
Cavity walls	36,000
Lofts	10,000
Solid walls	56,000
Floors	130,000

We have estimated the remaining potential[22] of a range of energy efficiency measures and the associated energy savings potential across the Bristol building stock using a variety of sources, including Bristol-specific data sources wherever possible. Further details behind the methodology used to generate these scenarios can be found in section 8.

4.3 Description of low carbon heating technologies

Even with the deployment of all efficiency measures in the existing building stock (as is the case under the high EE scenario), the remaining heat demand and resulting carbon emissions from both existing and new buildings in 2050 is 542 $ktCO_2$ / year. Deeper decarbonisation will require a switch from heating based on fossil fuels (currently mainly gas) to lower carbon heating options. The low carbon heating options considered in this study are heat networks, heat pumps, hybrid heat pumps, green gas, hydrogen and solar thermal.

[22] The remaining potential of an energy efficiency measure refers to the number of homes in which the measure is not already applied, but could be applied.

Heat networks

Heat networks are an approach to supplying heat whereby hot water (or, particularly in older systems, steam) is generated centrally and then delivered through insulated pipes to multiple buildings or even whole cities.

Heat networks have the potential to contribute to heat decarbonisation as they can use a variety of waste and renewable heat sources including heat from industry, power station waste heat (including Energy from Waste (EfW) plants), heat from rivers and other bodies of water, low grade waste heat from buildings, sewage systems and other sources.

Several heat networks are already in operation in Bristol, and others are currently in the construction or development and feasibility stages. The ultimate extent of heat network development in Bristol will to a large degree be dictated by the level of future local and national policy ambition. In this study, three scenarios for heat network uptake have been constructed assuming varying levels of future policy ambition: Low HNs, Medium HNs and High HNs.

Table 4-5: Summary of HN uptake in the three scenarios in 2025 and 2050. Percentages are of total heat demand in a particular segment in a particular year.

Heat demand connected	Units	Low HNs		Medium HNs		High HNs	
		2025	2050	2025	2050	2025	2050
Total	**GWh / year**	**28**	**144**	**86**	**457**	**144**	**1018**
	%	**1%**	**6%**	**3%**	**20%**	**5%**	**44%**
Domestic existing	%	1%	3%	1%	6%	1%	11%
Domestic new	%	0%	0%	19%	34%	59%	100%
Non-domestic existing	%	2%	14%	5%	26%	5%	39%
Non-domestic new	%	0%	0%	23%	31%	66%	100%

Table 4-6: High level summary of connected building stock segments across the scenarios. Existing and planned networks include: Temple & Redcliffe, City Centre Phases 1 & 2.

Decreasing likelihood of connecting at scale

Heat load type	HN uptake scenario		
	Low	Medium	High
Existing and planned networks	Connected	Connected	Connected
Key large heat users identified in master-planning studies	Not connected	Connected	Connected
New developments	Not connected	Some connected	Connected
Other existing buildings including domestic properties	Not connected	Some connected	Many connected

The heat demand connected in years 2025 and 2050 for the three uptake scenarios, segmented by connection type and tenure, is shown in Table 4-5.

In all scenarios, we have assumed that heat networks currently in the development or feasibility stages across Bristol are completed. Beyond this, the scenarios differ in the extent to which new heat networks are developed, and the extent to which existing or planned networks are expanded to connect additional customers. In the Low HN scenario, no further heat network development is achieved beyond the existing and planned networks.

We have considered three types of heat load (in addition to existing and planned networks), as shown in Table 4-6, for which widespread connection to heat networks is likely to require increasingly ambitious policy in Bristol. Some of these heat load types are assumed to connect to heat networks in the Medium HNs scenario, but widespread connection of the most challenging heat load types is assumed only in the High HN scenario.

Previous energy master-planning studies for Bristol[23,24] have identified a list of large individual heat users in the vicinity of existing and planned heat networks, including large public and commercial buildings (such as Bristol Arena, Bristol University Hospital, Croydon House, Fremantle House etc.); these represent further relatively ‘low hanging fruit’ for the Council to connect to a low carbon heat network, and are assumed to connect in the Medium HN scenario.

Deployment of heat networks in new developments is less challenging than retrofit of heat networks to most existing buildings, as this could be driven through planning policy. New developments also bring the advantages that there is typically a single decision maker on the customer side (the developer),

[23] Sustainable Energy Limited, Avonmouth and Severnside Heat Network Development Study, A report for South Gloucestershire and Bristol City Councils (pending publication)
[24] Sustainable Energy Ltd, City Centre Phase 2 – draft outputs (draft, pending publication)

simplifying project delivery, and that all customers can be connected from construction. Nonetheless, achieving widespread connection of new developments to heat networks will require sufficient Council ambition and strong planning policy. In the Medium HN scenario, approximately one third of all new developments built between 2017 and 2050 are connected to a heat network by 2050.

Most challenging of all is the widespread connection of existing buildings, including existing domestic properties. Retrofit of heat network connections to existing buildings is particularly challenging because this is less readily achieved through planning policy and regulation, and since it requires the agreement of a large number of individual decision-makers (households). Achieving retrofit of heat networks to existing buildings through regulation – such as the possible connection policy for existing buildings outlined in Appendix A – will require the highest level of policy ambition. In the Medium HNs scenario a small share of existing buildings are assumed to connect; in the High HNs scenario a higher number are assumed to connect, as evidenced in Table 4-5.

In both the Medium HNs and High HNs scenarios, we assume a lower rate of connection of existing domestic buildings than existing non-domestic buildings. This is because non-domestic users typically have larger heat demands than domestic users, resulting in economies of scale that mean non-domestic connections are often more economically favourable than domestic connections. In addition, since non-domestic buildings are less numerous, connection of non-domestic users is often easier to coordinate and deliver.

The detailed assumptions behind the connection of the building segments are shown in section 9, Appendix C. The extent of heat network rollout under the three uptakes scenarios is shown graphically in Figure 4-5, Figure 4-6 and Figure 4-7.

Figure 4-5: Networks assumed to be completed or constructed under the Low HN uptake

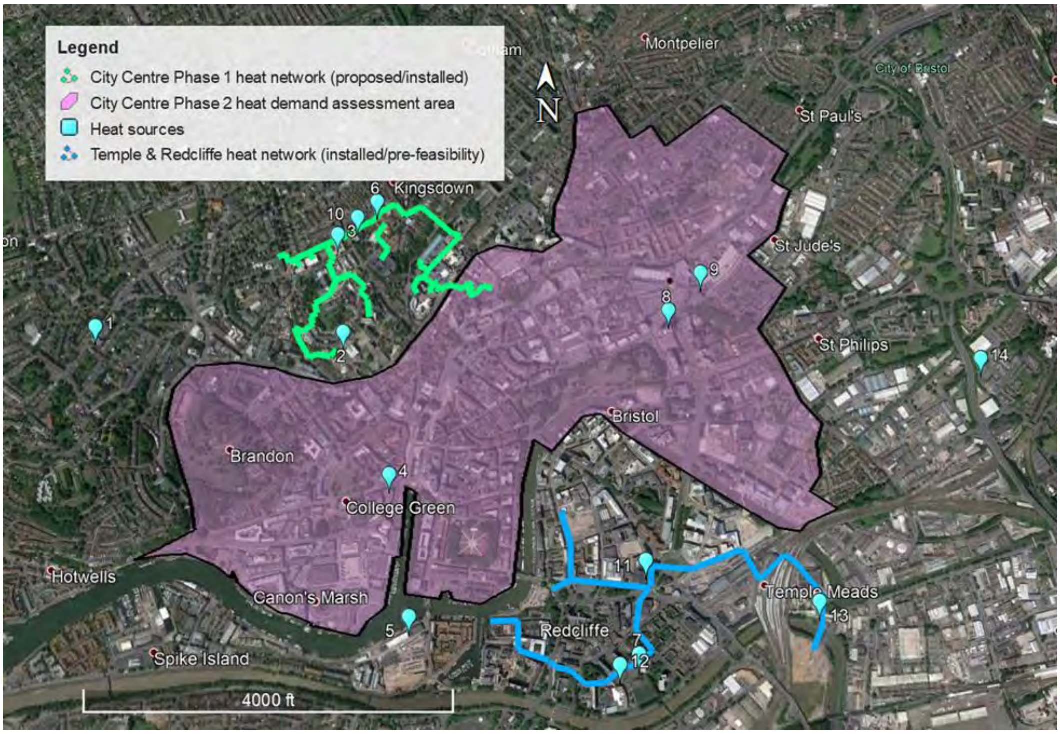
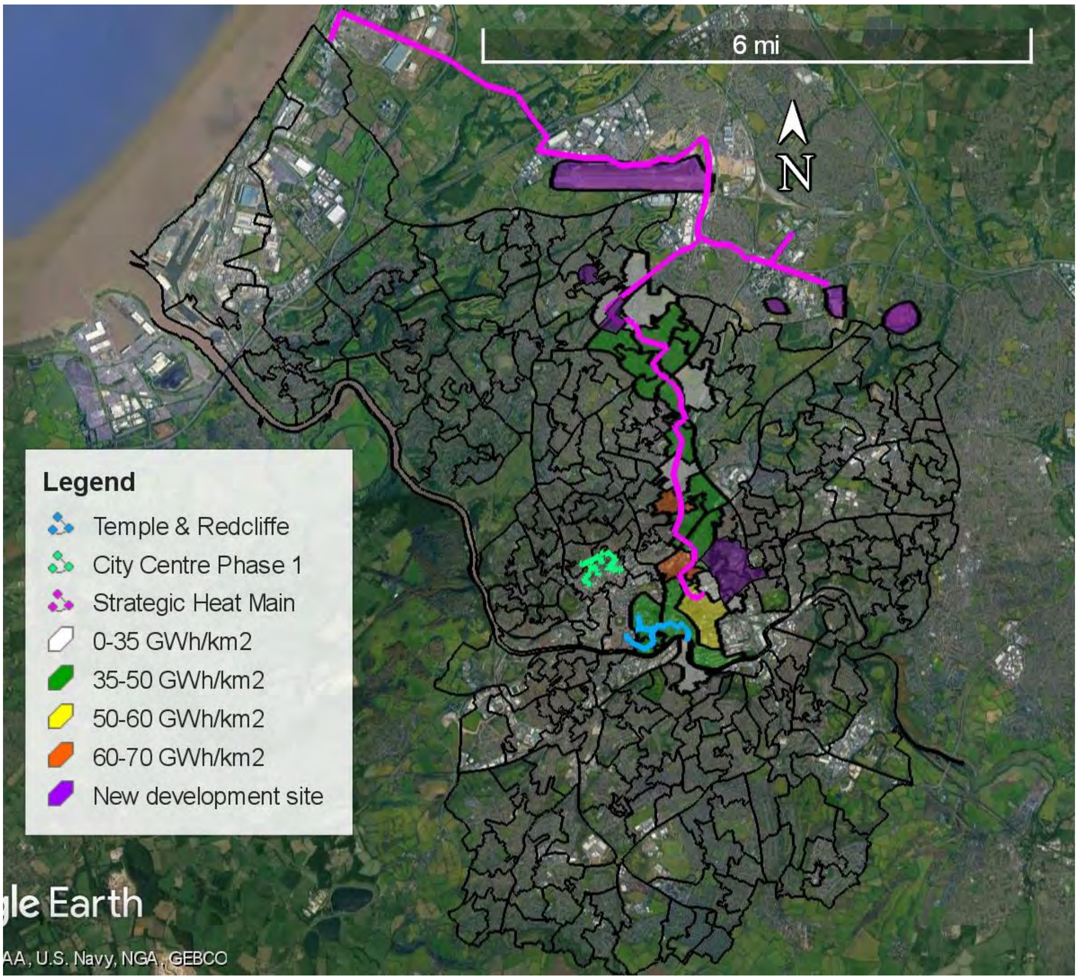
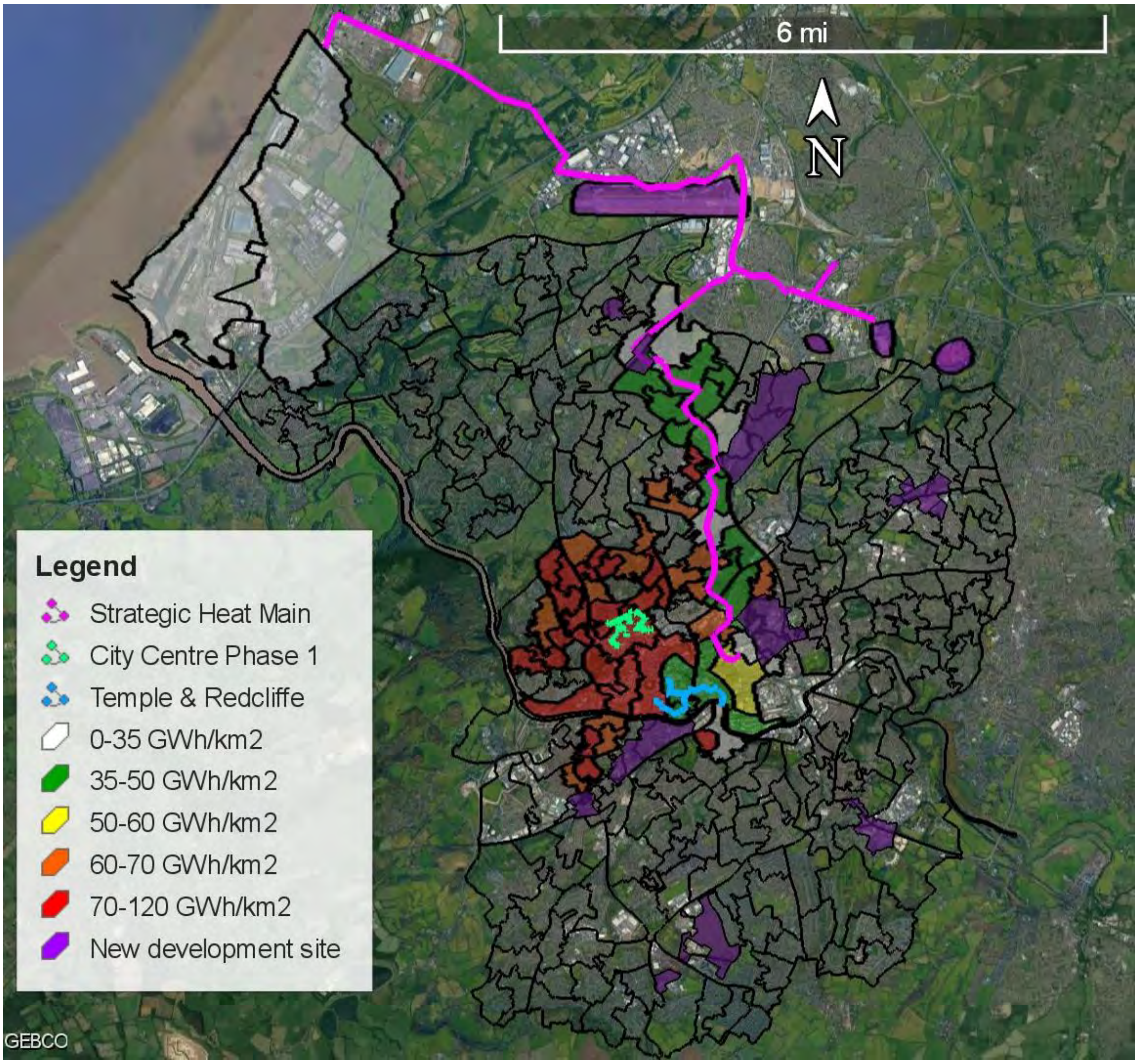


Figure 4-6: Map showing the connected segments and network routes under the Medium HN uptake. Shaded areas represent heat density[25] of the segment that connects to the SHM.



[25] Area heat density (measured in GWh/km^2/year) is defined as the heat demand, per unit area per year. .

Figure 4-7: Map showing the connected segments and network routes under the High HN uptake. Shaded areas represent heat density of the segment that connects to the SHM.



Two prior studies have been undertaken[26,27] to investigate low carbon heat sources that could supply heat to a network in Bristol. Several sources have been identified that utilize waste heat from industry, including Energy from Waste plants. Energy from Waste (EfW) is a process during which municipal waste is incinerated to raise steam to drive a turbine and generate electricity. To the extent that the waste fed into the EfW plant is biogenic[28] the process can generate lower carbon electricity than fossil fuel plants. This process, like all thermal generation, produces 'waste' heat that can be captured at relatively high temperatures as steam or hot water. This could provide a low carbon source of heat for Bristol's heat network. If heat networks are deployed to a significant extent, it is important that the feedstock for these facilities is available over the lifetime of the heat network (up to forty years) and that the carbon intensity of the generated heat remains low, such that EfW remains a reliable low carbon heat source. The feedstock for EfW is municipal solid waste (MSW) and some industrial and commercial waste. In the UK, the reliability of MSW supply in the future depends on changes that may occur further up waste hierarchy: reduce, reuse, recycle, recover and finally, dispose. There is in principle a risk that

[26] Sustainable Energy Limited, Avonmouth and Severnside Heat Network Development Study, A report for South Gloucestershire and Bristol City Councils (pending publication)
[27] WSP Parsons Brinkerhoff, Avonmouth & Severnside Heat Network Study – Heat Mapping Report, December 2015
[28] Biogenic content, rather than fossil carbon-based content, is made up of the constituents, secretions, and metabolites of plants or animals.

increased levels of recycling and the move towards the circular economy will reduce the available feedstock.

A recent report[29] by Defra examines the dependence of net CO_2 savings from EfW on EfW plant efficiency, biogenic content of waste and electricity grid carbon intensity. The report shows that capture of heat substantially improves the case for EfW versus landfill and allows a greater range of biogenic content to be viable in 2050. The report also finds that

- High efficiency solutions should be preferred, beyond that obtainable with mass burn incineration electricity only;
- Use of heat provides the simplest route to ensuring continued primacy of EfW over landfill;
- The biogenic cAontent of the waste should be maintained as high as possible through the removal of fossil plastics for recycling.

In terms of feedstock availability and opportunity to capture heat from it, a recent report[30] for Cadent Gas suggests a reduction in residual waste feedstock availability from 35 TWh/yr in 2015 to 20-30 TWh/yr nationally in 2050 mainly due to increased recycling rates. This study suggests a modest reduction in residual waste between 2015 and 2050, indicating that despite increased rates of reuse and recycling, there will remain substantial potential for EfW. However, the UK captures 80 kWh of heat per tonne of waste on average, compared with 2,550 kWh per tonne in Sweden, according to European benchmarks[31]. This suggests that even in the case of a reduction in residual waste to 2050, there is significant potential for the UK to capture a higher proportion of heat from the existing waste that it produces.

On the local level, BCC has strategy in place to move towards zero waste by maximising waste prevention, waste reduction, re-use and recycling. BCC has set itself a number of ambitious targets, including producing 'the lowest amount of residual household waste per person per year of any UK Core city'[32]. While the evidence in the paragraph above suggests EfW can provide a ready source of low carbon heat over at least the next 20-30 years, over the longer term national and local indicators show that it is nonetheless likely that a reduction in the level of waste will mean that EfW is no longer a viable low carbon source. It is therefore crucial that a credible alternative low carbon heat source for heat networks in the long term is identified and built into the overall heat strategy for Bristol. Various options, such as sourcing waste heat from other industrial processes, water-source heat pumps, bioenergy or hydrogen heating, are discussed below.

Table 4-7 summarises heat sources with capacity to supply heat to networks in Bristol. From these estimates, the water source heat capacity in Bristol is larger than that from EfW and industry. If EfW were no longer a viable low carbon heat source in the future, Table 4-7 shows that there is sufficient water source thermal heat capacity to replace heat demand met by EfW. Air source heat pumps could meet the demand in locations far from water sources.

In this study we have assumed that by 2050, the baseload heat demand (~70% of the total heat demand) is served by a combination of waste heat and river source heat pumps, including water from the floating harbour, the estuary and, potentially, the River Avon. Findings from a separate study by BCC on the City Centre Phase 2 (CCP2) heat network (ongoing at the time of completion of the modelling work in this study) suggest that there are significant challenges to using the river Avon as a heat source (including the tidal range, silting etc.). The benefit of using heat from the River Avon over the estuary is its proximity to the most heat dense areas in Bristol. However, if the challenges are insurmountable, the capacity of the estuary and floating harbour together would still likely be sufficient to serve the baseload heat demand. The peaking heat demand (~30% of the total heat demand) is

[29] Energy recovery for residual waste: A carbon based modelling approach, February 2014
[30] Anthesis/E4tech, Review of Bioenergy Potential: Technical report for Cadent Gas Ltd, 2017
[31] Tolvik consulting, UK Energy from Waste Statistics, 2016
[32] BCC, Towards a Zero Waste Bristol: Waste and Resource Management Strategy, 2016

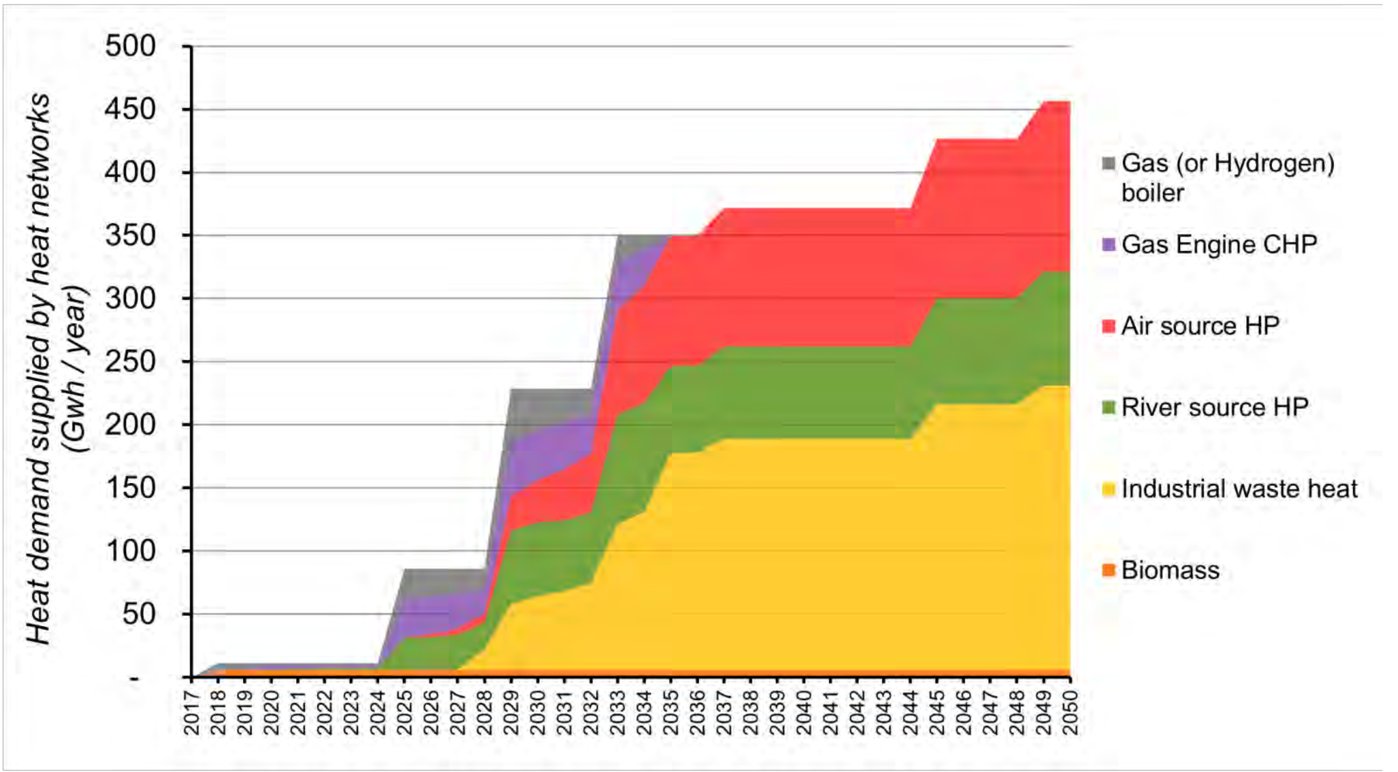
served by either air source heat pumps or hydrogen boilers, depending on the availability of hydrogen in the gas grid.

The heat supply profile for heat networks to 2050 is shown in Figure 4-8. This is for the case where no hydrogen is available and under the medium heat networks uptake scenario.

Table 4-7: sources of heat with potential to supply heat networks in Bristol

Heat source	Site	Capacity (MW_{th})	Fuel	Technology	Existing / planned development
Energy from Waste	Viridor	20	MSW	Mass burn with steam turbine	Planned
	SERC	20	MSW	Mass burn with steam turbine	Existing
Industrial	Rolls Royce	32-50	Gas	Gas turbine	Existing
Water source	River Avon and its tributaries local to Bristol, including the Trym and Frome	101[33]	Electricity	Water source heat pump	Planned
	Floating harbour	Unknown but likely at least MWs	Electricity	Water source heat pump	Planned
	Estuary	Unknown but likely 100s MW	Electricity	Water source heat pump	Planned

Figure 4-8: Heat network supply sources under medium heat network deployment (no H_2 grid)



[33] Atkins for DECC, National Heat Map: Water source heat map layer, 2015

Heat pumps & hybrid heat pumps

Heat pumps are a heating technology that extract heat from the air or ground, and in some cases water sources and deliver this heat at high efficiency to a building. They can do this even when the external temperature is much lower than the building temperature. A heat pump requires energy to achieve this heat transfer, usually in the form of electricity. Heat pumps are 2 to 5 times more efficient than traditional direct electric or storage heaters, where efficiency is defined as useful heat delivered per unit of electrical energy input[34].

Heat pumps have the potential to provide zero carbon heating in the case that they are supplied by fully decarbonised electricity. Heat pumps are a proven technology that is widely deployed in many other countries, although currently they are a niche option in the UK.

There are, however, constraints to the deployment of heat pumps. These include:

- Currently, heat pumps are costly when compared with gas boilers and direct (resistive) electric heating, with air-source heat pumps costing in the region of £6,000-10,000 for a typical domestic building and ground-source heat pumps in the region £10,000-20,000[35];
- Most heat pumps are designed to supply heat at a lower temperature than gas boilers (typically 55-60°C at most) and as such often require the replacement of existing radiators with large-area radiators or underfloor heating;
- Due to the lower operating temperature, heat pumps are only suitable for buildings of a sufficient level of energy efficiency; this is typically considered to mean those with an EPC rating of C or better, although this is dependent on other factors such as the size of the radiators;
- In order to provide hot water as well as space heating, it is usually necessary to install a hot water cylinder, presenting an additional space requirement compared with a gas combi-boiler, as well as an additional cost.

For buildings where the constraints relating to energy efficiency, radiator replacement and space for a hot water cylinder are prohibitive, hybrid heat pumps are an alternative solution. Hybrid heat pumps are systems integrating a heat pump with a boiler (usually gas, but could be oil or other fuel, although these would likely be more carbon intensive). The boiler is utilised at times of peak heating and/or hot water demand when the heat pump is unable to supply the full heat demand; the boiler typically provides heating only during cold winter days, but may provide hot water for much of the year. Hybrid heat pumps can be advantageous because they do not require energy efficiency improvements in the building (although this may still be desirable), and do not necessitate the replacement of radiators or the presence of a hot water cylinder. Due to the ability to provide heat using the boiler at peak times, a smaller heat pump may be installed as compared with the standard (non-hybrid) heat pump option. With the potential cost savings due to these factors, hybrid systems may be less costly overall than a standard heat pump, even after the cost of the boiler is factored in.

Hybrid heat pumps have four main disadvantages relative to standard heat pumps. Firstly, they rely on connection to the gas grid (in the case of gas-electric hybrids) and are therefore not suitable in all buildings. In the case of new build, gas connection is still required, where this can be avoided in the case of standard electric heat pumps (note that the constraints relating to energy efficiency and radiator replacement should not apply to new build anyway, so the advantages of a hybrid system are less clear, although the ability to avoid hot water storage would still apply). Secondly, they derive some of their energy from natural gas, and as such are not consistent with zero carbon heating unless natural gas is displaced by green gas (see next section). Thirdly, the level of carbon emissions reduction relies on the behaviour of the consumer to achieve a high share of heating from the heat pump rather than the gas boiler. Fourthly, the requirement to maintain two connections (gas and electricity) and maintain both the

[34] Electrical resistive heating is up to 100% efficient. Electrically-driven heat pumps usually have a seasonal efficiency of 200% to 500%. For each unit of electricity required to drive the heat pump, 2.5 to 4 units of useful heat are produced.
[35] Though communal systems where the ground array is shared between multiple buildings are cheaper on a per dwelling basis.

gas-based and electrical systems would be expected to lead to higher standing charges and maintenance fees.

New buildings are sufficiently energy efficient to be supplied by a heat pump, and so this is not a material constraint to the uptake of heat pumps in new buildings. The need for low temperature heating, and hence large area radiators or underfloor heating, is also less of a constraint for new buildings, since the low temperature system can be installed on construction, avoiding any replacement cost. The space constraint relating to the need for a hot water cylinder persists, but is also deemed to be less of an issue than for existing buildings since it can be 'designed in' on construction. With regard to existing buildings, under the aforementioned assumption that buildings with EPC rating C or better are suitable for heat pump installation, perhaps >30% of buildings in the UK's stock could be retrofitted with a heat pump today[36]. Those that are not suitable, due to thermal efficiency constraints, can be retrofitted with energy efficiency measures. Low and medium energy efficiency measures increase the number of suitable buildings. It is assumed in this analysis that under the high energy efficiency scenario, all existing buildings are suitably thermally efficient for heat pump installation, though some may still be have other constraints, e.g. space constraints.

With these assumptions, three different levels of heat pump deployment have been generated: Low HPs, Medium HPs and High HPs. Three further scenarios have been generated for the uptake of HHPs. The maximum possible proportion of the stock with HP and HHP installations, segmented into: domestic existing buildings, domestic new buildings, non-domestic existing buildings and non-domestic new buildings, is shown in Table 4-8 and Table 4-9. These reflect various levels of policy ambition for the uptake of these technologies. In theory, and under the assumptions in this study, all new buildings are suitable for HP and HHP uptake.

Table 4-8: Maximum uptake of heat pumps by sector in the three scenarios in 2025 and 2050

Heat demand connected	Units	Low HPs		Medium HPs		High HPs	
		2025	2050	2025	2050	2025	2050
Total	**GWh / year**	**66**	**146**	**79**	**579**	**189**	**1,806**
	%	**2%**	**6%**	**3%**	**25%**	**7%**	**78%**
Domestic	%	3%	7%	3%	28%	6%	71%
Non-domestic	%	2%	3%	2%	12%	9%	60%

Table 4-9: Maximum uptake of hybrid heat pumps in the three scenarios in 2025 and 2050

Heat demand connected	Units	Low HHPs		Medium HHPs		High HHPs	
		2025	2050	2025	2050	2025	2050
Total	**GWh / year**	**19**	**64**	**66**	**203**	**92**	**338**
	%	**1%**	**3%**	**2%**	**9%**	**3%**	**15%**
Domestic	%	1%	3%	3%	10%	3%	15%
Non-domestic	%	1%	2%	2%	5%	4%	9%

Green gas: biomethane and bioSNG

Green gas is a low carbon alternative to natural gas that can be used in gas boilers to produce lower carbon heat, or in gas CHP to produce lower carbon heat and electricity. The green gases considered in this study are biomethane and bio-synthetic natural gas (bio-SNG). Both are composed of methane (after removal of any impurities) and are hence chemically identical to natural gas, and so can be blended into the gas grid in any fraction. Whilst natural gas is extracted from deep underground rock

[36] Centre for Sustainable Energy, Mapping Energy Performance Certificate data by parliamentary constituency - Feasibility report to Citizens Advice (2015)

formations, biomethane is produced by anaerobic digestion of organic material. BioSNG is produced by the gasification of household biogenic waste, energy crops or waste wood. Literature values for the carbon intensity of these gases vary widely depending on production method; the assumptions used in this study are 0.07 $kgCO_2/kWh$ and 0.06 $kgCO_2/kWh$ for biomethane and bio-SNG respectively. The use of green gas brings some advantages over other low carbon alternatives as it can be injected into existing gas grid infrastructure (rather than requiring the repurposing of the grid to carry hydrogen, for example) and can be used by existing gas boilers (rather than requiring the installation of more costly heat pumps, for example). No changes are required at the building-level, as the green gas is indistinguishable from natural gas.

We have generated two different scenarios in this study for the deployment of green gas: no green gas and green gas at maximum deployment. The details of the maximum deployment scenario are shown in Table 4-10.

Literature estimates for the potential level of biomethane and bio-SNG production in the UK vary widely from 30 to 180 TWh / year by 2050. For this study, the total level of green gas deployment is based on the National Grid Two Degrees Scenario from the Future Energy Scenarios 2017[37], which includes 59 TWh of green gas by 2050 nationally. The economic potential of biomethane is estimated to be around 30 TWh of this, and is assumed to reach this limit in the 2030's. Based on Bristol's current share of national gas demand, these levels equate to approximately 370 GWh green gas in Bristol, of which 192 GWh is biomethane and the remainder is bio-SNG.

Table 4-10: Summary of the maximum green gas deployment scenario. Percentages are share of gas grid demand in Bristol.

Heat demand connected	Units	Maximum Green gas deployment	
		2025	2050
Total	**GWh / year**	**65**	**370**
	%	**3%**	**64%**
Biomethane	%	3%	33%
BioSNG	%	0%	31%

Hydrogen gas

An alternative potential route to decarbonise heat in Bristol is the use of hydrogen, delivered via a re-purposed gas distribution network. Hydrogen could provide heating using boilers similar to the gas boilers used in a majority of buildings in Bristol.

The potential benefits of hydrogen heating are that the building scale technology costs should be considerably lower than heat pumps (hydrogen boilers are expected to be similar to the cost of gas boilers once produced at scale), and hydrogen boilers would not necessarily require high levels of building energy efficiency, although this may still be preferable to reduce ongoing energy bills and further reduce carbon emissions. Hydrogen boilers could be implemented in all buildings connected to the gas grid, which is currently over 90% of Bristol's domestic stock and 88% of its non-domestic stock. It could also be the low carbon heating option requiring least consumer behaviour change. The large-scale use of hydrogen also reduces the electricity grid infrastructure challenge and additional generation capacity associated with the deployment of high levels of heat pumps.

It is important to note, however, that significant uncertainties remain over the technical and economic viability of the widespread use of hydrogen for heating, and that this is not a proven technology. These uncertainties are described further below.

[37] National Grid, Future Energy Scenarios, July 2017

Production Methods and CCS

The most cost-effective source of bulk low carbon hydrogen is likely to be steam methane reforming (SMR). SMR uses a natural gas feedstock, reacted with steam under high pressure, to produce hydrogen, a process that leads to direct CO_2 emissions. As a consequence hydrogen produced in this way can only be considered to be 'low carbon' when combined with carbon capture and storage (CCS)[38] to remove the CO_2 produced by SMR. Based on industry estimates of the carbon capture technologies that could apply in the 2030s and 2040s, we assume here that capture facilities are able remove 90%[39] of the direct CO_2 emissions from the flue gas. The CO_2 is then assumed to be transmitted to shoreline terminals, compressed and transmitted via offshore pipelines to offshore CO_2 storage sites.

Challenges and uncertainties

There are many challenges and uncertainties associated with using hydrogen for heat in Bristol. One of the largest challenges is the infrastructure undertaking of repurposing Bristol's current natural gas distribution network for hydrogen. Low pressure iron distribution pipes that are not suitable for hydrogen would need to be replaced, as would some of the steel gas transmission system[40]. Gas meters are likely to require replacement and there may be a need for gas detectors within buildings. Additional network surveys are likely to be needed to identify the requirement for pipe replacements. It will also be necessary to replace existing gas boilers with hydrogen-burning boilers at the time of grid conversion (it may also be possible to install gas- and hydrogen- compatible boilers in the run-up to the conversion), along with any other gas-based appliances such as ovens, hobs and fires.

It may also be necessary to replace some of the internal building pipework carrying the gas or hydrogen, although this is currently uncertain. The commercial viability of producing large quantities of low carbon hydrogen is also uncertain. As noted above, the production methods currently deemed most viable include SMR with CCS, although CCS has not yet been proven commercially viable. An alternative is to produce hydrogen by electrolysis, a process which is energy intensive and currently costly. Given these factors, there remains significant uncertainty around the cost and deliverability of this pathway for Bristol and nationally.

There are also concerns around the safety of distribution and use of hydrogen in buildings, and the associated consumer acceptability challenges. Trialling and demonstration projects are underway to understand the feasibility of large scale hydrogen use for heat and transport, in terms of cost, safety and distribution requirements[41]. Element Energy has recently undertaken research for BEIS on the supply chain of hydrogen for heating, including production, transmission and distribution[42]. The analysis and assumptions in this study are based largely on the datasets developed in that work.

The introduction of hydrogen into the gas grid and the phasing out of natural gas would require a coordinated national effort. If hydrogen were to be deployed, once fully introduced, there would be no remaining alternative gases circulating in the grid. Accordingly, two scenarios have been developed to reflect the deployment: one where hydrogen is deployed at its maximum potential and one where there is no hydrogen in the gas grid. There is no medium uptake scenario as the infrastructure costs are prohibitively expensive if the technology is not deployed at a large scale.

Compared to the other low carbon heating technologies analysed in this study, hydrogen gas deployment is the least mature. The timescale over which hydrogen may be deployed is therefore later, the specifics of which are shown in Table 4-11.

[38] Hydrogen for heat technical evidence and modelling project, (2017), a report by Element Energy, Jacobs and BGS for BEIS
[39] Hydrogen for heat technical evidence and modelling project, (2017), a report by Element Energy, Jacobs and BGS for BEIS
[40] Energy Research Partnership, Potential Role of Hydrogen in the UK Energy System, October 2016
[41] Hydrogen for Heat Programme, BEIS, Arup, Kiwa Gastec, 2017-2021
[42] Hydrogen for heat technical evidence and modelling project, (2017), a report by Element Energy, Jacobs and BGS for BEIS

Table 4-11: Deployment timeline of hydrogen.

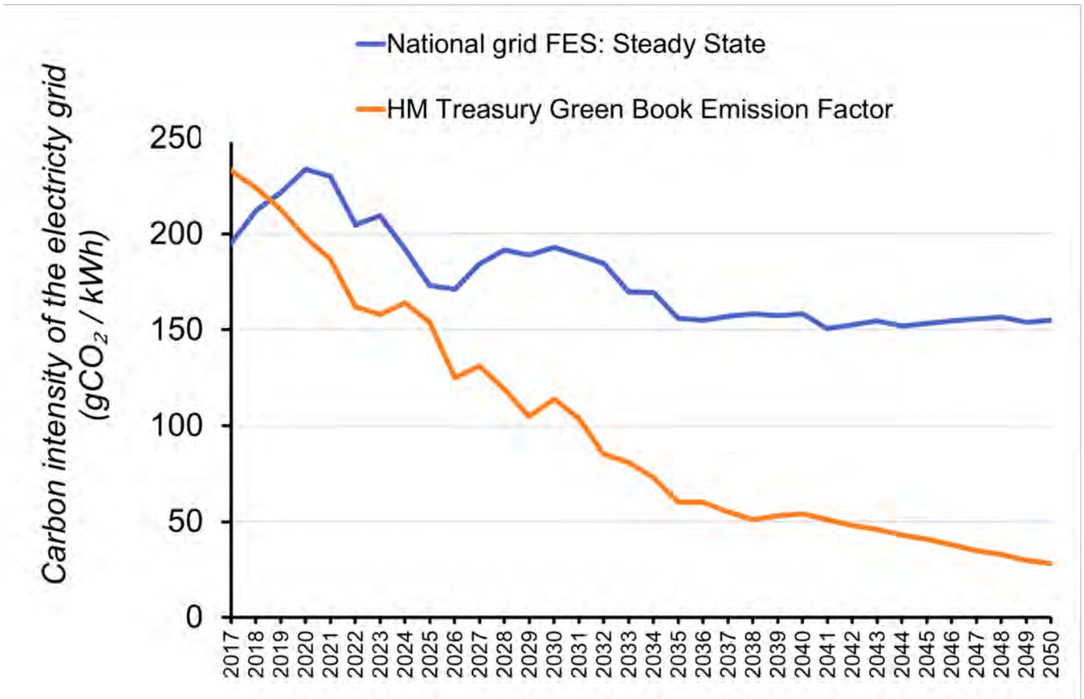
Deployment scenario	Proportion of gas demand met by hydrogen by year (%)					
	2040	2041	2042	2043	2044	2045
Maximum deployment	0%	20%	40%	60%	80%	100%

4.4 Grid decarbonisation

The carbon intensity of the electricity grid assumed in this study is shown in Figure 4-9 and is assumed to be dictated by the national generation mix. Two different trajectories have been selected: the Future Energy Scenarios ‘Steady State’ scenario[43] and HM Treasury Green book[44] emission factor. The FES steady state scenario is one where ‘business as usual prevails’[45] and investment in grid decarbonisation is limited. The Green book emission factor trajectory assumes grid decarbonisation down to less than 30 gCO_2/kWh in 2050.

The gas grid decarbonisation is uncertain as it depends on factors such as hydrogen deployment and the level of deployment of green gas sources. The carbon intensity of the gas grid depends on which gases are present and how they are produced, as previously explained in this Chapter. The carbon intensity of the gases in this study are shown in Table 4-12.

Figure 4-9: Carbon intensity of the electricity grid to 2050



[43] National Grid, Future Energy Scenarios, July 2017
[44] The Green Book, HM Treasure, Data Tables
[45] National Grid, Future Energy Scenarios, July 2017

Table 4-12: Carbon intensity of natural gas, green gas and hydrogen assumed

Gas	Carbon intensity (gCO_2 / kWh)
Natural gas	183
Hydrogen	22
Biomethane	74
BioSNG	63

4.5 Costing approach

We calculate the investment required for the roll out of the heating technologies for the different levels of uptake. This includes the costs of the component building-level technologies, fuel costs and infrastructure upgrade costs. All costs presented in this section are under the 'central' cost scenario. Two further cost sensitivity scenarios were developed: 'low' and 'high', and these are presented and discussed in section 6.1. A summary of the cost elements included in each of these categories is given in Table 4-13.

Table 4-13: Summary of costs included in the analysis

Building Level technology costs	Infrastructure costs	Fuel costs
• Energy efficiency and heating systems • Includes heat interface unit (HIU) & heat meter for HNs • Technology capex • Technology installation • Technology maintenance • End of life replacement	• Heat networks including energy centres, network (pipes), capex (installation, maintenance & replacement) • Electricity grid infrastructure • Repurposing of gas grid to deliver hydrogen	Retail costs for all fuels: • Natural gas • Electricity • Hydrogen • Biomethane • BioSNG

The heating technology costs for a typical building are shown in Table 4-14. The cost of retrofitting a typical existing building with energy efficiency measures is shown in Table 4-18.

Infrastructure costs are included for heat networks, electricity grid upgrades and gas grid repurposing. The infrastructure costs associated with the Low, Medium and High level of deployment of heat networks in Bristol are shown in Table 4-16. The heat network infrastructure costs are assumed to be incurred over the four years preceding to the completion of a new heat network 'phase'. We have assumed a fully low carbon peaking source to be required by 2035; we have assumed that if hydrogen is present in the gas grid, hydrogen boilers will supply the peak heat load to heat networks; where hydrogen is not available, we apply air source heat pumps. The associated energy centre costs are therefore different for these two cases, as shown in Table 4-16.

We derived the infrastructure costs associated with electricity grid upgrades by estimating the reinforcement cost associated with any increase in peak electricity demand for heating (beyond that associated with electric heating in 2017). The infrastructure costs and sources used to estimate the cost of repurposing the gas grid for hydrogen are shown in Table 4-17.

Finally, the retail prices of fuel assumed in the costing are shown in Table 4-18. The retail prices for electricity and natural gas are taken from the HMT Green Book[46]. Hydrogen and green gas costs have been estimated using production costs from literature[47] and converting these to retail prices.

Throughout this analysis, we present the cashflow in undiscounted terms and the base year for costs is 2016/17.

Table 4-14: Building-level cost comparison of technologies, excluding maintenance costs

		Installed cost per typical building (£)				Data source used
		Domestic		Non-domestic		
Technology	Components installed	Existing building	New build	Existing building	New build	
District Heating	New build: HIU[48], heat meter Existing building: HIU, heat meter, low temperature distribution system	5,400	1,900	11,400	6,900	DECC[49]
Heat pump (HP)	New build: HP only Existing building: HP, low temperature distribution system	10,700	5,900	27,400	18,900	Element Energy[50]
Hybrid heat pump (HHP)	Existing building: HHP only New build: HHP only	6,700	-	21,500	-	Element Energy[26]
Hydrogen boiler	Existing building: Hydrogen boiler, internal pipework New build: Hydrogen boiler, internal pipework	2,400	2,400	4,000	4,000	Element Energy[51]
Gas boiler	Existing building: gas boiler only New build: gas boiler only	2,100	2,100	3,400	3,400	Element Energy[52]
Electric heating	Existing building: electric heating system only New build: electric heating system only	1,100	1,100	2,200	2,200	Element Energy[28]

[46] HM Treasury, HMT Green Book, 2017.
[47] Sustainable Gas Institute, *A Greener Gas Grid: What are the options?*, 2017; Royal Society, *Options for producing low-carbon hydrogen at scale,* 2018.
[48] Heat interface unit.
[49] Department for Energy and Climate Change, Assessment of the Costs, Performance, and Characteristics of UK Heat Networks, 2015.
[50] Hybrid heat pumps study, a report by Element Energy for BEIS, 2017.
[51] Hydrogen for heat technical evidence and modelling project, A report by Element Energy, Jacobs and BGS for BEIS, 2017.
[52] Element Energy and E4tech, Cost analysis of future heat infrastructure options, Report for the National Infrastructure Commission (pending publication).

Table 4-15: Average cost of energy efficiency measures per typical installation

Insulation measure	Installed cost per typical Domestic building (£)
Solid wall insulation	8,500
Cavity wall insulation	2,800
Loft insulation	300
Window glazing	3,500
Floor insulation	1,000
Draught proofing	800

Table 4-16: Heat network infrastructure costs assumed for the three deployment levels

Item		Low HNs	Medium HNs	High HNs
Annual heat demand served		144 GWh	457 GWh	1,018 GWh
Network length	Primary	50 km	169 km	488 km
	Secondary	34 km	107 km	260 km
Number of connections		7,000	23,000	56,000
Cost of network	Primary	£70 m	£237 m	£686 m
	Secondary	£27 m	£82 m	£197 m
Energy centre cost	No H_2 grid	£289 m	£737 m	£1,480 m
	H_2 grid	£189 m	£476 m	£923 m
Total cost	No H_2 grid	£407 m	£1,107 m	£2,450 m
	H_2 grid	£286 m	£846 m	£1,806 m

Table 4-17: Infrastructure costs assumed for gas grid conversion and electricity grid upgrades

Fuel	Infrastructure cost component	Cost (£m)	Data source
Hydrogen	Distribution grid repurposing	£182 m	Element Energy & E4Tech for the NIC[53] and Element analysis
	New hydrogen transmission grid	£27 m	Element Energy & E4Tech for the NIC[29] and Element analysis
	Conversion of industrial heating systems from natural gas to hydrogen	£3 m	Cadent & Progressive Energy[54] and Element analysis
Electricity	Upgrading the electricity grid	Varies by scenario	Element analysis assuming reinforcement cost per additional peak electricity demand of £200/kW for transmission system and £650/kW for distribution system

[53] Hydrogen for heat technical evidence and modelling project, A report by Element Energy, Jacobs and BGS for BEIS, 2017.
[54] Cadent Gas & Progressive Energy Ltd, The Liverpool-Manchester Hydrogen Cluster: A Low Cost, Deliverable Project, 2017.

Table 4-18: Retail fuel prices assumed

Retail fuel prices p / kWh		2017	2030	2050
Natural gas	Non-domestic	2.6	4.2	4.2
	Domestic	4.0	5.0	5.0
Electricity	Non-domestic	11.3	14.5	14.5
	Domestic	16.3	19.1	19.1
Biomethane		8.6	8.6	8.6
BioSNG		7.3	7.3	7.3
Hydrogen		7.6	7.6	7.6

5 Heat decarbonisation scenarios

We define the varying levels of uptake for each heating technology in section 4; in this section, we present five heat decarbonisation scenarios and the associated outcomes in terms of carbon emissions and cost. We have constructed these scenarios based on different energy efficiency and heating technology uptake combinations.

When constructing these scenarios, our objective was to test the consistency of various pathways with Bristol's goal of becoming carbon neutral by 2050. We constructed one additional scenario, the Baseline scenario, to reflect a potential outcome should current policies remain as they are. The assumptions behind these scenarios are shown, at a high level, in Table 5-1. The level of deployment of each technology relates to the levels defined in sections 4.2 and 4.3.

Table 5-1: High level description of the technology deployment level in each scenario

	Baseline	High heat networks	High heat pumps	Decarbonised gas	High heat networks & high heat pumps	Mixed pathway
Energy efficiency	Low energy efficiency	High energy efficiency	High energy efficiency	High energy efficiency	High energy efficiency	High energy efficiency
Heat networks (HN)	Low HN deployment	High HN deployment	Medium HN deployment	Medium HN deployment	High HN deployment	Medium HN deployment until 2040
Heat pumps (HPs)	No HPs	Medium HPs & hybrid HPs	Widespread HP roll-out	Low HPs & hybrid HPs	Widespread HP roll-out	Widespread HP rollout to 2040
Green gas	No green gas	Maximum green gas deployment	No green gas	No green gas	Some green gas deployment	No green gas
Hydrogen (H_2) gas	No H_2	No H_2	No H_2	Full H_2 conversion in 2040s	No H_2	Full H_2 conversion in 2040s
Grid decarbonisation	National Grid FES Steady state	HMT Green Book	HMT Green Book	HMT Green Book	HMT Green Book	HMT Green Book

5.1 Baseline: results

The Baseline scenario reflects current policy ambition regarding the uptake of heating technologies. It assumes that current policy on low carbon heating technologies will not increase in ambition: only heat networks already in development and construction phases will be completed and deliver heat. No heat pumps are deployed and there is no low carbon gas in the gas grid. It assumes a low level of energy efficiency (mostly loft and cavity wall insulation in the domestic sector, with some low cost insulation measures and smart metering in the non-domestic sector). Regarding grid decarbonisation, the FES Steady State scenario[55] is followed, in which the grid decarbonises to approximately 150 gCO_2 / kWh by 2035 and stagnates at this level until 2050.

The heat demand profile shown in Figure 5-1 is dominated by gas boilers running on natural gas, this reflects the current way in which most heat demand is met in Bristol and in the UK as a whole. The total

[55] National Grid, Future Energy Scenarios, July 2017

heat demand in this scenario remains approximately constant at 3,000 GWh / year until 2035. This is because the increase in heat demand in new buildings is approximately offset by the implementation of low cost energy efficiency measures in the existing building stock. Beyond 2035, no further energy efficiency measures are applied and the heat demand increases due to the continuing increase in heat demand from new buildings. By 2029, the City Centre Phase 2 network will serve 116 GWh / year of heat, replacing mainly gas boilers and some electric heaters in the connected buildings.

Gas boilers dominate the carbon emissions, shown in Figure 5-2. From 2017 to 2050, the carbon emissions are relatively flat, falling from 650 ktCO_2 / year to 623 ktCO_2 / year over that period with a minimum of 575 ktCO_2 / year in 2035. This level of carbon emissions clearly falls well short of the ambition of carbon neutrality by 2050, as total emissions from heating are barely reduced from current levels. Total cumulative emissions to 2050 are 20.5 MtCO_2, as shown in Table 5-2.

Figure 5-1: Heat demand profile to 2050 in the Baseline scenario

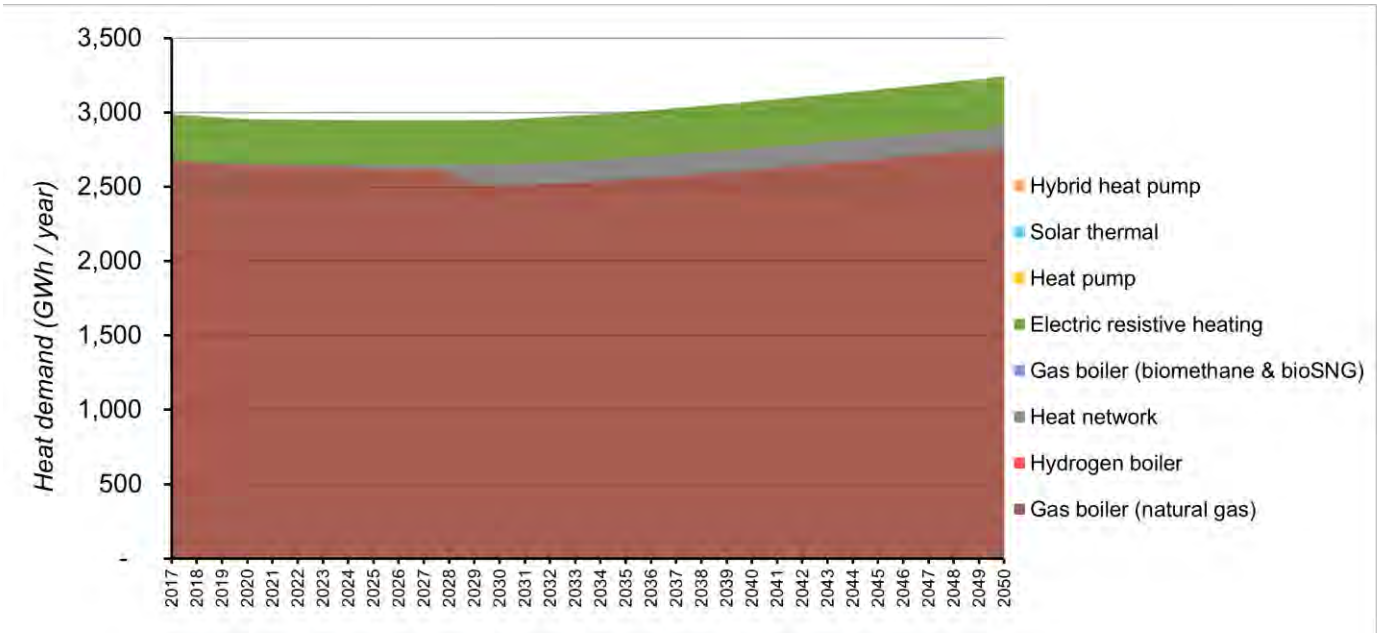
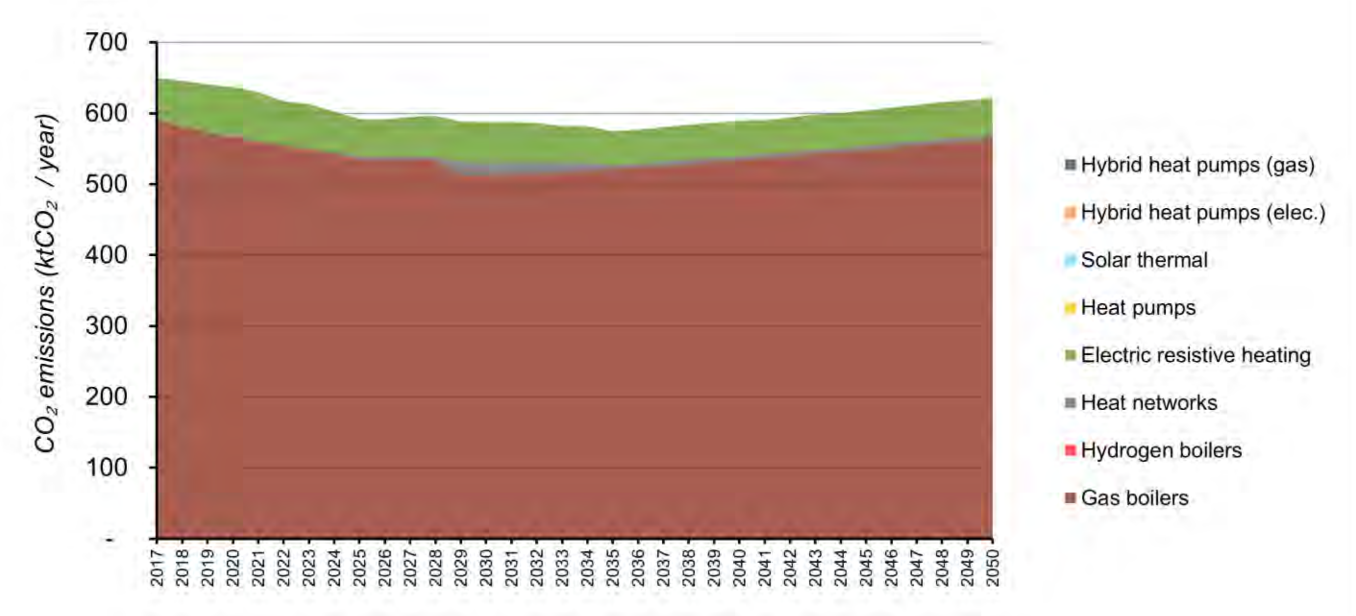


Figure 5-2: Carbon emissions to 2050 in the Baseline scenario



We display the investment profile for the Baseline scenario in Figure 5-3. This shows the distribution of costs, broken down into infrastructure, fuel and building-level costs. The annual investment is £237 million per year in 2017, and varies over the period to 2050 between £237 million and £307 million.

The annual investment peaks are attributed to infrastructure costs and occur at times when heat networks are built. The general increasing trend of annual investment is due to increasing fuel prices from 2017 to 2050. Building level costs are higher initially due to the installation of low cost energy efficiency measures by 2030; these then stabilise at around £60 million per year reflecting the cost of maintaining and replacing (mainly) gas boilers.

Cumulatively from 2017-2050, gas boilers make up 76% of the building-level costs, with the remaining 24% being made up of energy efficiency measures, electric heating and building-level heat network costs. Fuel costs are the most significant cost in the Baseline scenario and they increase over the period 2017-2050. This is due to a combination of the overall small increase in heat demand (Figure 5-1) and the increasing trend of natural gas and electricity prices to 2030 (Table 4-18). As much as 97% of the infrastructure costs are incurred from the construction and maintenance of heat networks. Cumulatively to 2050, we calculate that this scenario emits 20.5 $MtCO_2$ and costs £9.1 bn in the central cost scenario, but ranges between £7.9 bn and £9.8 bn in the low and high cost sensitivities respectively.

Figure 5-3: Investment profile to 2050 of the total costs incurred in the Baseline scenario

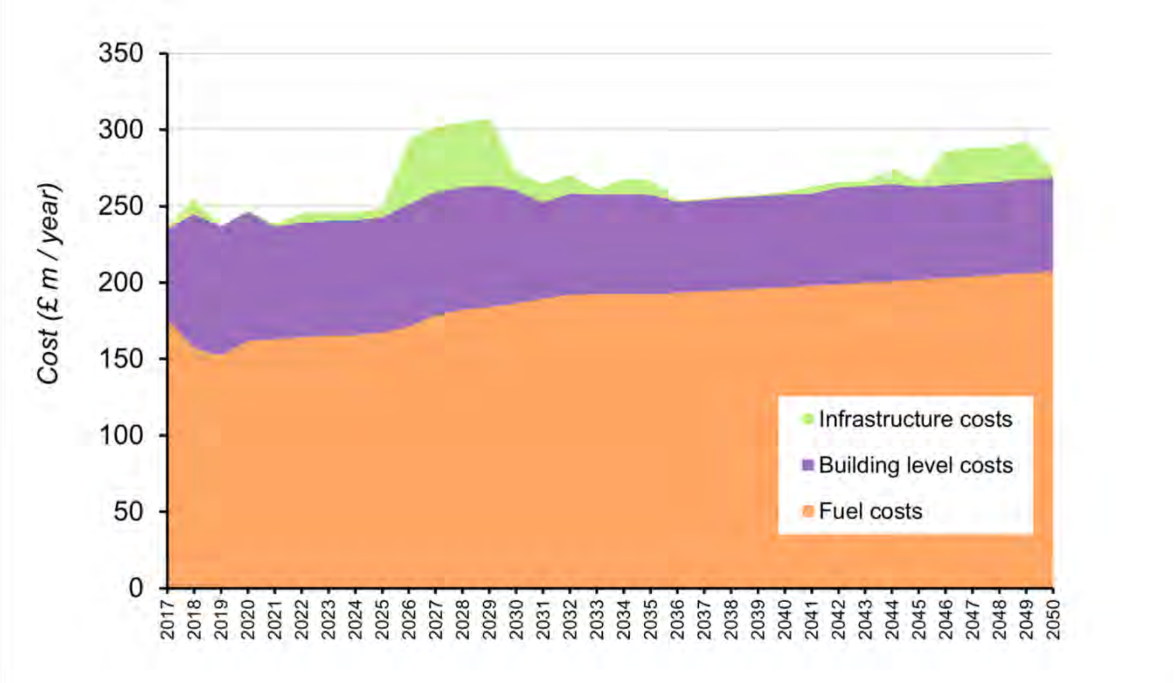


Table 5-2: Emissions and costs to 2050 for the Baseline scenario

		Baseline scenario
Annual emissions in 2050 ($ktCO_2$)		623
Cumulative emissions to 2050 ($MtCO_2$)		**20.5**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**
Building level costs (£ m)	**Building-level sub-total**	**2,328**
	Energy efficiency	280
	Heat networks (HIU & Low T)	56
	HPs & HHPs	0
	Hydrogen boilers	0
	Gas boilers	1,770
	Electric heating	221
	Solar thermal	0
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**
	Electricity grid upgrades	11
	Heat networks	407
	Hydrogen grid	0
Fuel costs (£ m)	**Fuel sub-total**	**6,335**
	Natural gas	4,444
	Electricity	1,891
	Hydrogen	0
	Biogas	0

5.2 High heat networks: results

The High heat networks scenario is driven by ambitious policy to develop decentralised energy. In order for a heat network to be built, large infrastructure changes must take place. These infrastructure changes typically mean that heat networks are built out in phases of investment, with each phase connecting a new tranche of customers. As a result, the heat network segment in Figure 5-4 increases in steps rather than increasing smoothly; these steps coincide with heat network connection years. In the High HN (Table 5-1) deployment case, these connection years coincide with the construction of the Strategic Heat Main (SHM).

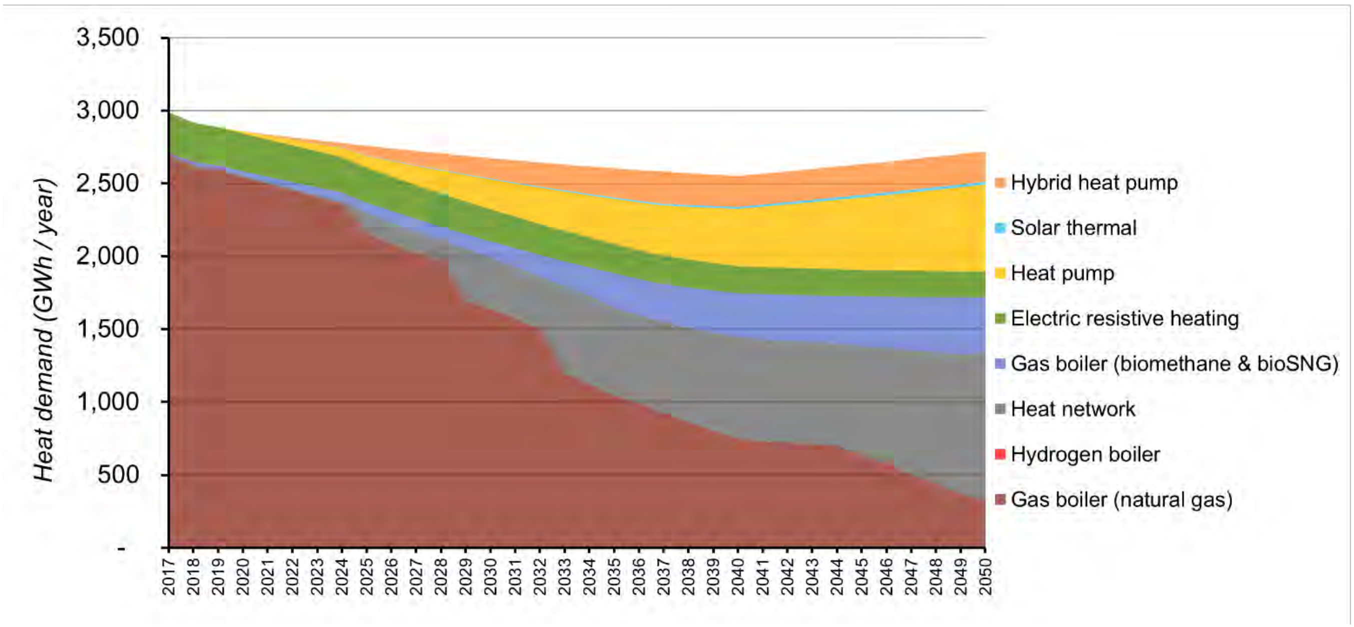
We have assumed that the SHM connects to Southmead in 2025 and to Bristol's city centre heat network in 2033. The carbon savings due to this connection are significant: the carbon emissions reduce from 383 $ktCO_2$/ year in 2032 to 330 $ktCO_2$ / year in 2033. This incurs infrastructure costs of ~£110m / year for the four years leading to this connection year, as shown in Figure 5-6.

A separate study by BCC on the carbon trajectory of the City Centre Phase 2 heat network (ongoing at the time of completion of the modelling work in this study) suggests that, for the heat to be sufficiently low carbon to justify its rollout in new development in place of heat pumps, low carbon waste heat from Avonmouth via the SHM will need to supply the city centre's heat network by 2028. On the basis of this separate work, we propose that development of the SHM should target connection to the city centre at the earlier date of 2028 at the latest[56].

The ambitious heat network uptake that is assumed in this scenario serves 1,018 GWh / year, or 37% of the heat demand, in 2050. The remaining 63% is served by heat pumps (20%), gas boilers (28%), hybrid heat pumps (7%), electric heating (5%) and solar thermal (1%). More than half of the remaining gas consumption in gas boilers and hybrid heat pumps is green gas by 2050.

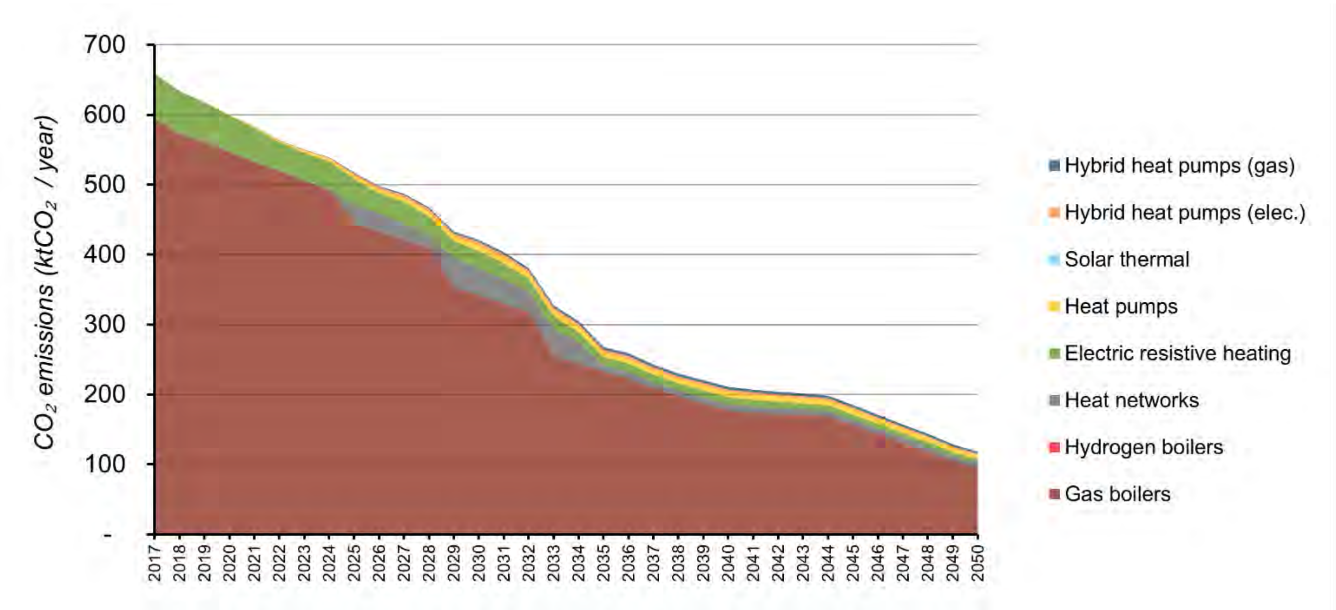
[56] The recommendation to accelerate the development of heat networks in Bristol is supported by the finding (described further below) that the High HNs scenario lags behind other scenarios in terms of the rate of carbon emissions reduction; faster development of the SHM and associated heat networks would bring this scenario further in line with the competing options.

Figure 5-4: Heat demand profile for the High heat network scenario



In the High heat networks scenario, the annual carbon emissions reduce from 659 ktCO_2 / year in 2017 to 118 ktCO_2 / year in 2050. Most of this decarbonisation is achieved due to the uptake of non-gas heating technologies, mainly heat pumps and heat networks. Uptake of heat pumps and hybrid heat pumps, contributes strongly to decarbonisation as the electricity grid decarbonises to 144 gCO_2 / kWh in 2030 and to 28 gCO_2 / kWh in 2050. Heat networks are supplied largely by low carbon heat sources, as shown in Figure 4-8. This leads to an average carbon intensity of 110 gCO_2 / kWh in 2030 and 7 gCO_2 / kWh in 2050 (this is the carbon intensity of the heat delivered, not the heat generated, so it takes into account transmission losses).

Figure 5-5: Carbon emissions to 2050 in the High HNs scenario



The investment profile is displayed in Figure 5-6. The infrastructure costs are significantly higher in this scenario than in the Baseline scenario. This is mainly due to heat network infrastructure costs, which make up 19% of the cumulative total cost to 2050, at £2.4 bn (see Table 5-3). Under the central cost scenario, the cumulative fuel cost to 2050 in this scenario is £5.8 bn, compared to £6.3 bn in the baseline scenario. The reduced fuel cost relative to the Baseline is due to the more efficient use of fuel in heat networks through the use of heat pumps and EfW, despite the higher cost of electricity relative to gas.

The building-level costs are higher initially, reaching £170m in 2018, compared to £80m in the Baseline scenario. This is due to the application of high cost energy efficiency measures in the High heat network scenario. By 2040, all energy efficiency measures have been applied and the building-level costs are relatively flat around £100m / year to 2050. This is higher than the annual building-level cost of £60m / year in 2050 in the Baseline scenario, reflecting the higher cost of replacing building-level heating systems (which include the more costly heat pumps and hybrid heat pumps) than in the Baseline scenario.

The cumulative total investment to 2050 in the High heat networks scenarios under the central cost case is £12.5 bn with cumulative emissions of 12.1 $MtCO_2$, compared with £9.1bn and 20.5 $MtCO_2$ in the Baseline scenario.

Figure 5-6: Investment profile to 2050 of the total costs incurred in the High HNs scenario

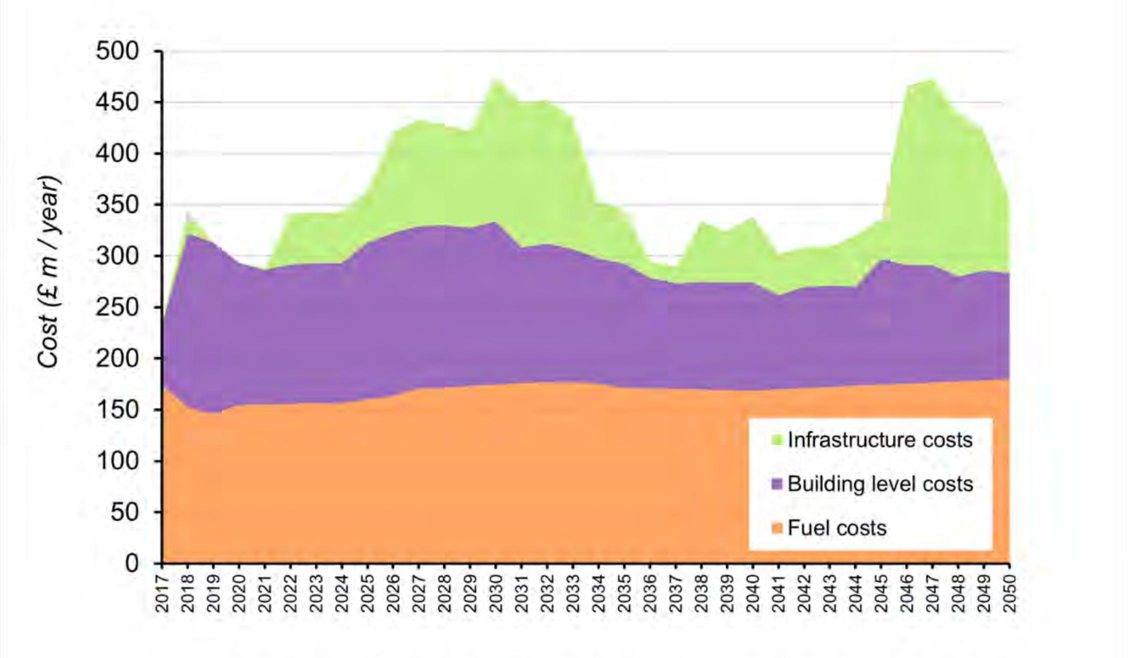


Table 5-3: Emissions and costs to 2050 for the Baseline and High HNs scenario

		Baseline scenario	High HNs
Annual emissions in 2050 ($ktCO_2$)		623	118
Cumulative emissions to 2050 ($MtCO_2$)		**20.5**	**12.1**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**	**12.5**
Building level costs (£ m)	**Building-level sub-total**	**2,328**	**4,248**
	Energy efficiency	280	1,099
	Heat networks (HIU & Low T)	56	305
	HPs & HHPs	0	1,223
	Hydrogen boilers	0	0
	Gas boilers	1,770	1,284
	Electric heating	221	197
	Solar thermal	0	140
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**	**2,521**
	Electricity grid upgrades	11	71
	Heat networks	407	2,450
	Hydrogen grid	0	0
Fuel costs (£ m)	**Fuel sub-total**	**6,335**	**5,766**
	Natural gas	4,444	2,417
	Electricity	1,891	2,721
	Hydrogen	0	0
	Biogas	0	628

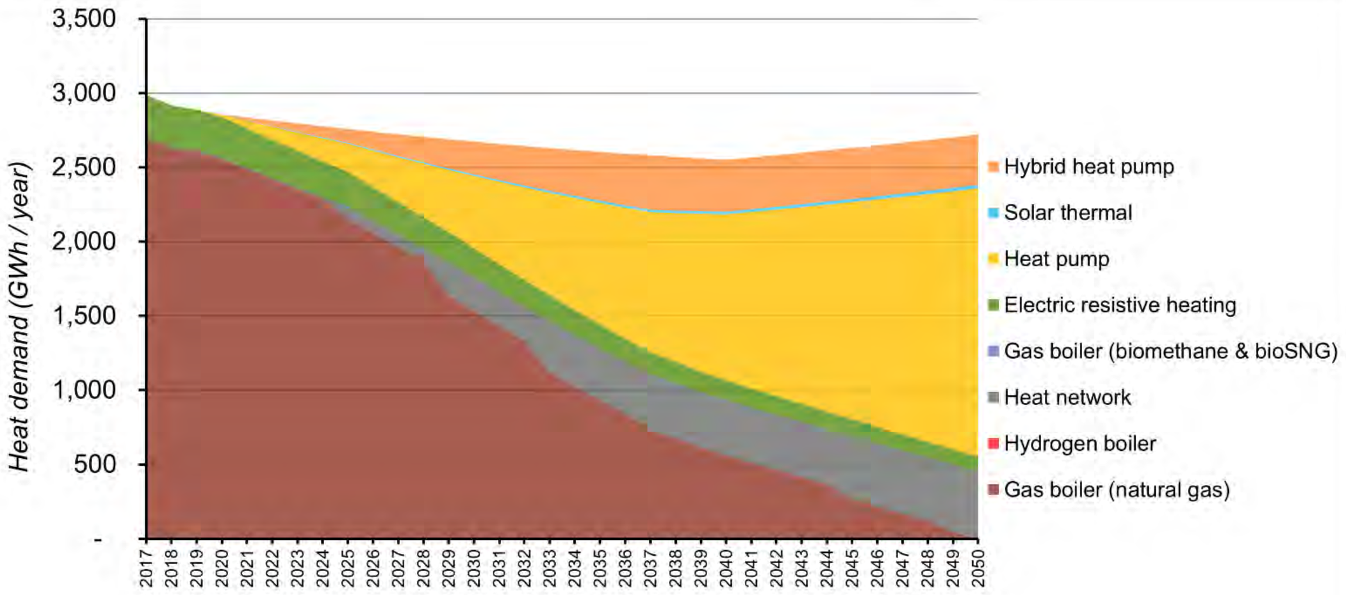
5.3 High heat pumps: results

The High heat pumps scenario relies on ambitious uptake of heat pumps as shown in Figure 5-7: by 2025, 7% of the heat demand is served by heat pumps, by 2035 this has risen to 31% and by 2050 to 66%. Over this time period, heat pumps replace gas boilers and electric (resistive) heaters.

By 2050, heating by gas is entirely phased out and heat demand is met entirely by electricity. Electric heaters are not phased out entirely because it is assumed that a small share of buildings remain unsuitable for a heat pump or a hybrid heat pump, even if retrofitted to be thermally efficient, due to constraints relating to external space and/or noise considerations (air source heat pumps require an outdoor unit which produces some noise).

Such buildings are more likely to be small flats. By 2050 the remaining 34% of heat demand is served by heat networks, hybrid heat pumps and solar thermal. In this scenario, the Medium HN level of deployment is applied serving 17% of the heat demand in 2050; this includes the construction of the SHM and the connection of 70% of new developments lying on its route. Hybrid heat pumps serve 12% of the heat demand in 2040; however, these switch from running on both natural gas and electricity until 2045, to running entirely on electricity thereafter, once all buildings are energy efficient enough to be supplied by a standard (non-hybrid) heat pump.

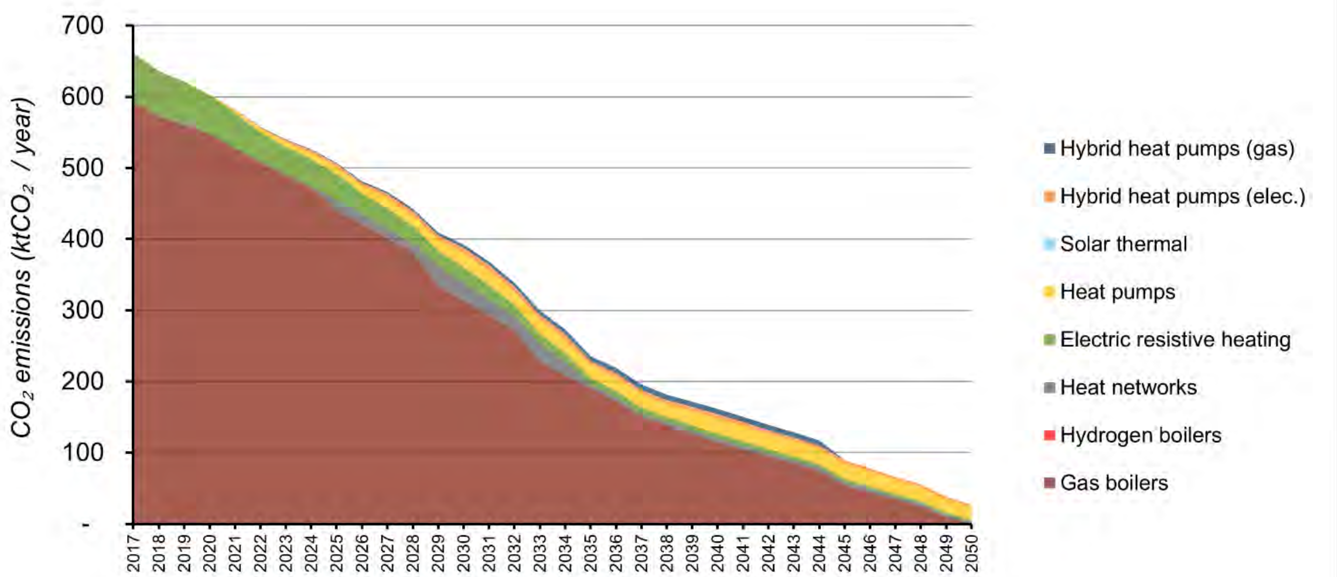
Figure 5-7: Heat demand profile to 2050 in the High HPs scenario



The carbon emissions trajectory in the High heat pumps scenario is shown in Figure 5-8. The level of carbon emissions in 2030 is 393 ktCO_2 compared to 588 ktCO_2 in the Baseline scenario. This level of decarbonisation is due to the switch from a reliance on natural gas to electricity, mainly from the uptake of heat pumps, combined with the decarbonisation of the electricity grid to 100 gCO_2 / kWh by 2030 (see Figure 4-9).

The level of carbon emissions achieved by 2050 in this scenario is 27 ktCO_2 / year. These remaining 27 ktCO_2 emitted per year are due to a reliance on an electricity grid that is not (quite) fully decarbonised, with a carbon intensity of 28 gCO_2 / kWh in 2050.

Figure 5-8: Carbon emissions to 2050 in the High HPs scenario

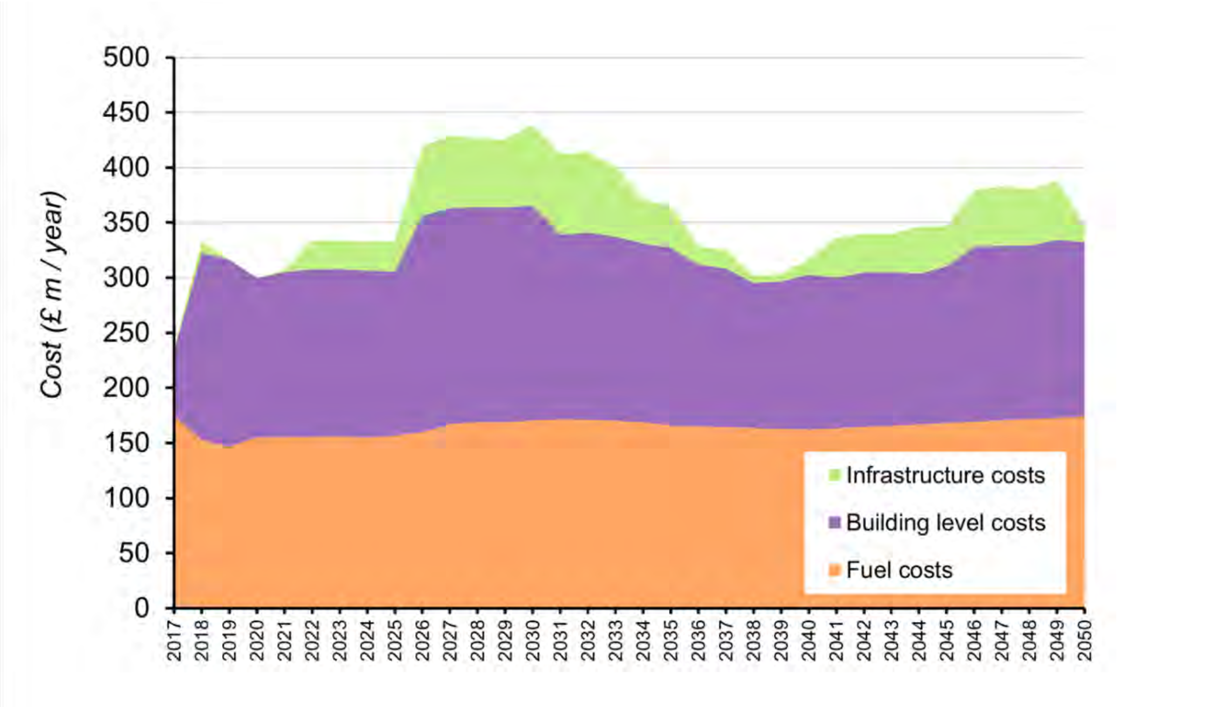


Once all efficiency measures are applied, the building level costs are approximately £150 m per year as compared to the annual building-level costs of £60 m in the Baseline case. This is due to the higher uptake of relatively costly technologies: heat pumps and hybrid heat pumps. Heat pumps and hybrid heat pumps serve 78% of the heat demand in 2050. In order to achieve this, more than 165,000 heat pumps and hybrid heat pumps installed by 2050, and these must be purchased, maintained and replaced at the end of their lifetime. Potential reductions in the unit cost of heat pumps from economies of scale and technology learning have been accounted for in this analysis, and we include here a 30% reduction in cost between today and 2030, based on a recent study by Element Energy for BEIS[57]. This incurs cumulative building-level costs of £2.7 bn (see Table 5-4). The remaining £2.5 bn of building level costs are spread between the application of efficiency measures (£1.1 bn), gas boilers (£0.9 bn) and other heating technologies (£0.6 bn).

The fuel costs incurred in this scenario remain at £160 m ± 15 m for the duration of the period studied in this report. The reduced fuel cost relative to the Baseline is due to the more efficient use of fuel in heat pumps and is despite the higher cost of electricity relative to gas, as in the High heat networks scenario. The full electrification of heat, mainly through heat pumps, is estimated to lead to an increase in peak electricity demand versus 2017 levels of approximately 170 MW. It is estimated that this could lead to additional electricity grid reinforcement costs of £150 m to 2050 (note that this does not account for changes in the non-heating peak electricity demand, which could reduce due to lighting and appliance efficiency improvements but could also be increased due to electrification of transport). While this is a substantial investment for the grid, it is a relatively small share of the overall investment in the scenario to 2050 of £12.1 bn.

The investment cost associated with heat network rollout is large in this scenario, at £1,100 m. This is because the Medium HN uptake is assumed in this scenario which includes the construction of the SHM and the distribution of low grade waste heat from Avonmouth. The construction of the SHM is a significant infrastructure undertaking.

Figure 5-9: Investment profile to 2050 of the total costs incurred in the High HPs scenario



[57] Element Energy and Eider Consulting for BEIS, *Hybrid Heat Pumps* (December 2017)

Table 5-4: Emissions and costs to 2050 for the Baseline and High HPs scenarios

		Baseline scenario	High HPs
Annual emissions in 2050 ($ktCO_2$)		623	27
Cumulative emissions to 2050 ($MtCO_2$)		**20.5**	**10.8**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**	**12.1**
Building level costs (£ m)	**Building-level sub-total**	**2,328**	**5,291**
	Energy efficiency	280	1,099
	Heat networks (HIU & Low T)	56	149
	HPs & HHPs	0	2,735
	Hydrogen boilers	0	0
	Gas boilers	1,770	945
	Electric heating	221	161
	Solar thermal	0	203
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**	**1,255**
	Electricity grid upgrades	11	148
	Heat networks	407	1,107
	Hydrogen grid	0	0
Fuel costs (£ m)	**Fuel sub-total**	**6,335**	**5,597**
	Natural gas	4,444	2,127
	Electricity	1,891	3,470
	Hydrogen	0	0
	Biogas	0	0

5.4 Decarbonised gas: results

The Decarbonised gas scenario was constructed to describe the outcome, in terms of carbon emissions and cost, if the gas grid were completely repurposed to distribute 100% hydrogen.

As described in section 4.3, hydrogen is not yet ready to be deployed at scale in the UK, due to remaining uncertainty over the commercial viability of hydrogen production at scale (which may require CCS), current gas grid infrastructure suitability and the safety of delivery of hydrogen to buildings. If hydrogen can be produced at scale in a cost-effective way, however, it could potentially be an attractive low carbon fuel. Economies of scale are likely to be important, as hydrogen production is expected to be more economic at large volumes, and the cost of repurposing and maintaining the gas grid would need to spread across a sufficiently large customer base.

As such, retaining a high proportion of buildings connected to the gas grid would be attractive in this scenario. As a result, other than a medium level of heat network deployment, rollout of heat pumps or hybrid heat pumps in off-gas buildings and the application of all energy efficiency measures, a low level of policy ambition is assumed regarding all other heating technologies until 2040. Between 2040 and 2045, the gas grid is repurposed to distribute hydrogen. All gas boilers are replaced by hydrogen boilers in households and non-domestic buildings. The peak heat demand from heat networks is also supplied by hydrogen boilers. This change is represented graphically in Figure 5-10.

The resulting impact on carbon emissions is a decrease from 427 $ktCO_2$ / year in 2040 to 58 $ktCO_2$ / year in 2050. The carbon trajectory for this scenario is illustrated in Figure 5-11. Although the level of decarbonisation reached in 2050 is reduced by more than 85% versus 2017 levels, deep decarbonisation is delayed to 2040, and the cumulative emissions reflect this. Cumulatively to 2050, the Decarbonised gas scenario releases 13.7 $MtCO_2$ versus 20.5 $MtCO_2$ in the Baseline scenario, shown in Table 5-5.

The investment profile for this scenario is shown in Figure 5-12. The general trend within the building-level cost segment is a decrease from 2018 to 2040, this reflects the rollout of the energy efficiency measures: their rollout is ambitious in the early years and all are installed by 2040. From 2040 to 2045, there is a sharp rise in the building level costs which is explained by the replacement of all natural gas boilers with hydrogen boilers which incurs unit, installation and maintenance costs. In addition to building-level costs, the infrastructure costs to repurpose the gas grid are also included, these occur between 2037 and 2045.

Another approach would be for 'hydrogen-ready' boilers that are capable of running on both natural gas and hydrogen (with only minor modifications required to switch between fuel 'modes') to be installed in the period leading up to the switchover, with the additional cost of this incurred over the years leading up to 2040. In this case only the cost associated with changing over the fuel mode (not replacing them) is incurred at the time of switchover of the gas network from natural gas to hydrogen. Hydrogen-ready boilers are not yet commercially available.

Cumulatively to 2050, the switch from natural gas to hydrogen is estimated here to cost £2.3 bn, which includes building-level costs (purchasing, installing and maintaining hydrogen boilers and replacing meters: £0.7 bn), infrastructure costs (repurposing the gas grid for hydrogen: £212 m) and hydrogen fuel costs: £1.4 bn.

As noted previously, there are significant uncertainties associated with the cost of hydrogen production and delivery to buildings; the cost assumptions used here are based on recent work by Element Energy in this field.

Figure 5-10: Heat demand profile to 2050 in the Decarbonised gas scenario

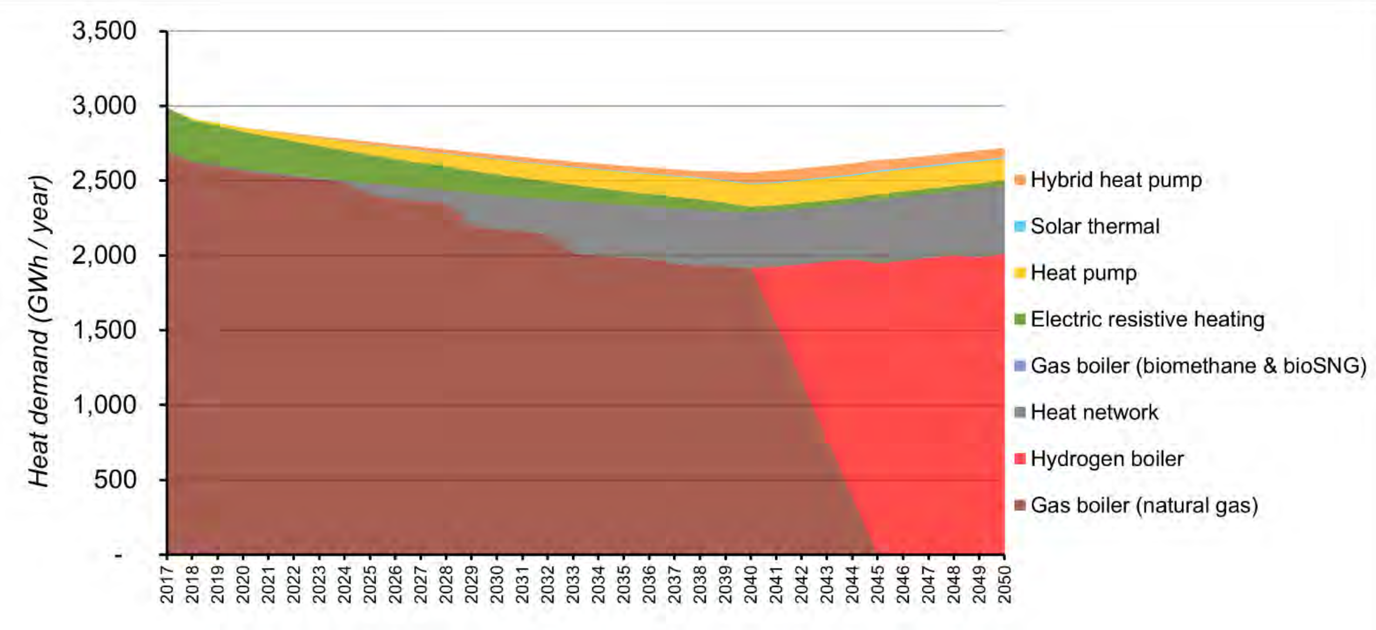


Figure 5-11: Carbon emissions to 2050 in the Decarbonised gas scenario

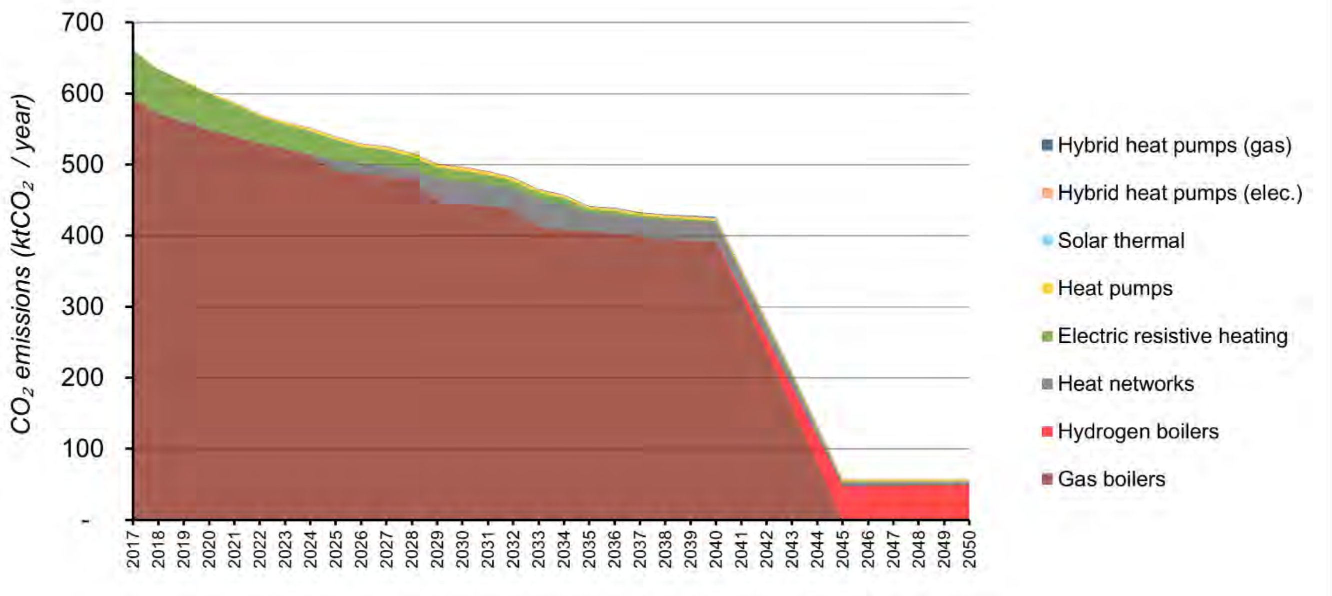


Figure 5-12: Investment profile to 2050 of the total costs incurred in the Decarbonised gas scenario

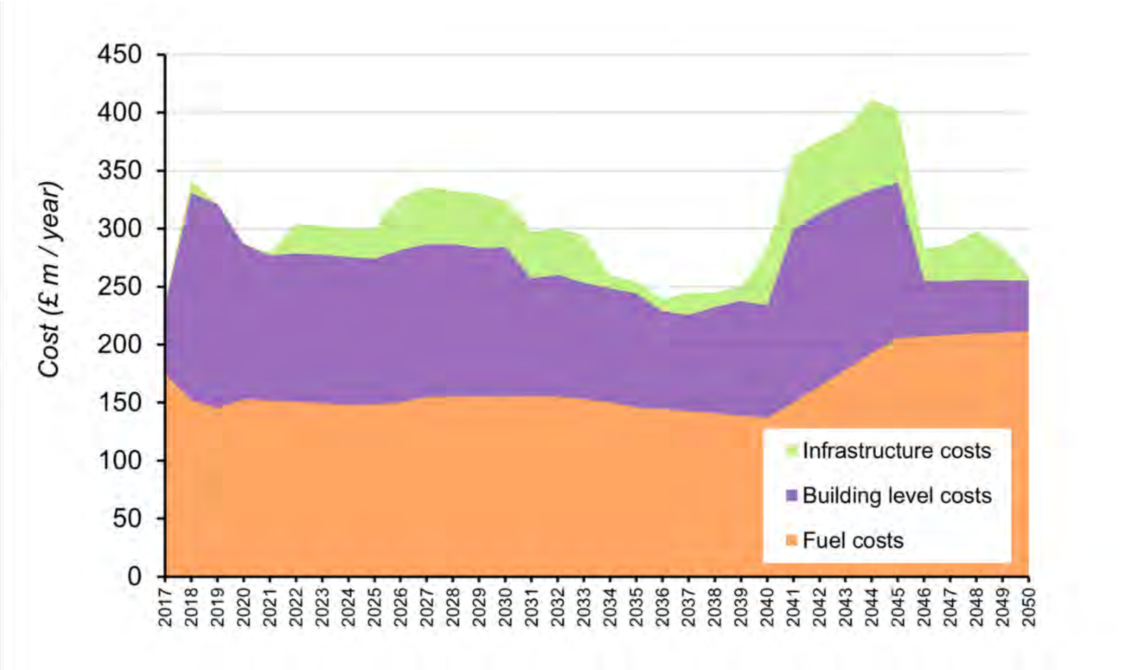


Table 5-5: Emissions and costs to 2050 for the Baseline and Decarbonised gas scenarios

		Baseline scenario	Decarbonised gas
Annual emissions in 2050 ($ktCO_2$)		623	58
Cumulative emissions to 2050 ($MtCO_2$)		**20.5**	**13.7**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**	**10.3**
Building level costs (£ m)	**Building-level sub-total**	**2,328**	**3,743**
	Energy efficiency	280	1,099
	Heat networks (HIU & Low T)	56	149
	HPs & HHPs	0	367
	Hydrogen boilers	0	656
	Gas boilers	1,770	1,288
	Electric heating	221	110
	Solar thermal	0	75
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**	**1,058**
	Electricity grid upgrades	11	0
	Heat networks	407	846
	Hydrogen grid	0	212
Fuel costs (£ m)	**Fuel sub-total**	**6,335**	**5,548**
	Natural gas	4,444	2,931
	Electricity	1,891	1,203
	Hydrogen	0	1,414
	Biogas	0	0

5.5 High heat networks & high heat pumps: results

The High heat networks & high heat pumps scenario determines the maximum level of decarbonisation achievable through the deployment of heat pumps, hybrid heat pumps, green gas and heat networks towards Bristol's target of achieving carbon neutrality by 2050. Highly ambitious policy would be required for the technology uptake levels in this scenario to be achieved. This scenario achieves carbon emissions of 26 $ktCO_2$ / year in 2050 and cumulatively, releases 10.1 $MtCO_2$ (Table 5-6).

The resulting heat demand met by each technology type is displayed in Figure 5-13. Under the assumptions in this scenario, heat networks serve 100% of the heat demand from new buildings and 20% of the heat demand from existing buildings by 2050. The remaining 80% (1,700 GWh / year) is served by heat pumps and hybrid heat pumps, which replace all gas boilers and most electric heaters by 2050.

The difference in the proportion of connected heat demand between the new and existing building segments reflects the higher barriers to connecting existing buildings to heat networks, also described above in section 4.3. Deployment of heat networks in new development can be driven by planning policy, and is more straightforward than in existing buildings since the whole development can be connected at construction (where retrofit to existing buildings requires engagement with each individual customer and connection over a longer period of time as the incumbent heating systems expire).

We propose that in the High HNs scenario up to 100% of new development could be connected to a heat network, whether a stand-alone network or one connected to the wider SHM, from 2021. This assumption is consistent with the aim of minimising carbon emissions, as heat networks fed predominantly by waste heat from EfW and water-source heat pumps (using a decarbonised electricity grid) will be the lowest carbon form of heating available to new developments. The share of existing buildings connected to heat networks is limited by the suitability of the area, based on a combination of heat density and proximity to existing and planned heat networks. Even in the High HNs scenario, we expect that this will be limited to approximately 20% of heat demand across Bristol.

Biomethane and bioSNG are gradually phased into the gas grid up to 2035-40 to reduce emissions from gas boilers that have not yet been replaced by another heating technology but, by 2050, all gas (including biomethane and bioSNG) has been phased out.

Hybrid heat pumps are also assumed to run fully on electricity by 2047 to reflect the fact that by this date, the High level of uptake of energy efficiency measures has been achieved, and essentially all buildings could be supplied by a heat pump alone, without the need for a hybrid system. In this scenario, green gas therefore acts as a bridging option to reduce emissions prior to 2050, but does not play a longer term role. This is in contrast to the High HNs scenario above, where green gas continues to play a role beyond 2050, and in the Decarbonised gas scenario, where gas (in the form of hydrogen) dominates heating after 2050.

Figure 5-14 shows the level of decarbonisation reached over the period 2017-2050. In 2025, 501 $ktCO_2$/ year are emitted; 86% of these are due to emissions from natural gas. In 2050 the emissions reduce to 26 $ktCO_2$ / year; 62% of these are due to emissions from the electricity grid which is not fully decarbonised, as shown in Figure 4-9. The remaining 38% are due to emissions from heat networks using EfW as heat sources. In this case, heat from the EfW facility is used directly to heat water for use in the heat network, rather than to generate electricity, and so the emissions factor is based on electricity forgone.

In this scenario, which completely relies on electricity as a fuel source in 2050, zero carbon heat would be achievable if the grid intensity were to fall to 0 gCO_2 / kWh. This level of grid decarbonisation has not been assumed in this study. The high level of heat network uptake assumed in this scenario contributes significantly to the overall decarbonisation, as seen by the step reduction in carbon emissions during key connection years, e.g. 2029 and 2033. By 2035, the gas engine CHP previously supplying the peak heat load (30% of the heat load) to heat networks is replaced completely by air source heat pumps. The lower carbon emissions from heat networks are seen from 2035 onwards.

The costs incurred in this scenario are shown in Figure 5-15. The building level costs are in the range £120-200 m / year, depending on the level of uptake of energy efficiency and low carbon heating technologies in that year. The main components of the building-level costs are heat pumps and hybrid heat pumps (47%), energy efficiency (21%) and gas boilers (19%); the remaining 13% of the building-level cost is associated with heat networks, electric heating and solar thermal technologies. The majority of the infrastructure costs incurred (95%) are from heat networks; the cost incurred is the same as in the High heat network scenario.

Figure 5-13: Heat demand profile to 2050 in the High HNs & high HPs scenario

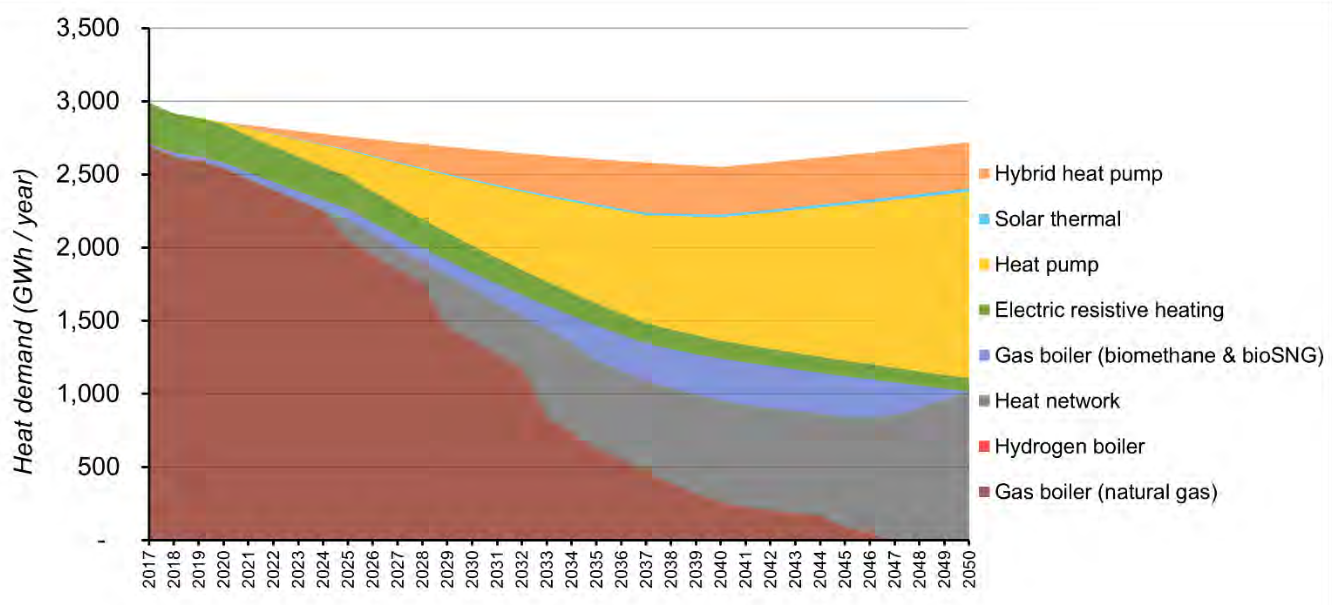


Figure 5-14: Carbon emissions to 2050 in the High HNs & High HPs scenario

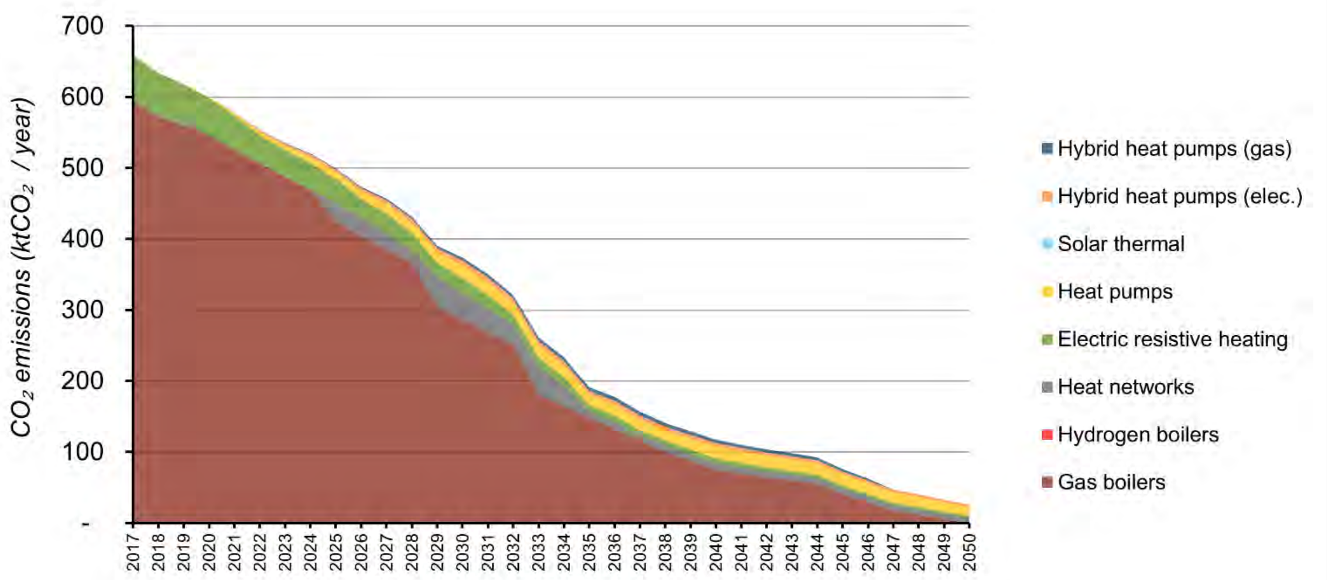


Figure 5-15: Investment profile to 2050 of the total costs incurred in the High HNs & high HPs scenario

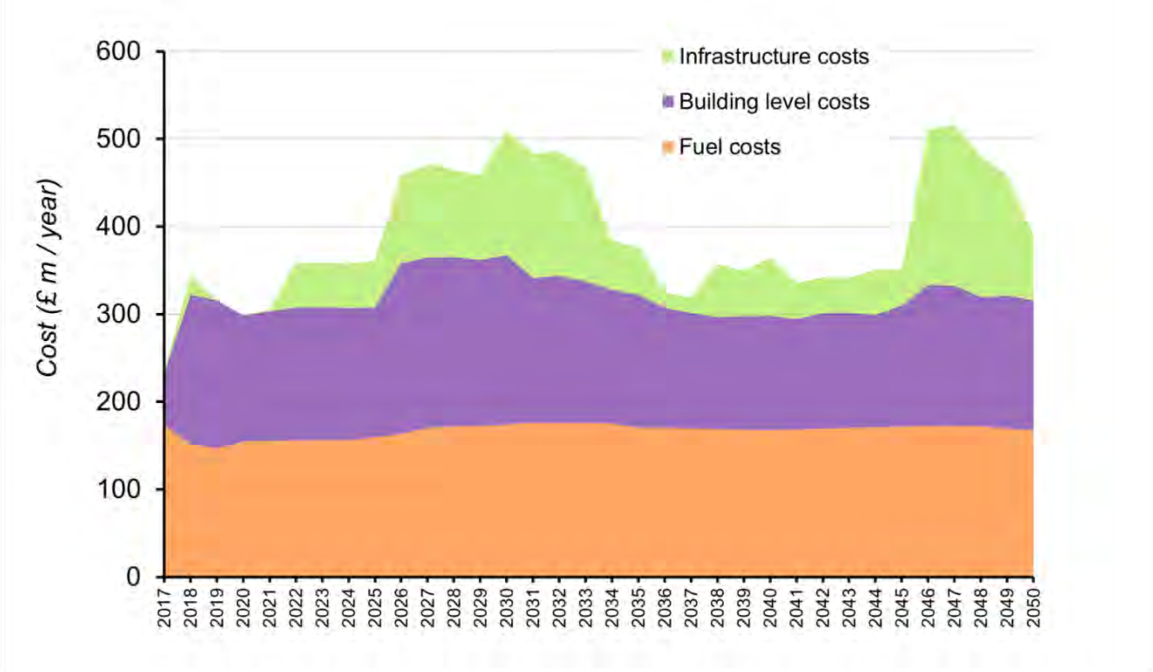


Table 5-6: Emissions and costs to 2050 for the Baseline and High HNs & high HPs scenarios

		Baseline scenario	High HNs & high HPs
Annual emissions in 2050 (ktCO$_2$)		623	26
Cumulative emissions to 2050 (MtCO$_2$)		**20.5**	**10.1**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**	**13.4**
Building level costs (£ m)	**Building-level sub-total**	**2,328**	**5,151**
	Energy efficiency	280	1,099
	Heat networks (HIU & Low T)	56	305
	HPs & HHPs	0	2,416
	Hydrogen boilers	0	0
	Gas boilers	1,770	988
	Electric heating	221	153
	Solar thermal	0	190
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**	**2,569**
	Electricity grid upgrades	11	119
	Heat networks	407	2,450
	Hydrogen grid	0	0
Fuel costs (£ m)	**Fuel sub-total**	**6,335**	**5,701**
	Natural gas	4,444	1,875
	Electricity	1,891	3,307
	Hydrogen	0	0
	Biogas	0	519

5.6 Mixed pathway: results

The Mixed pathway scenario represents a case that aims to address one of the key drawbacks of the Decarbonised gas scenario, which is the delay in action that results from the fact that low carbon hydrogen is unlikely to be commercially viable at scale until after 2035. As shown above, this results in a delay in decarbonisation, and higher cumulative emissions to 2050 than pathways deploying low carbon technologies at scale before 2030.

The Mixed pathway addresses this drawback of the Decarbonised gas scenario by deploying a substantial number of heat pumps and heat networks before 2035, roughly following the High HPs and Medium HN trajectories to that date, but after 2035 – reflecting a decision taken to deploy hydrogen heating in the intervening period – ramps down deployment of new heat pumps and heat networks from 2035 and converts the remaining gas demand to 100% hydrogen from 2040.

Given that the result is a more varied mix of heating technologies in 2050, and as a result the scenario will not benefit from the same level of economies of scale as the pathways with a single dominant heat supply option, it is likely that this scenario will not be the most cost-effective. However, it represents a lower risk pathway than the Decarbonised gas scenario in that it aims to keep open the options of decarbonising heat by heat pumps, heat networks and hydrogen until a later date, when further technology demonstration and deployment experience could allow a better-informed decision of the preferred pathway for Bristol.

The result is a scenario where, by 2050, 47% of the heat demand is served by heat pumps and hybrid heat pumps, 35% by hydrogen boilers, 14% by heat networks and the remaining 4% by electric heaters and solar thermal. The resulting carbon emissions are 42 ktCO_2 in 2050, compared to 623 ktCO_2 in the Baseline scenario.

The building-level costs shown in Figure 5-18 vary between £150m and £200m per year from 2018 to 2035. The majority of this cost is associated with the implementation of energy efficiency measures and the installation of heat pumps and hybrid heat pumps. Beyond 2040, no new heat pumps are installed. Gas boilers are replaced by hydrogen boilers from 2040 to 2045. The unit cost of hydrogen boilers is significantly less than that of heat pumps, and so the building costs are lower.

The fuel costs are approximately flat until 2040 at around £150m / year. Between 2040 and 2045, the gas grid is completely repurposed to distribute hydrogen, and by 2050 the fuel costs rise to £194m. Hydrogen fuel prices are more expensive because, under the assumptions in this study, hydrogen is produced using methane (the main component of natural gas), but there is an efficiency loss of 15-20%, in addition to the cost of CCS.

On the infrastructure-level, the cumulative heat network infrastructure cost is £877m (Table 5-7). A further £72m is estimated to be incurred due to electricity grid upgrades made during the period 2022-2036 to enable the ambitious heat pump deployment.

The cost of repurposing the gas grid is taken to be the same cost as in the Decarbonised gas scenario, at £212m incurred over the period 2037-2040. This reflects an assumption that the rollout of other low carbon technologies to replace gas during the earlier years would not generally be coordinated geographically to the extent that entire local portions of the gas grid could be decommissioned. This is perhaps somewhat conservative, but is deemed realistic given the significant challenge of ensuring all existing gas customers in an area can be converted to heat supply by a heat network or heat pump by 2040.

The Mixed scenario is therefore unlikely to be the most cost-effective scenario, but this can be seen as the cost of reducing the risk of missing the 2050 carbon reduction target, relative to the Decarbonised gas scenario, should hydrogen heating not prove to be deliverable.

Figure 5-16: Heat demand profile to 2050 in the Mixed pathway scenario

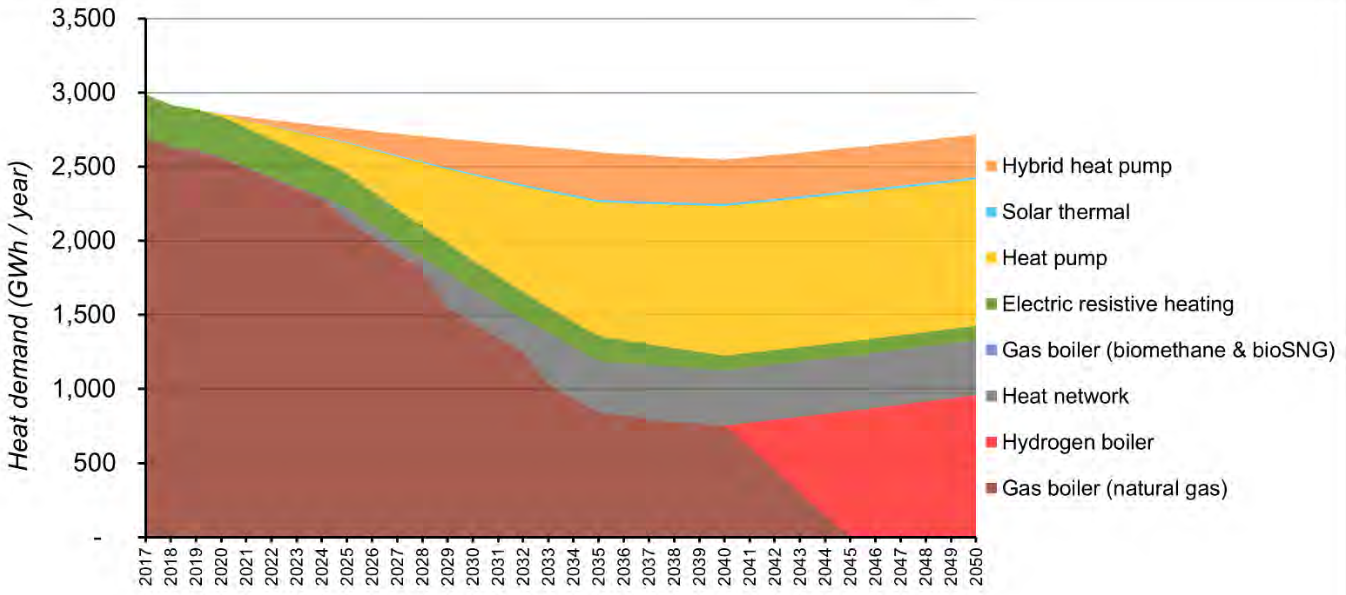


Figure 5-17: Carbon emissions to 2050 in the Mixed pathway scenario

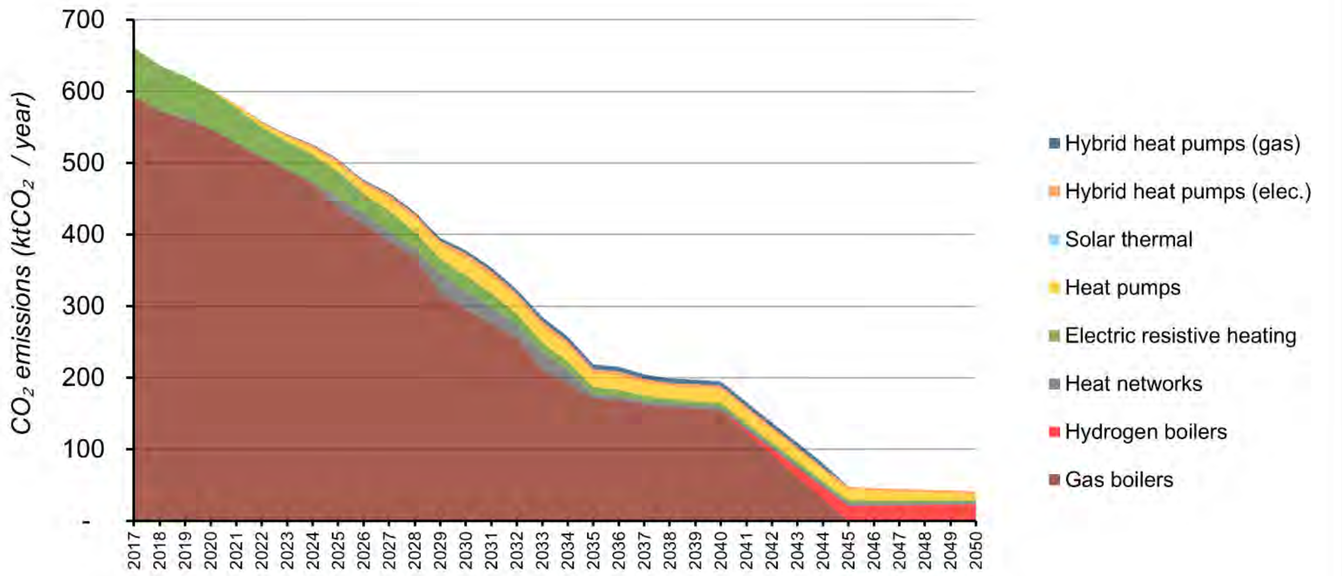


Figure 5-18: Investment profile to 2050 of the total costs incurred in the Mixed pathway scenario

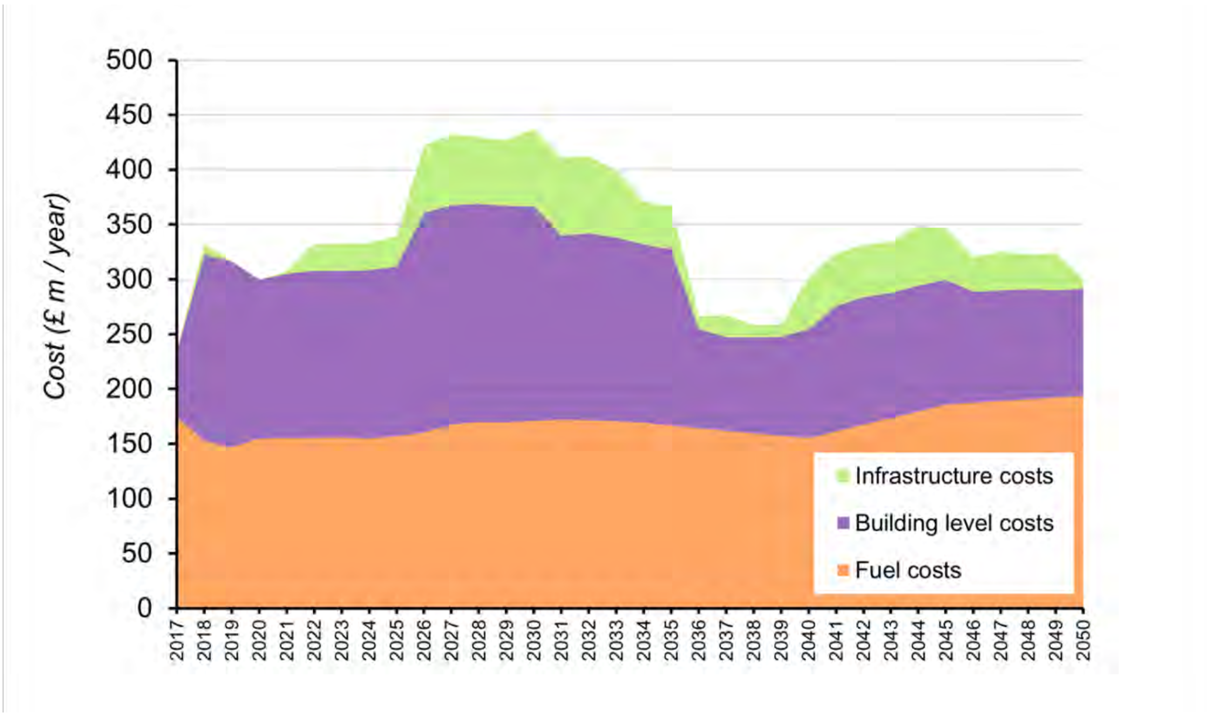


Table 5-7: Emissions and costs to 2050 for the Baseline and Mixed pathway scenarios

		Baseline scenario	Mixed pathway
Annual emissions in 2050 ($ktCO_2$)		623	42
Cumulative emissions to 2050 ($MtCO_2$)		**20.5**	**10.6**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**	**11.6**
Building level costs (£ m)	**Building-level sub-total**	**2,328**	**4,652**
	Energy efficiency	280	1,099
	Heat networks (HIU & Low T)	56	135
	HPs & HHPs	0	1,874
	Hydrogen boilers	0	316
	Gas boilers	1,770	918
	Electric heating	221	158
	Solar thermal	0	153
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**	**1,211**
	Electricity grid upgrades	11	72
	Heat networks	407	927
	Hydrogen grid	0	212
Fuel costs (£ m)	**Fuel sub-total**	**6,335**	**5,717**
	Natural gas	4,444	2,058
	Electricity	1,891	3,059
	Hydrogen	0	600
	Biogas	0	0

6 Discussion and conclusions

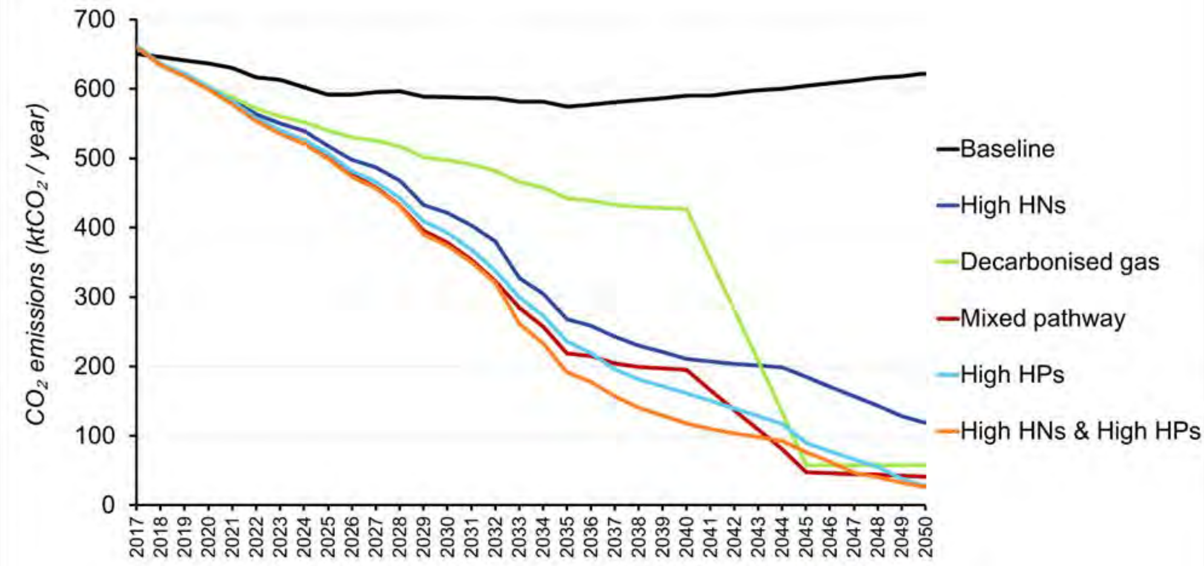
6.1 Comparison of scenario results

Level of decarbonisation achieved

A range of scenarios have been presented that achieve deep decarbonisation, reducing carbon emissions in Bristol's heat sector from an estimated 659 $ktCO_2$ / year in 2017 by up to 96% by 2050. The additional cumulative cost versus the Baseline to 2050 ranges from £1.2 bn to £4.2 bn under the central cost assumptions, for a Baseline scenario cost of £9.1 bn, saving up to 10 $MtCO_2$ cumulatively. This corresponds to an average cost of carbon abated to 2050 in the range £169/tCO_2 to £408/tCO_2. For comparison, the 'target-consistent' carbon price for 2050, used by the Government for policy appraisal, is currently set at £227/tCO_{2e}[58].

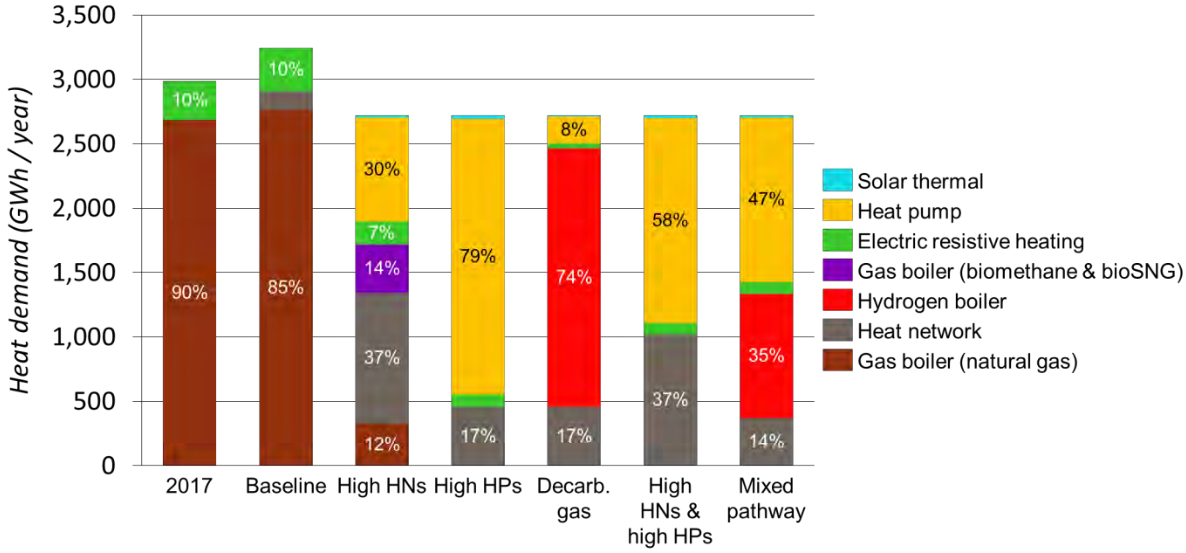
The two scenarios leading to the lowest carbon emissions are the High HNs & high HPs scenario and the High HPs scenario, as shown in Figure 6-1. The High HNs & high HPs scenario produces the lowest cumulative emissions of all scenarios considered. These all rely on high levels of HP uptake (until 2050 for High HPs and High HPs & high HNs, or until 2040 for the Mixed pathway, prior to deployment of the hydrogen grid). The residual emissions in 2050 under all scenarios arise because each scenario relies either on electricity from a grid that is not fully decarbonised, or on hydrogen produced using SMR/CCS for which the CO_2 cannot be completely captured, or both. These residual emissions are therefore related to factors which may be largely outside Bristol's control.

Figure 6-1: Annual carbon emissions across all scenarios



[58] HM Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions supporting tables, Table 3 (December 2017).

Figure 6-2: Heat demand met by each technology in 2050 in the six scenarios. NB: segment labels added only for values larger than 5%



Referring to Figure 6-1, the emissions in 2050 under the High heat networks scenario are 118 $ktCO_2$ / year; this is higher than in all other decarbonisation scenarios. The potential level of deployment of heat networks is limited by the share of heat demand located in areas where heat networks are expected to be viable, which is limited to sufficiently densely populated areas and new build developments.

As a result, gas boilers (which, in 2050, are served by both natural gas and green gas under this scenario) still serve a high proportion of the heat demand: in 2050 this represents 34% of the domestic heat demand and 17% of the non-domestic heat demand, or 700 GWh in total, as shown in Figure 6-2. While heat networks can play a key role in decarbonisation of Bristol's heat demand, this analysis clearly shows that deployment of heat networks alone will not be sufficient to reach deep decarbonisation of heat.

Under the assumptions in this report, the maximum potential for green gas deployment is around 370 GWh per year by 2050. At this level, green gas can supply more than half of the remaining demand for gas heating in the High HNs scenario. However, this leaves a remaining natural gas demand of more than 300 GWh, which is the source of the majority of carbon emissions in that scenario. This suggests that a combination of the maximum deployment level of heat networks and the maximum deployment level of green gas, while achieving very substantial emissions reduction, is not able to achieve deeper decarbonisation than around 80% versus current levels.

Cost comparison

We show a comparison of the total cumulative undiscounted cost to 2050 in each scenario in Figure 6-3. The cost has been calculated under three sets of cost assumptions, Low, Central and High, with the blue bar showing the cost under the Central cost assumptions and the error bar showing the range from Low to High. A summary breakdown of the costs in each scenario in terms of building-level costs, infrastructure costs and fuel costs is provided in Table 6-1.

A more detailed breakdown of the cost, for the Central cost assumption case only, is shown further below in Table 6-2 and Figure 6-4.

Figure 6-3: Total cumulative costs to 2050 in each scenario including cost sensitivity.

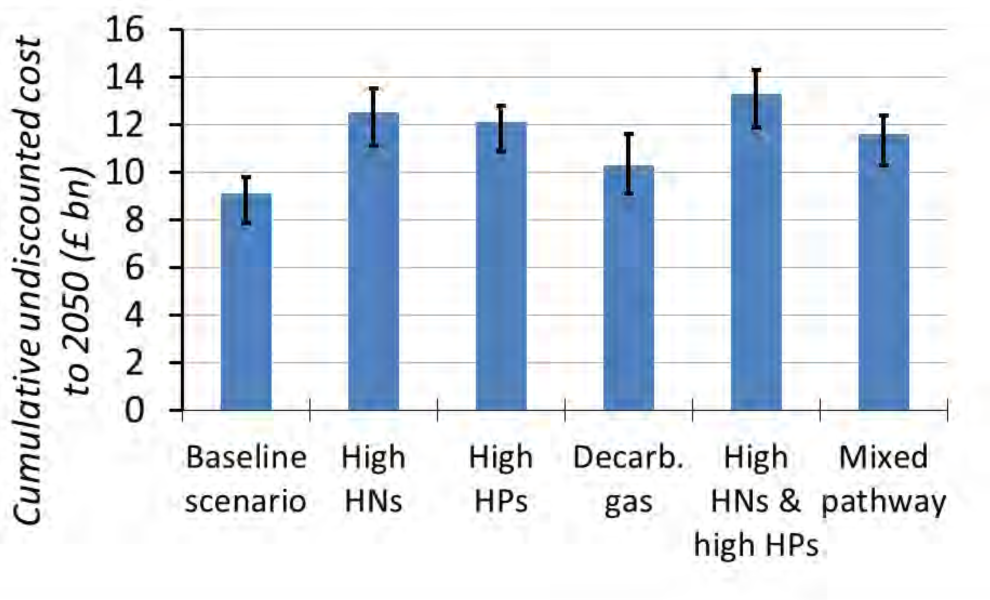


Table 6-1: Summary of cost breakdown with Low, Central and High sensitivities

		Baseline scenario	High HNs	High HPs	Decarb. gas	High HNs & high HPs	Mixed pathway
Cumulative undiscounted cost to 2050 (£ bn)	**Low**	**7.9**	**11.1**	**10.9**	**9.1**	**11.9**	**10.3**
	Central	**9.1**	**12.5**	**12.1**	**10.3**	**13.3**	**11.6**
	High	**9.8**	**13.5**	**12.8**	**11.6**	**14.3**	**12.4**
Building level costs (£ bn)	Low	2.3	4.1	5.0	3.7	4.9	4.5
	Central	2.3	4.2	5.3	3.7	5.2	4.7
	High	2.3	4.3	5.5	3.8	5.3	4.8
Infrastructure costs (£ bn)	Low	0.4	2.4	1.2	0.9	2.4	1.0
	Central	0.4	2.5	1.3	1.1	2.6	1.2
	High	0.4	2.6	1.3	1.1	2.7	1.3
Fuel costs (£ bn)	Low	5.2	4.6	4.7	4.5	4.6	4.7
	Central	6.3	5.8	5.6	5.5	5.7	5.7
	High	7.0	6.6	6.0	6.7	6.4	6.4

Figure 6-4: Total cumulative costs to 2050 in each scenario under the Central case cost assumptions. All costs are undiscounted.

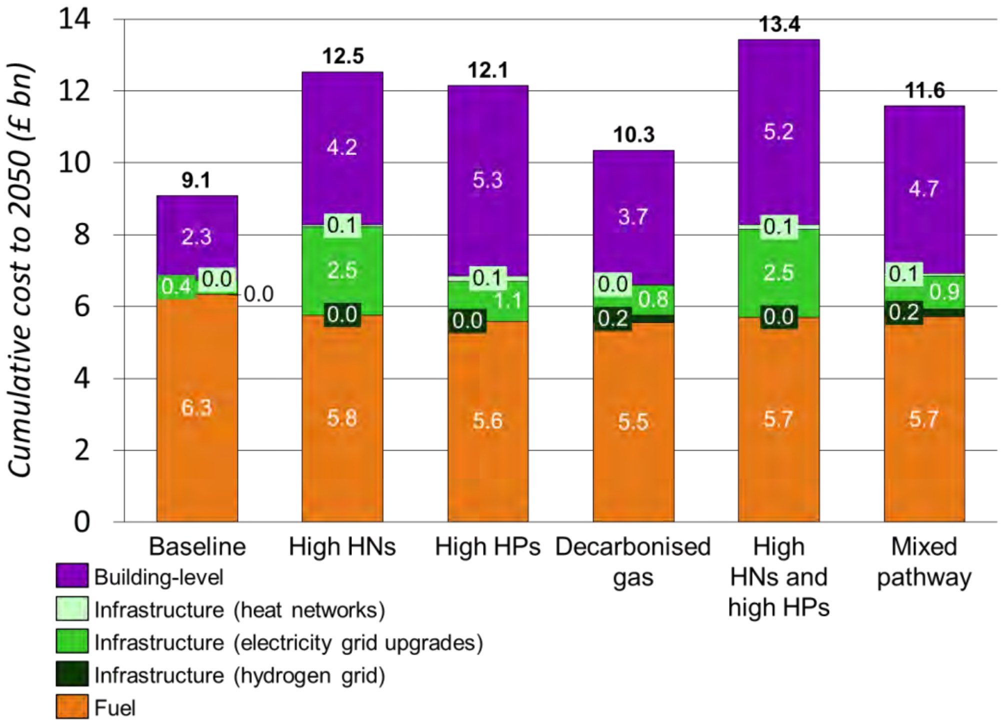


Table 6-2: Cost breakdown to 2050 under the Central cost assumptions.

		Baseline scenario	High HNs	High HPs	Decarb. gas	High HNs & high HPs	Mixed pathway
Annual emissions in 2050 (ktCO$_2$)		623	118	27	58	26	42
Cumulative emissions to 2050 (MtCO$_2$)		**20.5**	**12.1**	**10.8**	**13.7**	**10.1**	**10.6**
Cumulative undiscounted cost to 2050 (£ bn)		**9.1**	**12.5**	**12.1**	**10.3**	**13.4**	**11.6**
Building level costs (£ m)	**Building-level sub-total**	**2,328**	**4,248**	**5,291**	**3,743**	**5,151**	**4,652**
	Energy efficiency	280	1,099	1,099	1,099	1,099	1,099
	Heat networks (HIU & Low T)	56	305	149	149	305	135
	HPs & HHPs	0	1,223	2,735	367	2,416	1,874
	Hydrogen boilers	0	0	0	656	0	316
	Gas boilers	1,770	1,284	945	1,288	988	918
	Electric heating	221	197	161	110	153	158
	Solar thermal	0	140	203	75	190	153
Infrastructure costs (£ m)	**Infrastructure sub-total**	**419**	**2,521**	**1,255**	**1,058**	**2,569**	**1,211**
	Electricity grid upgrades	11	71	148	0	119	72
	Heat networks	407	2,450	1,107	846	2,450	927
	Hydrogen grid	0	0	0	212	0	212
Fuel costs (£ m)	**Fuel sub-total**	**6,335**	**5,766**	**5,597**	**5,548**	**5,701**	**5,717**
	Natural gas	4,444	2,417	2,127	2,931	1,875	2,058
	Electricity	1,891	2,721	3,470	1,203	3,307	3,059
	Hydrogen	0	0	0	1,414	0	600
	Biogas	0	628	0	0	519	0

The comparison of total cumulative undiscounted cost to 2050 across all decarbonisation scenarios (i.e. excluding the Baseline) suggests that, while there are substantial differences in the Central case cost, the range of uncertainty in the cost is of the order as the difference between scenarios. This suggests that there is no clear least cost scenario at this stage.

Despite this uncertainty, however, we are able to draw some important conclusions. Firstly, all decarbonisation scenarios are likely to be more costly than the Baseline scenario. Secondly, the analysis shows that of all pathways explored, the Decarbonised gas scenario carries the greatest uncertainty in cost – while the analysis suggests it could be the lowest cost scenario, it could also be higher cost than most of the other scenarios. The large uncertainty in the Decarbonised gas scenario, compared to other scenarios, is mainly attributed to the uncertainty surrounding the cost of producing large quantities of low carbon hydrogen. The production methods explored in this analysis include SMR with CCS, which has not yet been proven commercially viable, and electrolysis, which is currently costly.

It is important to note that the cost scenarios are in many cases 'uncorrelated' – meaning that if the future cost of one technology or fuel turns out to be closest to the 'High' estimate, it does not necessarily follow that the cost of all other technologies or fuels will also turn out to be closest to the 'High' estimate. For example, the hydrogen fuel cost and electricity fuel costs need not be correlated in the case where hydrogen is produced through SMR with CCS and electricity is largely generated from renewable sources; technological learning could lead to strong reductions in the cost of either one or both of those processes. Similarly, the cost of a heat pump need not be strongly correlated to the cost of converting the gas grid to hydrogen. Therefore, the overlap observed in the range between the Low and High cost estimates for most scenarios suggests that there is no clear winner in cost terms across the low carbon scenarios.

A third important conclusion of the cost comparison is that the investment required to achieve decarbonisation of heat is distributed in different ways across the scenarios. In particular, the share of investment required in building-level technologies, versus large infrastructure projects, varies widely. The scenarios that include a high level of deployment of heat pumps (which includes the High HPs, High HNs & High HPs and Mixed pathway scenarios) have the highest building-level costs, reflecting the higher capital cost of heat pumps relative to gas and hydrogen boilers. The total investment in building-level technologies ranges from £2.3 bn in the Baseline to £5.0 to 5.5 bn in the High HPs scenario.

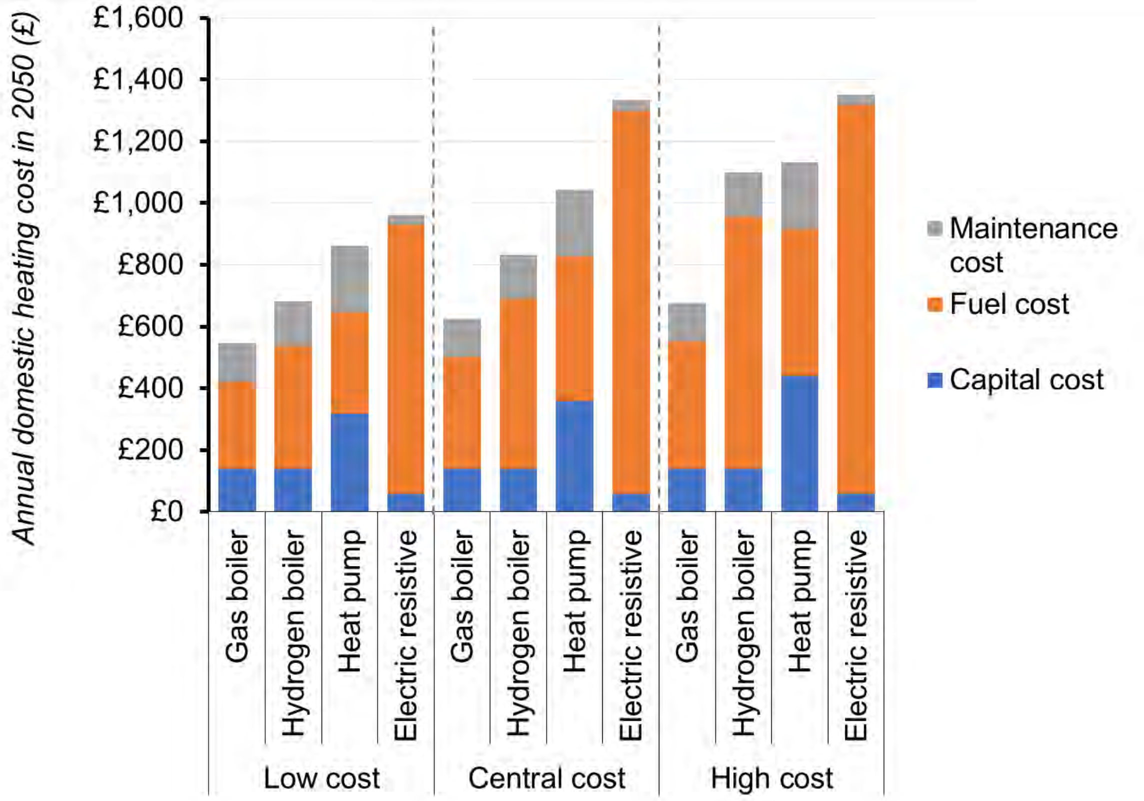
Infrastructure costs are highest in the scenarios with the greatest deployment of heat networks. These costs arise from the significant capital cost of the network and the heat generation plant in the energy centre (classified here as an infrastructure cost due to the large scale of each individual investment), and amount to £2.4 to 2.7 bn to 2050 in the High HNs scenarios. For comparison, the estimated infrastructure cost associated with repurposing the gas grid to deliver hydrogen is £212m, and the estimated cost to upgrade the electricity grid in the High HPs case is £148m. This demonstrates that while the infrastructure costs associated with converting the gas grid to enable hydrogen heating, or of reinforcing the electricity grid to allow widespread deployment of heat pumps, are substantial, this represents a relatively small share of the overall cost of heating, which is dominated by the fuel and building-level costs.

A further important point relates to the distinction between total cumulative cost to 2050, and annual cost in 2050. For example, under the Central cost sensitivity, the lowest cumulative fuel cost is found for the Decarbonised gas. This, however, is not reflective of the fuel costs associated with hydrogen heating, but of the continued use of natural gas heating until 2040.

This can be explained more clearly using Figure 6-5, which shows a comparison of the estimated average annual cost of heating in 2050 for the four main building-level heating systems. The figure shows the cost of heating in terms of capital cost (the cost of the boiler, heat pump or electric heater), the maintenance cost and the fuel cost. This is shown for the three cost sensitivity cases presented for the average household heating demand in 2050 of 6,500 kWh per year.

Under all cost sensitivities, gas boilers are the lowest cost heating option, due to the lowest fuel costs, and direct electric heating is the most costly heating option, due to the highest fuel costs. The relative cost of hydrogen heating and heat pump heating varies across the Low, Central and High cost cases – noting again that the costs in these two cases need not be strongly correlated (i.e. the Low cost case for one of the options could co-exist with the High cost case for the other). This supports the earlier conclusion that the uncertainty in cost for the hydrogen and heat pump options is currently too large to identify the lowest cost option with confidence.

Figure 6-5: Projected average annual domestic heating cost in 2050 for the four main heating technologies



6.2 Risks

We presented in the above section a comparison of the level of decarbonisation achieved in each scenario, and the cost incurred. Beyond the impact on cost and emissions, the scenarios described have a variety of associated risks, with the potential to impact on different stakeholders. Any decisions on heat decarbonisation policy in Bristol should account for these potential risks and weigh them against the evidence presented above relating to emissions reduction potential and cost.

The key risks associated with the different technology options are presented in Table 6-3, along with an indication of the risk bearer, the type of risk and potential actions to mitigate the risk.

Table 6-3: Summary of the key risks associated with the uptake of each heating technology

Risk description	Risk bearer	Risk type	Mitigating factors
Heat networks			
Availability of feedstock for EfW reduces due to e.g. increased recycling rates, or the planned EfW facilities are not constructed for some other reason	All	Financial	Provision of clear and stable policy signal on future of EfW
Required heat offtake tariff from EfW or industrial process prohibits financial viability	Consumer	Financial, Climate	Few competitor markets for EfW heat
EfW no longer considered a sufficiently low carbon source of electricity and/or heat.	All	Financial	Provision of clear and stable policy signal on future of EfW or diversification of waste heat source
Anticipated heat demand does not materialise, leading to lower revenues than expected to network operator. Competing technologies contribute to this risk	Private or government	Financial	Consumer incentives & connection policy guarantees
Natural monopoly of heat networks leads some consumers to be locked into high energy bills once connected	Consumer	Financial	Classification system to ensure development only of cost-effective networks, price regulation. Programmes such as the Heat Trust, launched in 2015) offer customer protection. BCC is committed to fair pricing and customer protection.
Natural monopoly of heat networks leads to poor quality of service for some consumers	Consumer	Service	Classification system for heat networks, Regulated service
Suggested heat network sites in city centre are unsuitable due to severity of hazards, e.g. construction of a network adversely impacting the quality of underground surface water body	Ecosystem	Climate	All heat network development underpinned by careful feasibility study
Policy implemented to address the above issues is unsuccessful and the targeted level of heat network deployment is delayed or not achieved.	All	Climate	
Heat pumps			
Required electricity grid upgrades cannot happen fast enough, restricting HP deployment	Private, Consumer	Climate	Flexible regulation to allow more advanced planning
High electricity costs to consumers to fund substantial upgrades to electricity grid.	Consumer	Financial	Demand side response and other smart grid interventions are expected to reduce reinforcement costs
Capital costs of heat pumps remain high, leading to high heating costs for consumers.	Consumer	Financial	Financial subsidies, supply chain support/investment
Poor quality heat pump installation leads to poor performance of technology.	Consumer	Service	Quality assurance programmes & training
Behaviour change required to use heat pumps results in perception of lower quality of service to consumers.	Consumer	Service	Training & information programmes

Policy implemented to address the above issues is unsuccessful and the targeted level of heat pump deployment is delayed or not achieved.	All	Climate	
Hydrogen			
Large-scale hydrogen production using SMR and CCS is not commercially available soon enough to implement this pathway, leading to higher cumulative emissions to 2050.	All	Climate	Policy support for trialling & investment in research. Pursue 'low regrets' actions now so that not dependent on timely availability of SMR/CCS and to keep alternative decarbonisation pathways open.
Delivery of hydrogen to existing buildings cannot be proven to be sufficiently safe at viable cost by the time required to implement this pathway, leading to delays in emissions reduction.	All	Climate	Research into these issues is being undertaken early, such that the feasibility of this pathway should be understood in time to switch to another pathway if not viable
Reliance on natural gas import for hydrogen production using SMR impacts energy security.	Government	Energy security	Multiple other pathways to H_2 production, although likely to be less cost-effective
Some consumers do not accept hydrogen as a safe and viable alternative to gas, leading to delays in rollout.	All	Climate	Evidence & information campaigns
Some consumers do not accept hydrogen as a safe and viable alternative to gas, leading to a large share of consumers using alternative technologies (e.g. heat pumps), impacting negatively on the cost of the hydrogen option.	Consumer, Private, Government	Financial	Evidence & information campaigns; potentially mandating conversion to hydrogen.
Consumers perceive the hydrogen switchover and appliance replacement as inconvenient and leading to a lower quality of service.	Consumer	Service	Quality assurance standards
Policy implemented to address the above issues is unsuccessful and the targeted level of hydrogen deployment is delayed or not achieved.	All	Climate	
Energy efficiency measures			
High capital cost of certain efficiency measures e.g. hard to treat solid walls, hard to treat cavity walls	Consumer	Financial	Financial subsidies and government policies to create market certainty.
Energy efficiency rollout is delayed, with knock-on impact that HPs cannot be installed in many existing buildings.	All	Climate, financial	Policy to support rollout of measures
National Government fails to bring forward credible energy efficiency policy. The result may be that the targeted level of energy efficiency rollout is delayed or not achieved.	All	Climate	

6.3 Low regrets actions

The majority of the decarbonisation scenarios, and all scenarios that reach the lowest levels of cumulative emissions to 2050, have several commonalities in the short term. We have identified these commonalities as ‘low regrets’ actions, which should be acted on urgently in order to keep pace with the required level of emissions reduction.

Low regrets action 1: retrofit of all existing buildings to EPC C wherever practical

The first low regrets action we propose is retrofit of as many buildings to EPC C as is practical. This will help to ensure lower energy bills for consumers irrespective of the long-term pathway. High levels of energy efficiency are also a pre-requisite for deep electrification of heat using heat pumps.

The number of energy efficiency measures currently being installed falls well short of the number required to achieve this. For example, under the Energy Company Obligation (ECO) and Green Deal, approximately 40,000 solid walls were insulated per year between 2013 and 2015[59]. Scaling on the basis of the number of households in Bristol and in GB[60], Bristol’s ‘share’ of this equates to approximately 300 solid wall insulations per year. This is significantly fewer than the 2,500 per year required between today and 2040 to follow the level of uptake presented in the scenarios, which we deem a low regrets action. This will involve targeting the estimated 36,000 cavity walls, 10,000 lofts, 56,000 solid walls, and 130,000 floors that remain uninsulated, or insufficiently insulated, in Bristol.

While funding for ECO has been committed to 2021/22, the proposed form of the scheme represents a scaled-back version of the scheme relative to the period between 2013 and today, and so would not be expected to drive the level of uptake required in the low regrets actions described here. Following the Government’s commitment in the Clean Growth Strategy to extend support for home energy efficiency to 2028, an update to the national energy efficiency policy framework is expected.

We suggest that the energy efficiency rollout described here under the low regrets actions will likely be reliant on national policy; however, we recommend that Bristol should actively promote the deployment of energy efficiency in the city.

Policy action to achieve this includes: raising awareness of the benefits of energy efficiency to residents and businesses, identifying households eligible for national schemes (such as the Energy Company Obligation) and identifying other investable energy efficiency opportunities. Bristol could also join with other local authorities (or through the mayoralty of the West of England) to lobby the national government to raise the level of ambition for energy efficiency policy, providing an evidence base to demonstrate the need for increased ambition. We also recommend the continued support of existing initiatives that address this action, such as *Warm-up Bristol*.

Low regrets action 2: promote the extensive development of low carbon heat networks in Bristol including the Strategic Heat Main

We recommend strong planning policy and financial support for the roll out of heat networks in new and existing buildings, to the extent set out in the ‘Medium HN’ level of deployment. This includes the completion of Temple & Redcliffe, City Centre Phase 1 and 2, and construction of the Strategic Heat Mainly to allow the supply of low carbon waste heat from Avonmouth to the city centre. This entails the connection of approximately 3,300 new buildings and 6,700 existing buildings by 2030, representing 26% of the new build heat demand and 8% of existing building heat demand by that date.

As part of this, there should be a credible strategy to decarbonise the carbon intensity of the heat supplied to the network over time towards zero emissions, using waste heat, heat pumps, and potentially green gas or hydrogen and bioenergy. The availability of these low carbon sources has been discussed in the main body of the report.

[59] Green Deal and Energy Company Obligation, National Audit Office for the Department of Energy & Climate Change, 2016
[60] The number of solid wall insulation measures installed in Bristol over this period is not known.

Our model assumes that the expansion of the network (known as City Centre Phase 2) is fed by low carbon waste heat in 2033. Ongoing work shows that, for Bristol to be on track with its emissions intensity targets for heat networks, this must be done earlier, by 2028. In support of this, our models show that the High HNs scenario lags the other decarbonisation scenarios, apart from the Decarbonised gas scenario, in terms of carbon emissions.

Therefore, our recommendation is that the development and decarbonisation of the SHM, which connects to the city center heat networks, be carried out as soon as possible.

Heat networks are robust to most long-term pathways, since they could be supplied by a range of sources including heat pumps and waste or environmental heat and, potentially, green gas or hydrogen, and offer economies of scale for these technologies. They can also bring additional flexibility to the energy system.

Development of heat networks is one of the areas where Bristol is able to have the greatest level of influence. The development of the Strategic Heat Main will require a strong coordinating role for the local authority, a potential direct role for the local authority in the investment in and/or operation of heat networks, as well as a key role for planning policy.

As described in section 3.6, city planning or heat zoning has commonly played an effective role in creating efficient heat networks with high connection rates in other countries. Initially, planning policy to encourage or require new buildings, particularly large new developments, to connect to heat networks is instrumental in driving their deployment. For the heat network to expand more substantially, however, it may be necessary for connection policy to extend to existing buildings including domestic properties.

The draft revised National Planning Policy Framework[61] states that in determining planning applications, '*local planning authorities should expect new development to comply with any development plan policies on local requirements for decentralised energy supply unless it can be demonstrated by the applicant, having regard to the type of development involved and its design, that this is not feasible or viable*'.

We have therefore proposed a set of criteria, forming part of a connection policy framework, to define zones in which BCC has an ambition for the development of heat networks. Our recommendation is to adopt a system under which existing or planned heat network schemes could become 'classified' networks where a range of conditions are met relating to the cost of heat to consumers, carbon intensity and service quality.

There is a precedent for such a classified system with associated connection policy in France, as described in section 3.6. An outline of a possible formulation of the classification system is presented in section 7. Once a heat network scheme is classified, connection policy relating to the scheme is conferred upon it. The details of the connection policy are likely to evolve over time; in the early stages, it may be applied to ensure that large new developments in the vicinity of the classified network are connected (unless conditions of exemption are met, such as clearly defined cost-effectiveness criteria). The connection policy could evolve to include large existing heat users at suitable 'trigger points' such as extensive renovation or, potentially, replacement of the main heating system. In the longer term, where this is deemed appropriate and the highest levels of connection to heat networks are desired, the connection policy could extend to existing domestic customers.

Planning policy is a necessary condition for heat network development, but may not be sufficient alone. There are also important barriers to development of heat networks relating to the high upfront cost and relatively long payback periods (or equivalently, moderate to low rate of return). In order to address this, it may be important, at least in some cases, for the local authority to be an investor and/or delivery partner in heat network development. Bristol City Council already has experience of delivering and

[61] Ministry of Housing, Communities & Local Government, National Planning Policy Framework – Draft text for consultation, 2018

operating existing heat networks in the city, and should consider whether this could be extended to the level of heat network deployment envisaged in the scenarios presented.

Low regrets action 3: strengthen new building planning policy to ensure all new buildings are served by low carbon heat networks or heat pumps, or equivalent low carbon options

There should be no barrier to supplying the great majority of new buildings by either a heat pump or a low carbon heat network, and deployment of these technologies in most new buildings will be crucial to achieving the level of deployment presented in the scenarios. In the short term, this will help to build the supply chains for these technologies and ensure they are able to ramp up to the required deployment level in later years.

Bristol's adopted Core Strategy requires developers to demonstrate that heating systems have been selected according to the heat hierarchy, which strongly encourages connection to existing, or new, renewable or otherwise gas-fired CHP distribution networks. However, this policy has been questioned by some developers, who have made the case that direct electric heating is a lower carbon option than gas-based CHP.

Bristol's planning policy should be updated to ensure that, wherever possible, all new buildings are served either by low carbon heat networks or heat pumps. Furthermore, the policy should promote heat networks ahead of heat pumps only in cases where either the carbon intensity of the heat supplied is equivalent to or lower than that for heat pump heating, or where a credible strategy can be presented for the heat network to achieve this following replacement of the current heat source(s). The system of heat network 'classification' described above, and the associated connection policy, offers an approach through which this can be implemented.

To some extent, this low regrets action can be achieved through Bristol's own planning policy. However, there appear to be limits to the application of this policy at a local level based on the draft revised National Planning Policy Framework[61]. This framework appears more supportive of heat networks (decentralised energy) than other low carbon heating technologies such as heat pumps. The level of uptake of heat pumps suggested in this low regrets action would require national planning policy framework to be substantially more supportive than the current draft revision[61] suggests. It would require national building regulations either to tighten carbon emissions requirements such that gas and direct electric heating are unlikely to be compliant, or through a direct requirement to use low carbon alternatives such as heat pumps wherever feasible. Bristol could therefore lobby the national government on this topic.

A potentially powerful approach that we would recommend is the construction of demonstration or 'exemplar' developments to stricter levels of carbon emissions than existing regulations, supplied by heat networks and/or heat pumps, which can be used to show the viability of this solution and to better understand consumer experience of these options.

Low regrets action 4: promote extensive deployment of heat pumps in existing buildings and off-gas grid buildings in particular

We recommend strong policy support for roll out of heat pumps in existing buildings (as well as new buildings), including deployment of in the region of 20-30,000 heat pumps by 2030 in the domestic existing building stock. This should be directed initially (but not necessarily exclusively) towards decarbonising heating in the roughly 19,000 off-gas grid households in Bristol, where the cost of heating is currently higher, and where there are fewer long-term low carbon options.

The associated level of deployment of heat pumps in the 2020s will enable early assessment of consumer acceptance, the required level of financial support, and the effectiveness of supporting policy, to help inform the decision on Bristol's long-term heat decarbonisation pathway. The extent of cost reduction achieved through supply chain improvements and manufacturing economies of scale will also allow a more accurate assessment of the cost of this option, providing important evidence for the longer term decision.

To put our recommended low regrets level of uptake into perspective, approximately 10,300 ground and air source heat pumps were accredited per year across GB under the Renewable Heat Incentive (RHI) between 2014 and 2018. Scaling according to the number of households in Bristol and GB, Bristol's 'share' of this amounts to approximately 70 heat pumps installed per year. The level of heat pump deployment assumed in the low regrets actions (18,000 heat pumps by 2030) is approximately 1,500 new installations per year, an increase of more than 20 fold. The required level of deployment of heat pumps in existing buildings would therefore necessitate the formulation of a policy incentive substantially more attractive to consumers than the RHI to date.

The tariff payable for air-source heat pumps under the Domestic RHI was increase in late 2017, and as of June 2018 stands at 10.49 p/kWh up from 7.63 p/kWh in December 2017; the impact of this increased incentive on uptake is not yet clear. Our view is that the high upfront capital cost of heat pumps, along with the disruption involved (particularly where new radiators and a hot water cylinder are required, and energy efficiency improvements are needed), mean substantial barriers to uptake remain. Although there exist barriers to the high level of uptake of heat pumps presented here, it is interesting to put the uptake level into the perspective of the current rate of existing heating system turnover.

Consider that the average lifetime of a domestic gas boiler is 15 years and that gas boilers account for ~90% of heating systems in Bristol's domestic stock. There are approximately 200,000 domestic dwellings in Bristol, therefore, on average 12,000 new gas boilers are installed in Bristol's domestic stock every year, compared to the 1,500 new heat pump installations per year suggested in our low regrets actions. We therefore suggest that this level of uptake is ambitious but attainable, and that changing consumer behaviour away from gas boilers and towards heat pumps is an effective way to reach the targets set out in our low regrets actions.

The deployment of heat pumps in existing buildings is less easy for Bristol to influence than the rollout of heat networks and planning policy for new development, and will be reliant on national legislation, most likely through an improved RHI or successor scheme. There is currently uncertainty about what will follow the current RHI, which extends to 2020/21. However, Bristol could consider the implementation of a local scheme to promote heat pumps. This could aim to bring residents and businesses together with local developers to raise awareness of heat pumps and their benefits, as well as the awareness of the RHI. The scheme could also aim to address some of the remaining barriers to uptake of heat pumps under the RHI such as the high initial investment required, for example with investors (potentially including the local authority itself) offering low-interest loans or with third parties providing the upfront capital cost for the works. Approaches such as the *Energiesprong*[62] model offer inspiration for how such schemes could be implemented.

6.4 Achieving carbon neutrality – the need to go beyond 'low regrets' actions

Figure 6-6 presents a scenario in which the low regrets actions described above are implemented, but no further action beyond those measures is taken. The figure shows that the low regrets actions achieve substantial reductions in carbon emissions in the short and medium term, down from 660 ktCO_2 / year in 2017 to 338 ktCO_2 / year in 2035 (a 48% reduction from today).

After 2035, however, progress stagnates, and although emissions fall further to 265 ktCO_2 / year in 2050 (a 60% reduction from today), this falls well short of Bristol's goal of becoming carbon neutral by 2050. The remaining emissions are dominated by the continuing use of gas for heating. In 2050, gas boilers running on natural gas still serve 44% of the heat demand (Figure 6-7).

[62] http://energiesprong.eu/

Figure 6-6: Annual carbon emissions projection to 2050 under the level of heating technology deployment described in the 'low regrets actions'

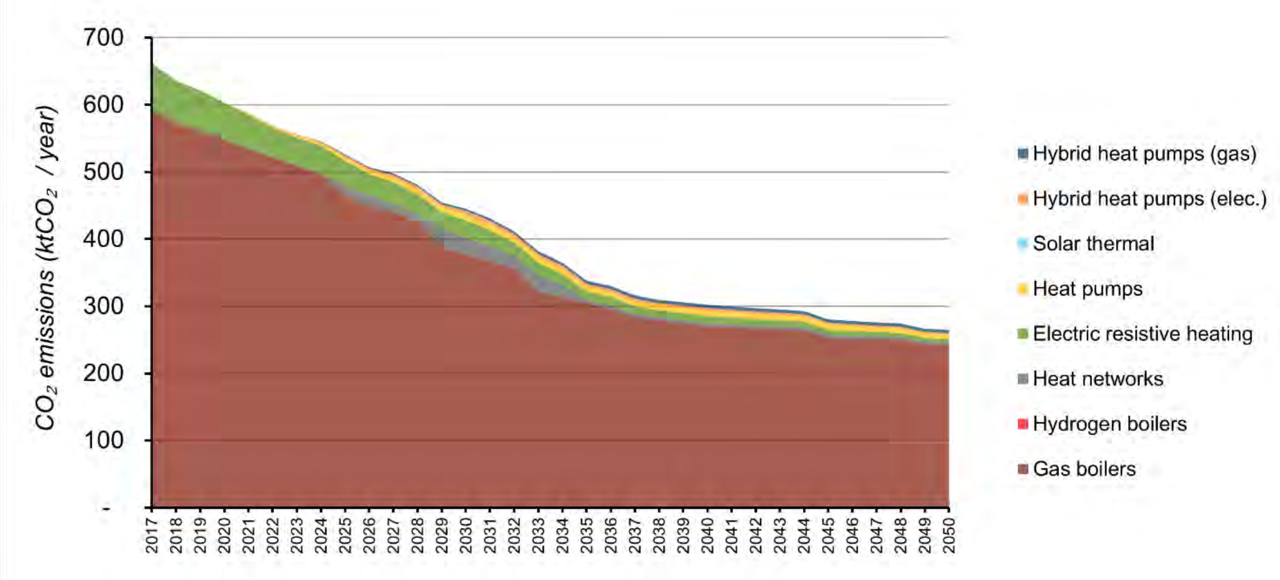
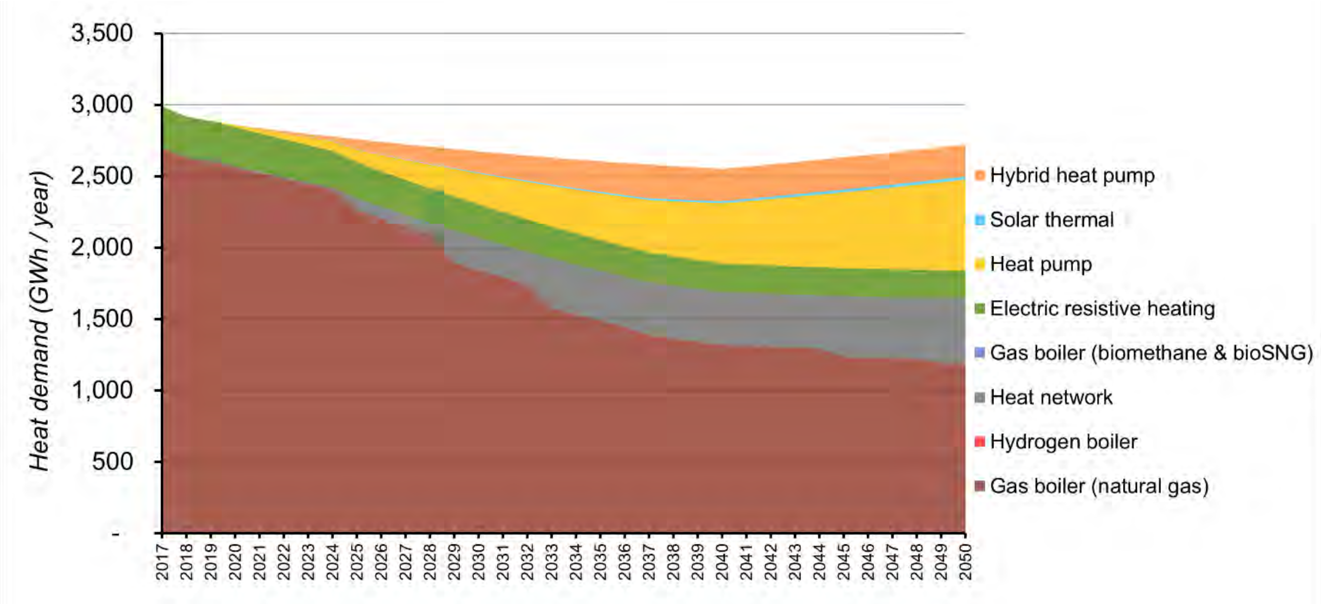


Figure 6-7: Annual heat demand profile to 2050 under the level of heating technology deployment described in the 'low regrets actions'



Despite representing a much higher level of ambition than current policy, the low regrets actions therefore do not come close to the goal of completely decarbonising Bristol's heat by 2050. Bristol's heat policy, supported at the national level, must therefore be substantially more ambitious than the low regrets measures to achieve the target of carbon neutrality by 2050.

No scenario presented in this work reaches full carbon neutrality by 2050, for the reasons discussed in section 2.2. However, the scenarios that achieve the deepest decarbonisation over the period 2017-2050, with emissions falling below 50 $ktCO_2$ / year in 2050 and hence representing a greater than 90% reduction versus today, are the High HPs, High HNs & high HPs and Mixed pathway scenarios. In each of these scenarios, a very high level of deployment of at least one heating technology is required, going substantially *beyond* the low regrets actions.

Another key decision must therefore be made regarding the long term pathway to achieve complete or near-complete decarbonisation by 2050. The scenarios presented above suggest that in order to meet the 2050 target, a decision on the long-term pathway is likely to be required during the period 2025-2030 at the latest, following which the possible pathways diverge more clearly.

Uncertainty over the cost and viability of the technology options to deliver the pathway to 2050 means this decision cannot be made today. This relates in particular to the uncertainty surrounding the commercial viability of low carbon hydrogen deployment, but also to the uncertainty surrounding the cost and viability of the highest levels of deployment of heat pumps (where deployment is contingent on consumer acceptance of the technology and very high levels of energy efficiency retrofit) and heat networks (where deployment is contingent on high levels of local authority planning and coordination, sufficient low carbon heat source availability and consumer acceptance).

Our recommendation at this stage is therefore for Bristol to implement (or help to implement) the low regrets actions and to learn from this experience, building a stronger evidence base on the cost and other implications of deployment of each technology option. This will help to ensure that the technology supply chains for the technologies develop to a point where they are able to deliver the level of deployment required in the long term, or it becomes clear that they cannot.

While the low regrets actions entail substantial levels of deployment of energy efficiency, heat pumps and heat networks to develop this evidence base, in the case of hydrogen heating they do not. For this technology, it will be necessary for the component technologies – including hydrogen production, CCS and delivery of hydrogen to buildings – to be demonstrated in a more targeted way. This will reduce uncertainty around the feasibility of taking each component to the commercial scale. These demonstrations will form the evidence base to inform what will likely be a national decision on the viability of this option.

7 Appendix A: Outline of a suggested approach to planning and connection policy for HNs

A specific objective of this study is to develop criteria for defining zones with potential for the development of heat networks and to recommend potential formulations of an appropriate planning and connection policy to ensure the growth of low carbon heat networks in Bristol. Section 4.3 describes the scenarios for heat network development across Bristol, and further detail behind the assumptions made in each scenario is given in section 9.

To achieve the high level of HN deployment described requires that:

- Planned and proposed heat networks go ahead, and key large heat users are connected;
- New developments are connected to existing heat networks, made 'connection ready' for planned heat networks or act as an anchor for the development of a new heat network;
- Existing buildings are connected to existing heat networks over time, so that the heat networks 'grow' to incorporate a greater fraction of heat demand over time;

Achieving this outcome is likely to require a HN connection policy framework that includes policy for both new development and existing buildings, and takes into consideration not only existing heat network schemes but also planned and proposed heat networks. A proposed outline HN connection policy framework, developed as part of this study, is shown in the following figures.

Figure 7-1: Suggested framework used to determine the HN connection policy for new and existing buildings

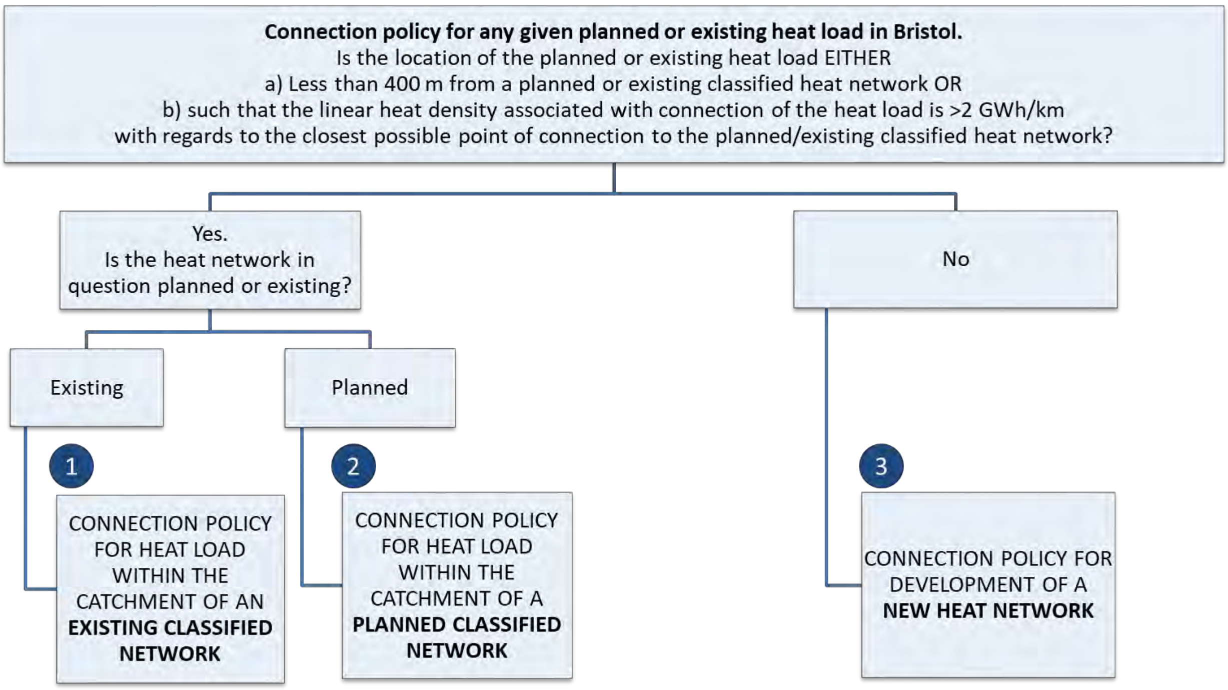


Figure 7-2: Connection policy for heat load within the catchment of an Existing classified network

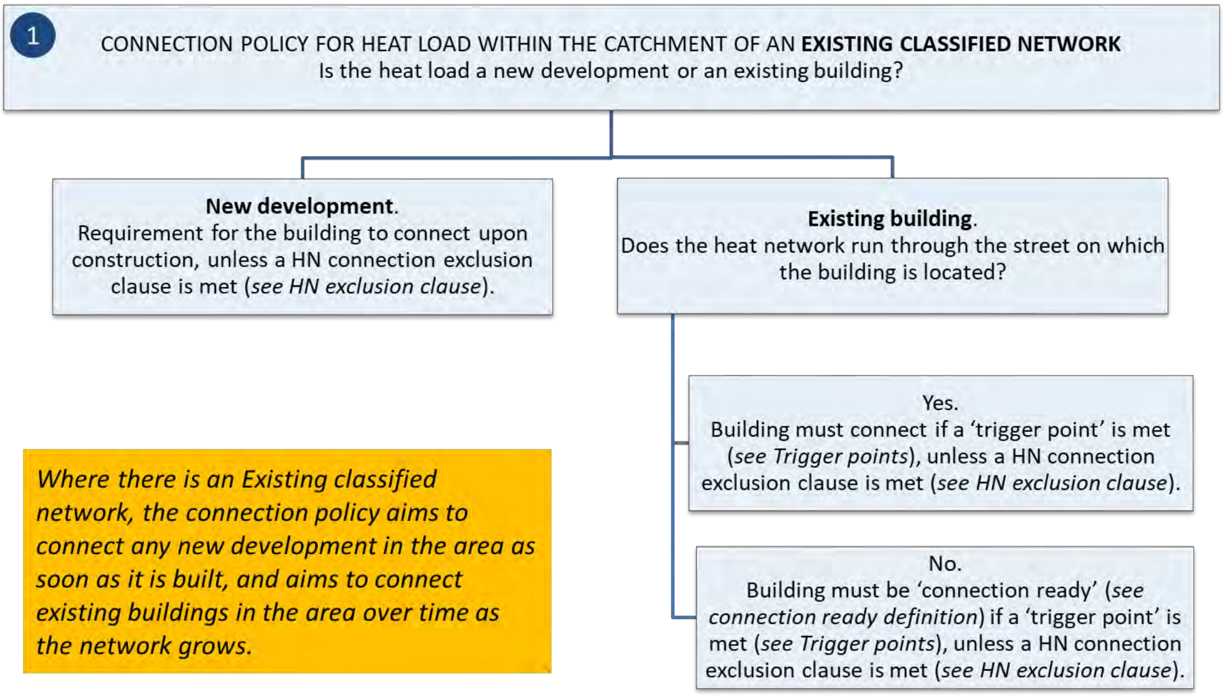


Figure 7-3: Connection policy for heat load within the catchment of a Planned classified network

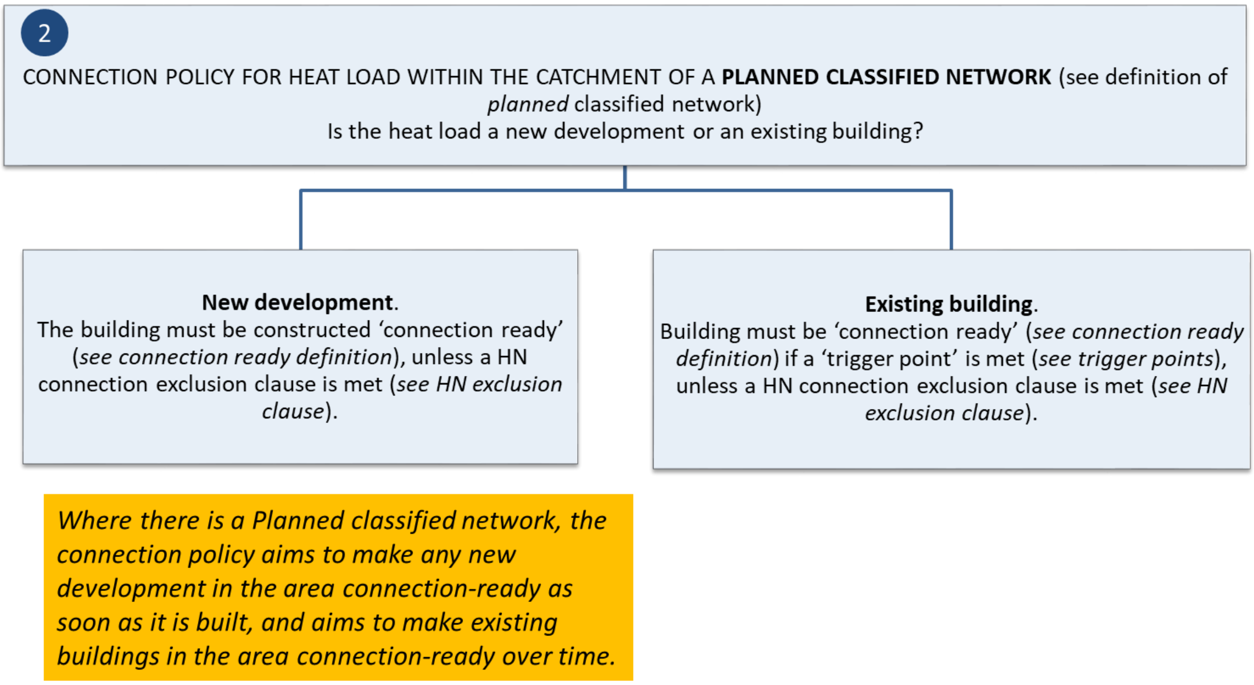
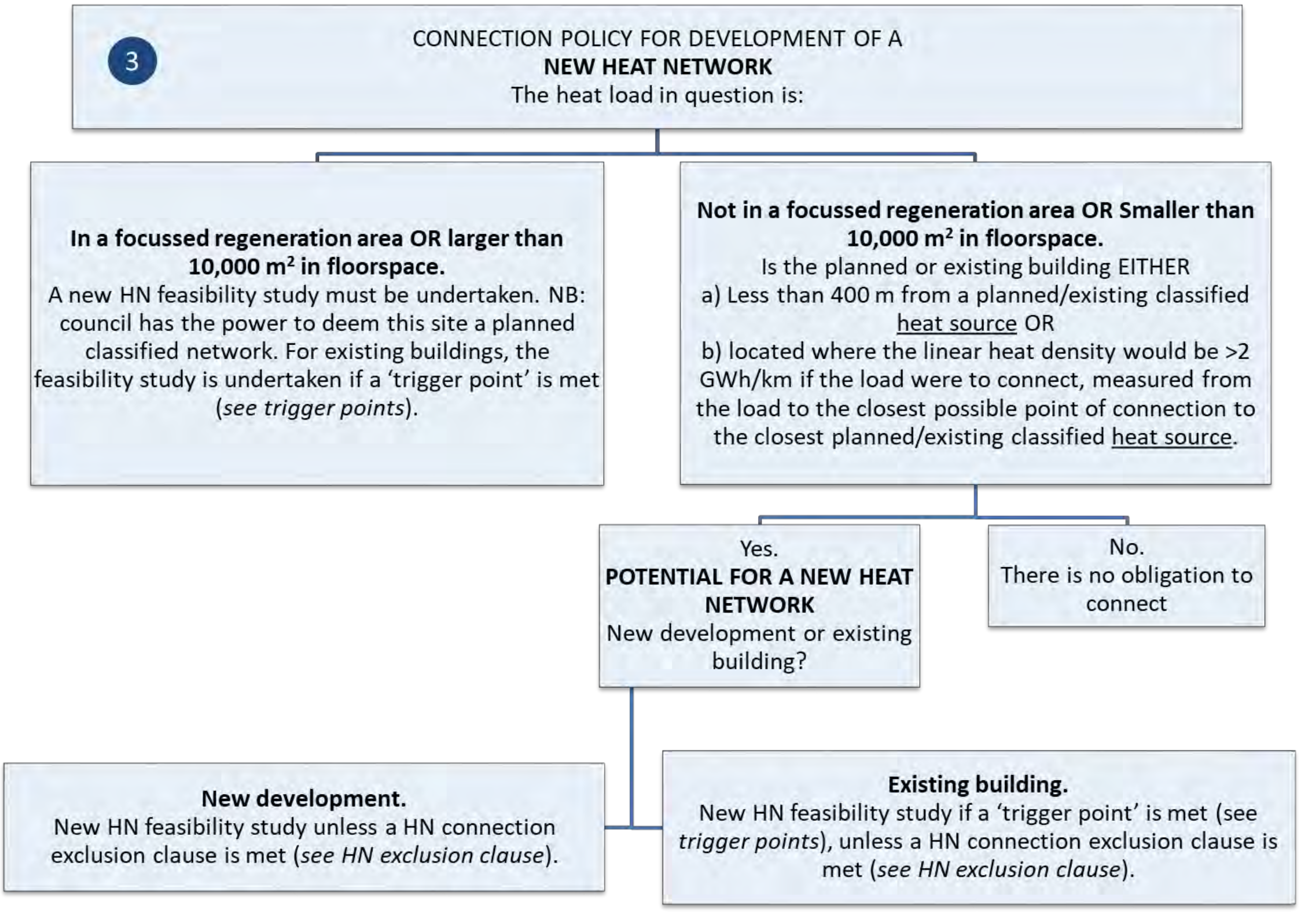


Figure 7-4: Policy for the development of a new heat network



A classified heat network or source

The definition of a ‘classified’ heat network should be specified to align with the Council’s strategic priorities for heat network development, including the objectives of providing low cost and low carbon heat to consumers, the need to work within any infrastructure-related or other constraints, and any other key objectives. As a starting point, we propose the following example terms. The Council would have the power to ‘classify’ a network or source if:

- The network/source is supplied by at least 50% renewable or recovered energy sources and will be able to retain this proportion as demand increases;
- There are no constraints to growth of the network in terms of infrastructure capacity;
- The network/source will supply heat at a ‘reasonably cost-effective’ price;
- There is a system to record the amount of heat delivered at each ‘node’ (or delivery point) of the heat network.

A classified network is one which the Council deems capable of delivering cost-effective low carbon heat to new customers, and the growth of which the Council wishes to promote. The Council should keep a register of the existing networks and sources, and their classification. This definition is provided as a starting point, and should be adapted to meet BCC’s objectives for heat networks as appropriate.

Planned classified heat network

A planned classified network is one which, if constructed as planned, would satisfy the requirements to be deemed a classified network. In addition, it should be deemed sufficiently likely by the Council that the planned network will be constructed, and that is will be constructed to satisfy the requirements of a classified network. The threshold for demonstrating this should be at the discretion of the Council. For private sector-led schemes, threshold requirements could relate to demonstration of funds committed, for example. For a scheme led by Bristol City Council, it could relate to the presence of a stated policy and timeline for development of the network.

Exclusion clauses

There may be valid reasons to exclude certain heat loads from the requirement to connect to a heat network under the connection policy described above. The exclusion criteria should be defined carefully to avoid enforcing heat network development where this can be shown not to be viable or another option can be shown to be equivalent or better in terms of meeting the Council’s key strategic objectives, and is preferred by relevant stakeholders, but also not to present ‘loopholes’ that undermine the connection policy such that it does not have the intended effect of supporting growth of heat networks across the region. As a starting point, we propose the following exclusion criteria, which should be adapted by the Council. It may also be necessary to review the exclusion clauses over time to minimise unintended consequences and ‘optimise’ the HN connection policy framework. The Council may grant an exclusion where sufficient evidence of any of the following points is provided:

- There is a severe physical constraint between the existing or proposed heat network route and the heat load in question which means connection is not technically feasible, including:
    - A major road,
    - A railway line,
    - A river;
- It is not ‘economically sensible’ to connect for any reason (using a definition for ‘economically sensible’ determined by the Council and not the stakeholder representing the heat load, such as a developer). ‘Economically sensible’ is not intended to mean economically optimal (for example, DH may not have to be lower cost than gas or direct electric heating as those options may not meet some of the Council’s key objectives such as carbon emissions reduction), but

rather that it must be reasonably cost-effective, for example below a typical benchmark. It may be appropriate to include a benchmark for both (i) lifetime cost of heat to the end user and (ii) upfront cost to the building developer/owner.

- The linear heat density[63] to the nearest point on the existing or proposed network along the shortest route is <0.5 GWh/km/year (including internal pipework to a development of several buildings);
- The heat load is Passivhaus certified;
- The heat load can present a plan for the decarbonisation of its heat that is less carbon intensive than connection to a HN.

Recommended trigger points for the connection of existing buildings

In this suggested framework, an eligible existing building in a classified heat network catchment area will either be required to connect to the heat network, to be 'connection ready' or to conduct a HN feasibility study at certain 'trigger points'. Typical trigger points are when the building is renovated and when its heat system is replaced. These are defined in more detail below.

Renovation, inclusion if any of the following points are met:

- The building is >1,000 m^2;
- The renovation increases the gross internal floor area of the property by >150 m^2 or >25%;
- The renovation leads to a change in floor use class;
- A planning application is made relating to major renovation of the building or heating system.

Heat system replacement, e.g. gas boiler replacement. The HN owner is responsible for providing a temporary hot water source until connection to the network is made.

Exceptions are made if:

- The building does not have heating installations;
- The building is temporary (<2 years);
- The building is a monument;
- The building is supplied by >60% renewable heat (as per the Renewable Energy Directive definition i.e. electric resistive heating would not qualify), where the generated energy is locally usable but where it cannot be fed back into the network, or where the heat is provided by: list of a heat pump, biofuel, recovered heat;
- The building's heat requirements are not compatible with those delivered by the network (pressure, temperature, other);
- The network cannot deliver heat to the building in a suitable timescale. NB this reason becomes invalid if the network supplies an alternative heat source temporarily;
- If linking the building to the network is not economically sensible. NB this is determined by the Council and not the developer, as in the HN exclusion clause.

Defining 'connection ready' buildings

'Connection ready' is a definition for buildings that are intended connect to a heat network in the future. We propose the following definition as a suggestion for BCC's further development:

- The heating and hot water of a connection ready building must be supplied via a single point for each building;

[63] Linear heat density (measured in GWh/km/year) is defined as the ratio of the annual heat delivered to the length of the heat network piping (measured from the heat delivery point to the closest network section)

- Single buildings must have low temperature hot water heat distribution to achieve consistently low return temperatures in line with the Heat Networks Code of Practice for the UK/Bristol City Council Connection Pack (or other future replacement standard);
- Provisions made in the building fabric such as soft-points in the building walls to allow pipes to be routed through from the outside at a later date;
- External (where detail is available) and internal district heat pipework routes identified and safeguarded;
- Space identified for the heat exchanger;
- Provision for monitoring equipment as specified by the HN provider;
- Multiple occupancy buildings must have communal heating based on low temperature hot water heat distribution;
- Developments connecting several heat loads must have provisions for a single plant room, located adjacent to the planned (or if not planned, likely) heat network route, producing all hot water via a communal heating system, including engineering measures to facilitate the connection of an interfacing heat exchanger.

Once a building is made ‘connection ready’, we suggest that it will then connect to the heat network if either of the following criteria are met:

- The network route comes within 20m of the single heating and hot water connection point of the building;
- The linear heat density is >0.5 GWh/km/year measured from the single heating and hot water connection point of the building to the closest possible point of connection to the heat network.

Example case

It is the year 2024, and a home owner in Southmead, whose home is currently heated using a gas boiler, is considering a renovation; the home owner would like to understand what the consequences of the construction of the SHM are for their home. Suppose that BCC has classified the SHM and it is planned to connect to Southmead in 2025. The SHM is therefore a ‘planned classified heat network’. The home is 200m from the planned route of the SHM.

Refer first to the initial segment of the HN decision tree, as in Figure 7-1. The SHM is a planned classified network, and the home is within the catchment area since it is less than 400m from the planned route. Therefore, we refer to branch (2) for connection policy for heat load within the catchment of a planned classified network.

We now refer to the expanded version of branch (2), as in Figure 7-3. The building in question is an existing building, so the connection policy means that the building must be connection ready if a trigger point is met, unless a HN connection exclusion clause is met.

We first refer to the Exclusion clauses (see above) to determine if the building is excluded from connection to a HN. A typical existing home may be expected to have with an annual heat demand of 10,000-20,000 kWh/yr; at 200m from the SHM the linear heat density for connection of a single existing home is likely to be much less than 0.5 GWh/km/year. Therefore, the building is excluded; it need not connect nor be made ‘connection ready’ at this time.

We now consider this same home ten years later, in the year 2034. The network has by this time been extended to connect to a large new development. The network route now runs down the same road as the one on which the existing home in question is located, so that the network route passes within 10m of the building. The building owner wishes to replace their heating system again. Heating system replacement is, as for the renovation in 2024, a ‘trigger point’ for connection to the heat network. However, now that the network route is much closer than it was ten years previously in 2024, the linear heat density of the connection of the home to the network is greater, likely around 1-2 GWh/km/year (for an annual heat demand of 10,000-20,000 kWh/yr). As a result, the building is no longer excluded on linear heat density grounds. Suppose also that the building in question does not meet any other exclusion clause criteria. The building must be connection ready and will connect to the network once provisions are made for connection to a network, as defined above under ‘connection ready’.

8 Appendix B: Methodology used to generate energy efficiency uptake scenarios

Implementing energy efficiency measures in the existing building stock leads to a reduction in fuel demand, and therefore cost savings to the end-user and carbon emissions reduction across the sector. The efficiency measures considered in this study are shown in Table 8-1.

Table 8-1: Description of energy efficiency measures applied to Bristol's existing building stock

Sector	Measure category	Measure description
Domestic	Solid wall insulation	Internal or external wall insulation
	Cavity wall insulation	Easy to treat, hard to treat or limited potential wall insulation
	Loft insulation	Insulation thicknesses: 50-124 mm, 125-199 mm Easy to treat and hard to treat
	Floor insulation	Categorized into suspended timber floors and solid floors
	High efficiency glazing	Categorized by potential: from single glazing, from pre-2002 single glazing, from pre-2002 double glazing
	Doors & draught proofing	
Non-domestic	Building Fabric	Insulating fabrics e.g. multi-foils, EPS, expanded polystyrene
	Building instrumentation & control	Including smart metering

The general approach used to determine the extent to which energy efficiency measures could decarbonise Bristol's heating sector was firstly to determine the total remaining potential and then to understand the cost effectiveness of the measures making up that remaining potential.

The remaining potential was calculated by evaluating the number of buildings to which energy efficiency measures could be applied, the heat and fuel demand savings from applying these measures and the potential carbon savings.

The segmentation of these measures into cost-effectiveness bands was based on the findings of a recent Element Energy analysis[64] of the cost-effectiveness of the various measure types at the national level. The process and sources used are described in further detail in Table 8-2.

[64] Element Energy and E4tech, Cost analysis of future heat infrastructure options, Report for the National Infrastructure Commission (pending publication)

Table 8-2: Efficiency measures applied to Bristol's existing stock – process methodology and sources used

Key aspects	Key data and tools	Description
Estimation of remaining potential Estimation of GWh saved	**Domestic**	
	Private Sector Housing Stock Condition Survey, ORS for Bristol City Council, 2011	Spatial projections of domestic builds to 2036
	Information provided by BCC	Energy consumption of new buildings by type, floor area of new builds by type
	Element Energy & Energy Saving Trust for the Committee on Climate Change, 2014	Energy savings from energy efficiency measures; remaining potential for measures for which there is no Bristol-specific data
	Non-Domestic	
	Building Energy Efficiency Survey (BEES)	Efficiency measure converted into fuel consumption savings by measure type

Remaining potential

The remaining potential for energy efficiency in Bristol's building stock is presented in Table 8-3. These measures yield heat demand savings relative to 2017 levels of 27% in the Domestic sector and 28% in the Non-domestic sector.

Solid wall insulation was identified as the measure with the highest remaining potential in Bristol's existing domestic building stock, with potential savings of 226 GWh / year. Cavity and loft insulation have a lower remaining potential due to a large number of installations already implemented. However, these measures could still bring savings of 93 GWh / year in the domestic building stock.

Other efficiency measures included could bring a further 194 GWh / year savings in the domestic stock.

In the non-domestic sector, no Bristol-specific data was available on the remaining potential. Instead the approach was to directly calculate the potential heat demand savings in Bristol by scaling the national savings that each efficiency measure yields in each sub-sector. The total savings from building fabric and building instrumentation & control in the non-domestic sector was 302 GWh / year. The fuel savings were calculated from the heat demand savings, from which CO_2 savings were derived. The efficiency measures identified in this report yielded potential CO_2 emissions savings of 189 ktCO_2 per year from current emissions of 660 ktCO_2 per year.

Table 8-3: Total remaining potential in Bristol's Domestic existing housing stock

	Measure category	Remaining potential (# buildings)	Heat demand savings (GWh)	CO_2 savings ($ktCO_2$ / yr)
Domestic	Solid wall insulation	55,900	226	52
	Cavity wall insulation	36,100	86	20
	Loft insulation	10,300	7	2
	Floor insulation	130,000	93	22
	High efficiency glazing	61,900	81	19
	Doors & draught proofing	95,700	20	5
Non-domestic	Building fabric	N.A.	127	29
	Building instrumentation & control	N.A.	175	40

Cost-effectiveness of energy efficiency measures

The approach used to determine the cost-effectiveness of the energy efficiency measures described is based on Element Energy's recent work for the National Infrastructure Commission[65], which included an assessment of the cost-effectiveness of energy efficiency across the UK as a whole. That report found that the various energy efficiency measure types could be assigned to three levels of cost-effectiveness: Low cost, Medium cost and High cost in the proportions shown in Table 8-4. The thresholds for the £/ tCO_2 saved in each cost effectiveness band are shown in Table 8-5.

Table 8-4: Proportion of remaining potential that is assigned to each cost-effectiveness band for each efficiency measure

	Measure category	Scenario		
		Low cost energy efficiency	Medium cost energy efficiency	High cost energy efficiency
Domestic	Solid wall insulation	15%	66%	19%
	Cavity wall insulation	67%	23%	10%
	Loft insulation	97%	0%	3%
	Floor insulation	1%	3%	96%
	High efficiency glazing	32%	68%	0%
Non-domestic	Building Fabric	21%	8%	71%
	Building instrumentation & control	21%	8%	71%

Table 8-5: Definition of the cost-effectiveness bands by £/ tCO_2

Cost-effectiveness band	Cost effectiveness range (£/ tCO_2 abated)
Low cost	<0
Medium cost	0-200
High cost	>200

[65] Element Energy and E4tech, Cost analysis of future heat infrastructure options, Report for the National Infrastructure Commission (pending publication)

The remaining potential represents the maximum savings that could be made if all measures were applied, these are shown in Table 8-6, segmented by cost effectiveness band. In reality, the measures will be rolled out gradually. The deployment trajectories followed in this report for the three scenarios presented are shown in Figure 4-3.

In the 'No energy efficiency' scenario, the heat demand profile is identical to that shown in Figure 4-3 and the heat demand rises due to the construction of new buildings.

In the Low energy efficiency and Medium energy efficiency scenarios, all energy efficiency measures are applied by 2035. In 2035, the annual heat demand savings are 198 GWh (Low energy efficiency) and 452 GWh (Medium energy efficiency). These savings are relative to the case where no energy efficiency measures are applied beyond 2018. In the High energy efficiency scenario, all energy efficiency measures are applied by 2040 delivering annual heat demand savings in 2040 of 720 GWh.

Table 8-6: Total heat demand savings potential in Bristol's existing building stock

Cost-effectiveness band	Total energy savings potential – domestic (GWh / yr)	Total energy savings potential – non-domestic (GWh / yr)
Low cost	150	48
Medium cost	235	19
High cost	128	140
Total	***513***	***207***

9 Appendix C: Key assumptions for the uptake of heat networks

Table 9-1: Key assumptions for each HN uptake scenario 2050

Heat load type	HN uptake scenario		
	Low HNs	**Medium HNs**	**High HNs**
Existing and planned networks	Completion and expansion of Temple & Redcliffe, assumed connection by 2022, excluding Redcliffe Phase 2. Completion and expansion of City Centre Phase 1, assumed connection in 2022. Construction of City Centre Phase 2, assumed connection in 2029. Including: 'City Hall' & surrounding buildings, 'Central area'.	Low HNs uptake assumptions	Low HNs uptake assumptions
Key large heat users identified in master-planning studies	No additional connections	Construction of Strategic Heat Main (SHM) including connection of large existing heat users: Southmead (connection in 2025), Bristol City centre West (connection in 2033), Bristol City Centre East (2033)	Medium HNs uptake assumptions and additionally: Connection of large existing eat users in Avonmouth North & South.
New developments	No additional connections	Connection of 70% of new developments along the SHM route including Southmead and Lawrence Hill	Creation of networks in all new build development starting in 2025, gradually extended as new developments are built incl.: Bristol South (Brislington, Bath Rd., Central Bedminster, Parson St.), East Bristol (Fishponds), North Bristol (Lockleaze). Connection of large existing users in Avonmouth North & South.
Other existing buildings	No additional connections	Connection of 15% of existing buildings within the LSOAs[66] which the SHM route runs through by 2050	Connection of 30% of existing buildings within the LSOAs which the SHM route runs through by 2050; connection of 20% of existing buildings finding themselves in a LSOA adjacent to one with a heat network (providing heat density in LSOA in question not less than that it is adjacent to); connection of 25% of existing buildings in Red LSOAs (where heat demand is >70 GWh / km^2) by 2050 Connection of 13% of existing buildings in Red LSOAs (where the heat demand is 60-70 GWh / km^2) by 2050.

[66] LSOA (Lower Layer Super Output Area) is a geographic area used for the reporting of small area statistics in England and Wales

10 Appendix D: Technology uptake descriptions

This section outlines the deployment trajectories for heating technologies under the various levels of uptake defined in this report. It also outlines the assumed electricity and gas grid decarbonisation. This Appendix is intended to accompany Table 1-1 and Table 5-1.

Energy efficiency:

Figure 10-1: Projection of Bristol's heat demand to 2050 with varying levels of energy efficiency applied

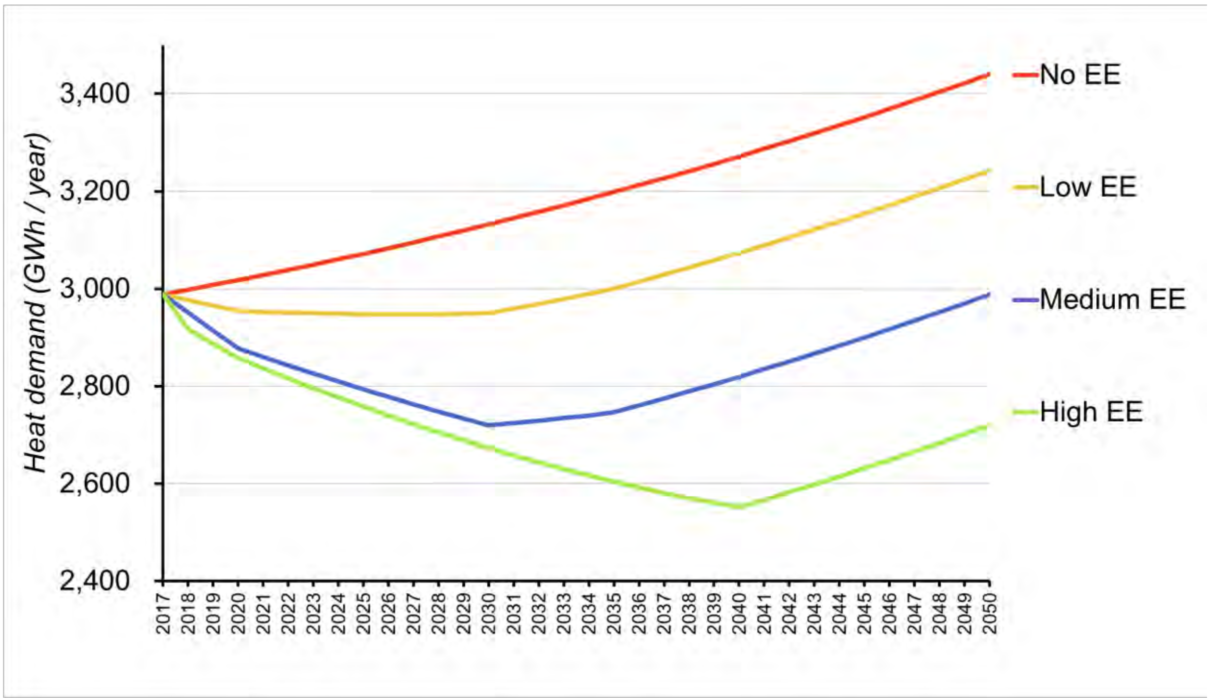


Table 10-1: Estimated number of retrofits required by 2040 to reach the high energy efficiency target in Bristol's domestic stock

	Measure category	Number of measures installed by 2040
Domestic	Solid wall insulation	55,900
	Cavity wall insulation	36,100
	Loft insulation	10,300
	Floor insulation	130,000
	High efficiency glazing	61,900
	Doors & draught proofing	95,700
Non-domestic	Building fabric	N.A.
	Building instrumentation & control	N.A.

Table 10-2: Proportion of remaining potential that is assigned to each cost-effectiveness band for each efficiency measure

	Measure category	Scenario		
		Low cost energy efficiency	Medium cost energy efficiency	High cost energy efficiency
Domestic	Solid wall insulation	15%	66%	19%
	Cavity wall insulation	67%	23%	10%
	Loft insulation	97%	0%	3%
	Floor insulation	1%	3%	96%
	High efficiency glazing	32%	68%	0%
Non-domestic	Building Fabric	21%	8%	71%
	Building instrumentation & control	21%	8%	71%

Table 10-3: Definition of the cost-effectiveness bands by £/ tCO_2

Cost-effectiveness band	Cost effectiveness range (£/ tCO_2 abated)
Low cost	<0
Medium cost	0-200
High cost	>200

Heat networks:

Table 10-4: Summary of HN uptake in the three scenarios in 2025 and 2050. Percentages are of total heat demand in a particular segment in a particular year.

Heat demand connected	Units	Low HNs		Medium HNs		High HNs	
		2025	2050	2025	2050	2025	2050
Total	**GWh / year**	**28**	**144**	**86**	**457**	**144**	**1018**
	%	**1%**	**6%**	**3%**	**20%**	**5%**	**44%**
Domestic existing	%	1%	3%	1%	6%	1%	11%
Domestic new	%	0%	0%	19%	34%	59%	100%
Non-domestic existing	%	2%	14%	5%	26%	5%	39%
Non-domestic new	%	0%	0%	23%	31%	66%	100%

Heat pumps:

Table 10-5: Maximum uptake of heat pumps by sector in the three scenarios in 2025 and 2050

Heat demand connected	Units	Low HPs		Medium HPs		High HPs	
		2025	2050	2025	2050	2025	2050
Total	**GWh / year**	**66**	**146**	**79**	**579**	**189**	**1,806**
	%	**2%**	**6%**	**3%**	**25%**	**7%**	**78%**
Domestic	%	3%	7%	3%	28%	6%	71%
Non-domestic	%	2%	3%	2%	12%	9%	60%

Hybrid heat pumps:

Table 10-6: Maximum uptake of hybrid heat pumps in the three scenarios in 2025 and 2050

Heat demand connected	Units	Low HHPs		Medium HHPs		High HHPs	
		2025	2050	2025	2050	2025	2050
Total	**GWh / year**	**19**	**64**	**66**	**203**	**92**	**338**
	%	**1%**	**3%**	**2%**	**9%**	**3%**	**15%**
Domestic	%	1%	3%	3%	10%	3%	15%
Non-domestic	%	1%	2%	2%	5%	4%	9%

Green gas:

Table 10-7: Summary of the maximum green gas deployment scenario. Percentages are share of gas grid demand in Bristol.

Heat demand connected	Units	Maximum Green gas deployment	
		2025	2050
Total	**GWh / year**	**65**	**370**
	%	**3%**	**64%**
Biomethane	%	3%	33%
BioSNG	%	0%	31%

Hydrogen:

Table 10-8: Deployment timeline of hydrogen.

Deployment scenario	Proportion of gas demand met by hydrogen by year (%)					
	2040	2041	2042	2043	2044	2045
Maximum deployment	0%	20%	40%	60%	80%	100%

Grid decarbonisation:

Figure 10-2: Carbon intensity of the electricity grid to 2050

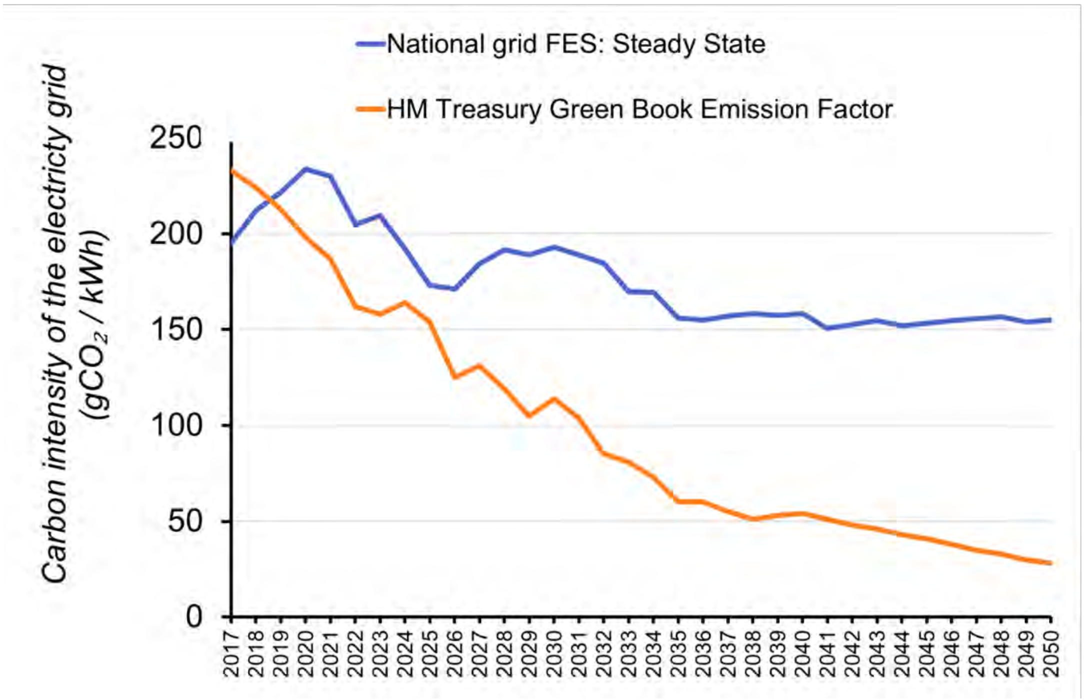


Table 10-9: Carbon intensity of natural gas, green gas and hydrogen assumed

Gas	Carbon intensity (gCO_2 / kWh)
Natural gas	183
Hydrogen	22
Biomethane	74
BioSNG	63

11 Appendix E: Informing policy on direct (resistive) electric heating for new buildings

11.1 Introduction

Low regrets action 3 of this work is: to *strengthen building planning policy to ensure all new buildings are served by low carbon heat networks or heat pumps, or equivalent low carbon options*. Our building stock analysis shows that 10% of Bristol's heat demand is currently met by electricity, with the vast majority of this being direct (resistive) electric heating. The purpose of this Appendix is to bring together the evidence in this report demonstrating that widespread installation of direct (resistive) electric heating in new buildings is inconsistent with Bristol's commitments to mitigate climate change and that heat pumps and low carbon heat networks should be deployed instead wherever viable.

Direct (resistive) electric heaters work by converting electrical energy to heat energy via the process of passing current through an electric resistor. This process has an efficiency of close to 100%, where efficiency is defined as useful heat delivered per unit of electrical energy input. Heat pumps are a different form of electric heating and are several times more efficient than traditional direct (resistive) electric or storage heaters. Heat pumps usually have a seasonal efficiency approximately in the range 200% to 500%[67]. For each unit of energy (usually electricity) required to drive the heat pump 2 to 5 units of useful heat are typically produced.

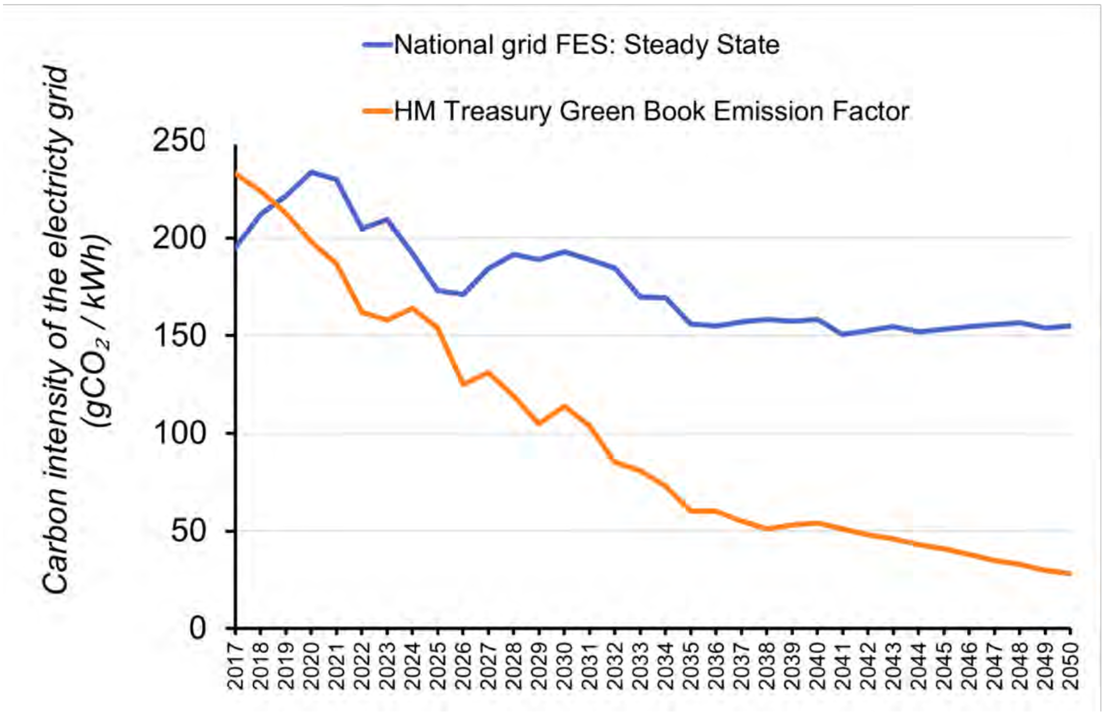
11.2 Impact of continued reliance on direct (resistive) electric heating

Carbon impacts

Although heat pumps and direct (resistive) electric heaters both rely on electricity, heat pumps are 2 to 5 times more efficient, as noted above. This means that for every direct (resistive) electric heater that is installed in place of a heat pump, the carbon emissions are expected to be 2 to 5 times greater. The current carbon intensity of the electricity grid is still well over 200 gCO_2/kWh (see Figure 11-1) and is only expected to go below 50 gCO_2/kWh by 2040 at the earliest, even in an ambitious grid decarbonisation scenario. Under the National Grid's less ambitious Steady State scenario, the grid is not expected to decarbonise below 150 gCO_2/kWh over the next 30 years. There is thus uncertainty over the extent to which the grid can decarbonise, and this is largely dependent on factors driven by national government. Local government can, however, influence policy on energy efficiency, by promoting efficient use of energy for space heating and hot water through use of heat pumps or low carbon heat networks.

[67] Element Energy for BEIS, Hybrid Heat Pumps (December 2017)

Figure 11-1: Carbon intensity of the electricity grid to 2050



The heat network options studied in this report will be increasingly supplied by low carbon heat sources, as shown in Figure 11-2. We see from the resulting carbon trajectories, displayed in Figure 11-3, that heat networks can achieve an average carbon intensity of 110 gCO_2 / kWh in 2030 and 7 gCO_2 / kWh in 2050 (this is the carbon intensity of the heat delivered, not the heat generated, so it takes into account transmission losses). We see from Figure 11-3 that the carbon impact of heat networks is considerably lower than direct (resistive) electric heating when fed increasingly by industrial waste heat from EfW plants. We also see the significantly lower carbon intensity of heat pumps relative to direct (resistive) electric heating. As mentioned elsewhere in this report, it should be a requirement for heat networks to achieve carbon emissions lower than direct (resistive) electric heating and comparable with heat pumps. Heat networks that do not meet these standards should not be promoted by BCC and they should not be ‘classified’.

Figure 11-2: Heat network supply sources under medium heat network deployment (no H_2 grid)

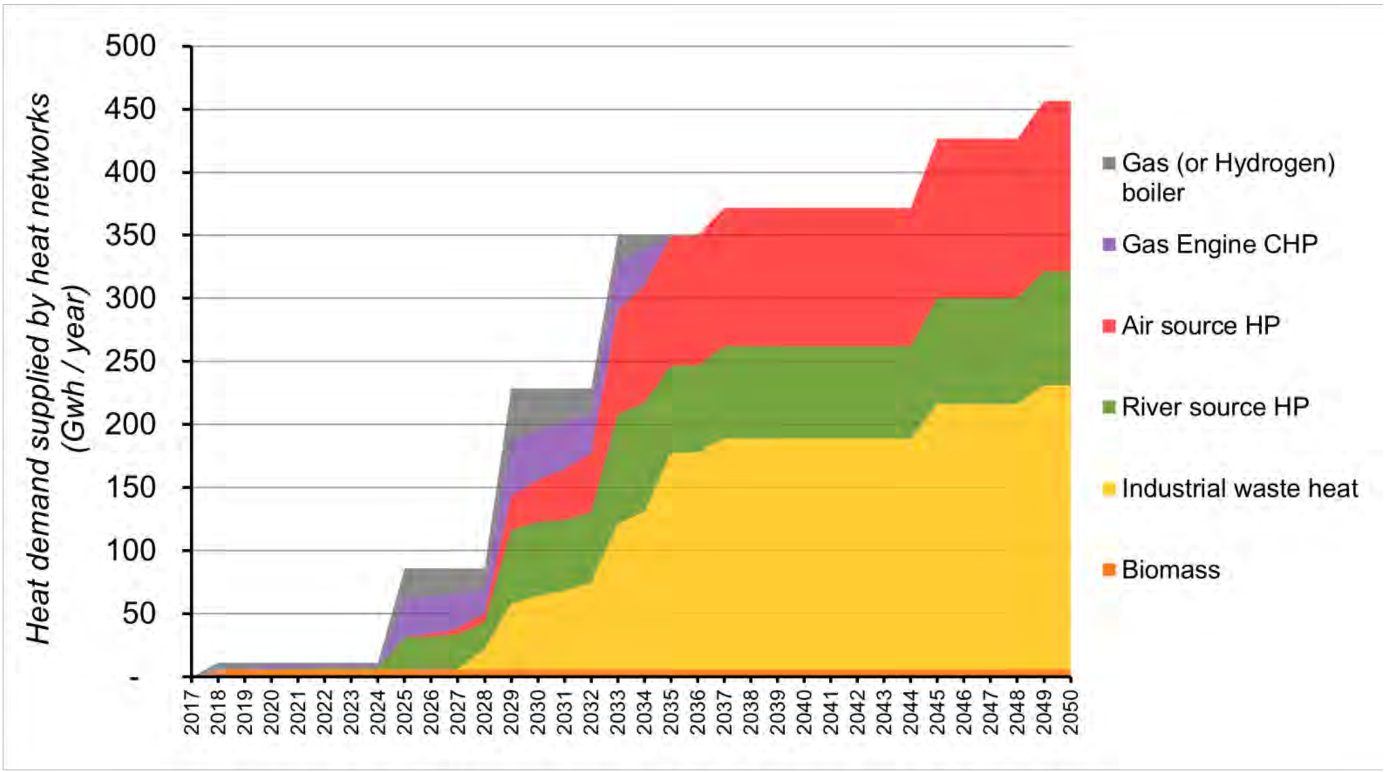
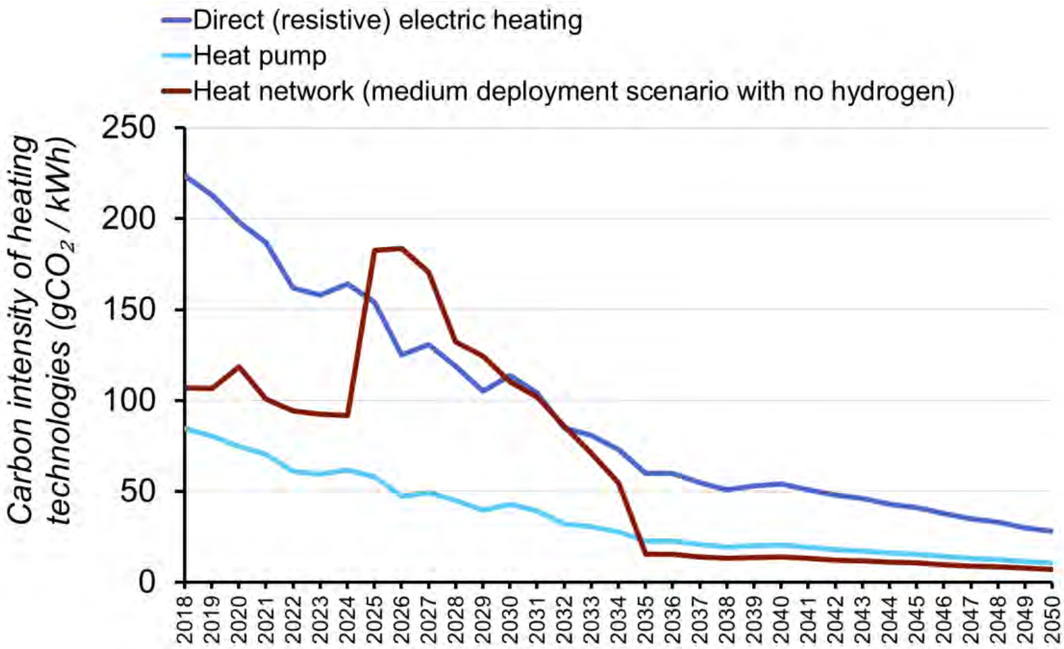


Figure 11-3: Estimated[68] carbon intensity of three domestic heating technologies in Bristol to 2050



[68] Estimate assumes average efficiency of a domestic heat pump to be 265%, and the average electricity grid intensity in HM Treasury's Green Book Emission Factor

Grid impacts

The impact on the electricity grid of deploying direct (resistive) electric heating for new buildings is likely to be significant. The peak electric load of direct (resistive) electric heaters relative to heat pumps is likely to be greater by at least a factor of their efficiency (2 to 5). The additional load associated with electric heating may require costly grid reinforcements that could therefore be reduced by using a more efficient form of heating, such as heat pumps. A recent report[69] on heat decarbonisation challenges studied the challenges of meeting the peak winter heat demand. The study identified that at on the 1st March 2018 (during a cold weather event in the UK), the peak hourly local gas demand occurring at 6pm was 214 GW, compared with a peak electrical supply of 53 GW occurring at the same time. If the instantaneous peak heat demand is several times larger than the instantaneous peak electricity demand, converting all heat demand to electricity will require several times more electricity capacity than the grid is currently designed to operate with. In this appendix we refer only to heating technologies in new buildings, which is a segment of the building stock in which efficient heating technologies are available in most cases. Heat pumps can mitigate much of this impact (by the factor their efficiency: 2 – 5).

It is known that the efficiency of heat pumps becomes lower as the external heat temperature reduces, meaning that the efficiency of heat pumps can be at its lowest during times of peak heat demand (i.e. very cold days). However, a recent report[70] by Element Energy for BEIS suggests that even when operating at an external temperature of -7ºC, the efficiency of a heat pump can be above 2 with a heat supply temperature of 45ºC – which is sufficiently high for energy efficient new buildings. Therefore, the peak electricity demand should be reduced by at least a factor of two relative to direct (resistive) electric heating. The contribution of direct (resistive) electric heaters versus heat pumps to the peak electricity demand may be even higher than a factor of 2 – 5. This is because heat pumps are likely to be used in a more continuous, less ‘peaky’ way than direct (resistive) electric heaters.

Consumer impacts

In this study we have estimated the annual domestic heating cost of a typical new building constructed today for heat pumps and direct (resistive) electric heating, the findings are shown in Figure 5-11. It is assumed that the total installed cost of a 5 kW heat pump in a new building is £3,100 for the heat pump without installation, £300 for the hot water cylinder, £2500 for installation costs and £200 for annual maintenance, based on recent Element Energy studies[71,72]. It is assumed[73] that direct (resistive) electric heating costs are £1,150 for purchase and installation, and £35 for annual maintenance. Finally, it is assumed that the annual heat demand for a new building is 5,000 kWh[74]. We see in Figure 5-11 that under the three cost sensitivities undertaken in this study, the annual domestic heating cost in a new home is lower for a heat pump than for direct (resistive) electric heating.

There are additional benefits of a lower electricity demand for buildings with heat pumps versus direct (resistive) electric heating such as reduced fuel poverty and reduced dependence on the fluctuating price of electricity.

[69] UKERC, Heat decarbonisation challenges: local gas vs electricity supply (August 2018)
[70] Element Energy for BEIS, Hybrid Heat Pumps (December 2017)
[71] Element & E4tech for the NIC, Cost analysis of future heat infrastructure options (March 2018)
[72] Element Energy for BEIS, Hybrid Heat Pumps (December 2017)
[73] Element & E4tech for the NIC, Cost analysis of future heat infrastructure options (March 2018)
[74] Based on DCLG, Energy Performance of Buildings Directive (2013). It is assumed in this directive that the annual energy demand for heating and hot water in a typical new semi-detached house is 6,000 kWh and 4,200 kWh in a typical new mid-floor flat.

Figure 11-4: Estimated average annual domestic heating cost of a new building today for heat supplied by heat pump and direct (resistive) electric heating