Climate Change Committee

The Sixth Carbon Budget

Buildings

This document contains a summary of content for the buildings sector from the CCC's Sixth Carbon Budget Advice, Methodology and Policy reports.

Introduction

The Committee is advising that the UK set its Sixth Carbon Budget (i.e. the legal limit for UK net emissions of greenhouse gases over the years 2033-37) to require a reduction in UK emissions of 78% by 2035 relative to 1990, a 63% reduction from 2019. This will be a world-leading commitment, placing the UK decisively on the path to Net Zero by 2050 at the latest, with a trajectory that is consistent with the Paris Agreement.

Our advice on the Sixth Carbon Budget, including emissions pathways, details on our analytical approach, and policy recommendations for the buildings sector is presented across three CCC reports, an accompanying dataset, and supporting evidence.

- **An Advice report**: *The Sixth Carbon Budget – The UK's path to Net Zero*, setting out our recommendations on the Sixth Carbon Budget (2033-37) and the UK's Nationally Determined Contribution (NDC) under the Paris Agreement. This report also presents the overall emissions pathways for the UK and the Devolved Administrations and for each sector of emissions, as well as analysis of the costs, benefits and wider impacts of our recommended pathway, and considerations relating to climate science and international progress towards the Paris Agreement. Section 2 of Chapter 3 contains an overview of the emissions pathways for the buildings sector.
- **A Methodology Report:** *The Sixth Carbon Budget – Methodology Report*, setting out the approach and assumptions used to inform our advice. Chapter 3 of this report contains a detailed overview of how we conducted our analysis for the buildings sector.
- **A Policy Report:** *Policies for the Sixth Carbon Budget and Net zero*, setting out the changes to policy that could drive the changes necessary particularly over the 2020s. Chapter 3 of this report contains our policy recommendations for the buildings sector.
- **A dataset** for the Sixth Carbon Budget scenarios, which sets out more details and data on the pathways than can be included in this report.
- **Supporting evidence** including our public Call for Evidence, 10 new research projects, three expert advisory groups, and deep dives into the roles of local authorities and businesses.

All outputs are published on our website (www.theccc.org.uk).

For ease, the relevant sections from the three reports for each sector (covering pathways, method and policy advice) are collated into self-standing documents for each sector. A full dataset including key charts is also available alongside this document. This is the self-standing document for the buildings sector. It is set out in three sections:

1) The approach to the Sixth Carbon Budget analysis for the buildings sector
2) Emissions pathways for the buildings sector
3) Policy recommendations for the buildings sector

Chapter 1

The approach to the Sixth Carbon Budget analysis for the buildings sector

Introduction and key messages

The following sections are taken directly from Chapter 3 of the CCC's Methodology Report for the Sixth Carbon Budget.[1]

This chapter sets out the method for the buildings sector Sixth Carbon Budget pathways.

The key messages are:

- **Background**. Direct greenhouse gas (GHG) emissions from buildings were 87 Mt CO_2e in 2019, accounting for 17% of UK GHG emissions. These emissions are mainly the result of burning fossil fuels for heating. Emissions from electricity use – known as indirect emissions – are caused primarily by the use of lighting and appliances, and are also covered in our assessment of the electricity sector.[*] Buildings emissions are primarily CO_2, with 1.4 Mt of methane and 0.8 Mt CO2e of emissions from fuel combustion processes and nitrous oxide in hospitals.

- **Options for reducing emissions**. Options for reducing emissions include: behavioural change, which can drive down or alter patterns in the consumption of energy; energy efficiency measures, which save energy; and fuel-switching away from fossil fuels to low-carbon alternatives.

- **Analytical approach**. Our starting point for this analysis has been the 2019 Net Zero report, which showed that the Net Zero target means eliminating buildings emissions by 2050. We have used bottom-up analysis to produce a set of pathways to deliver this, and use scenarios to explore a range of different futures. We include new evidence on: technical and economic potential for measures; the costs and savings associated with behaviour change, efficiency measures and low-carbon heat; as well incorporating updated evidence on deployment constraints and delivery feasibility.

- **Uncertainty.** We have used the scenario framework to test the impacts of uncertainties, and to inform our Balanced Net Zero Pathway. The key areas of uncertainty we test relate to: energy costs; behaviour change; energy efficiency uptake, costs and savings; heat supply; heat technology costs, lifetimes, sizing and efficiency; and the pace of action.

We set out our analysis in the following sections:

1. Current and historical emissions in buildings
2. Options to reduce emissions in buildings
3. Approach to analysis for the Sixth Carbon Budget

[*] We consider these emissions from an energy demand perspective in this chapter.

1. Current and historical emissions in buildings

Buildings emissions mainly stem from burning fossil fuels for heating.

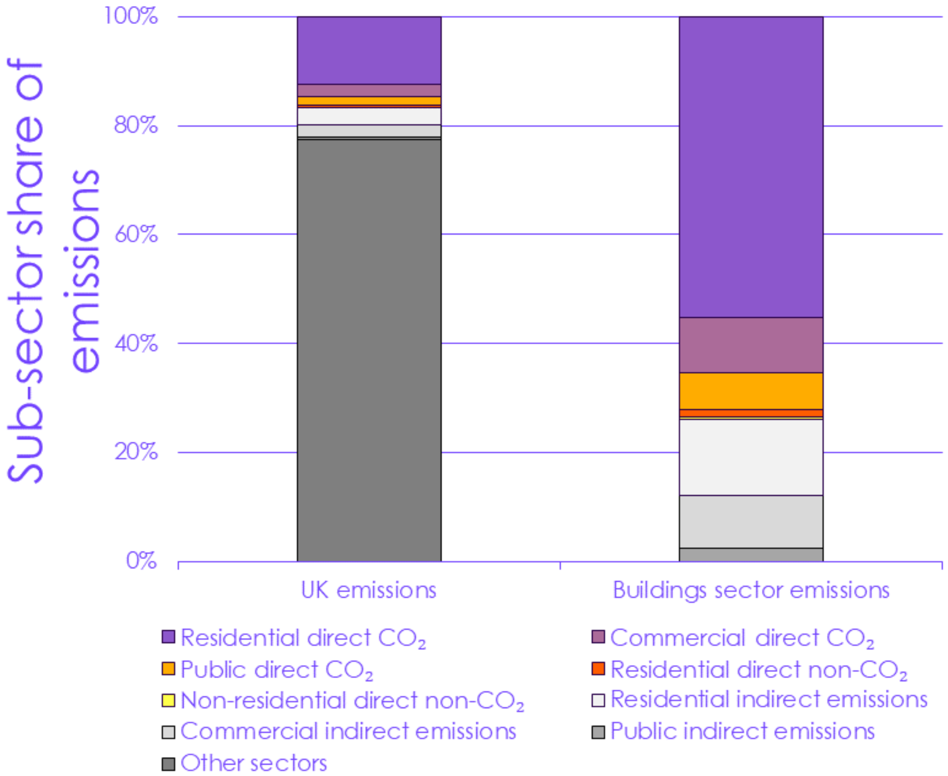
Direct greenhouse gas emissions from buildings were 87 $MtCO_2e$ in 2019, around 17% of the UK total.[2] Including indirect emissions, buildings account for 23% of the UK total (Figure M3.1):[3]

- **Direct building CO_2 emissions.** These were 85 $MtCO_2$ in 2019, split between homes (77%), commercial buildings (14%) and public buildings (9%).[4] Direct emissions in buildings result primarily from the use of fossil fuels for heating. Around 74% of the UK's heating and hot water demand in buildings is met by natural gas, and 10% by petroleum,[†] with smaller amounts of other fuels such as coal and biomass.[5]
- **Indirect building emissions**. Buildings are responsible for 59% of UK electricity consumption,[‡] equivalent to a further 31 $MtCO_2e$ of indirect emissions.[6] Most electricity use (counted as indirect emissions) stems from appliances and lighting in homes, and cooling, catering and ICT equipment in non-residential buildings.
- **Non-CO_2**. Around 1.4 $MtCO_2e$ of methane and 0.8 $MtCO_2e$ of nitrous oxide emissions were associated with buildings in 2019.[7] The use of nitrous oxide as an anaesthetic accounts for just under 0.6 $MtCO_2e$ of these emissions. Other non-CO_2 emissions are produced by fuel combustion processes.

[†] Includes heating oil and LPG.

[‡] Including a proportional share of intermediate consumption in the power sector.

Figure M3.1 Breakdown of buildings sector GHG emissions (2019)



Source: National Atmospheric Emissions Inventory (2020) *Breakdown of UK GHG emissions by source and greenhouse gas*; BEIS (2020) *DUKES, Electricity: commodity balances (DUKES 5.1)*.

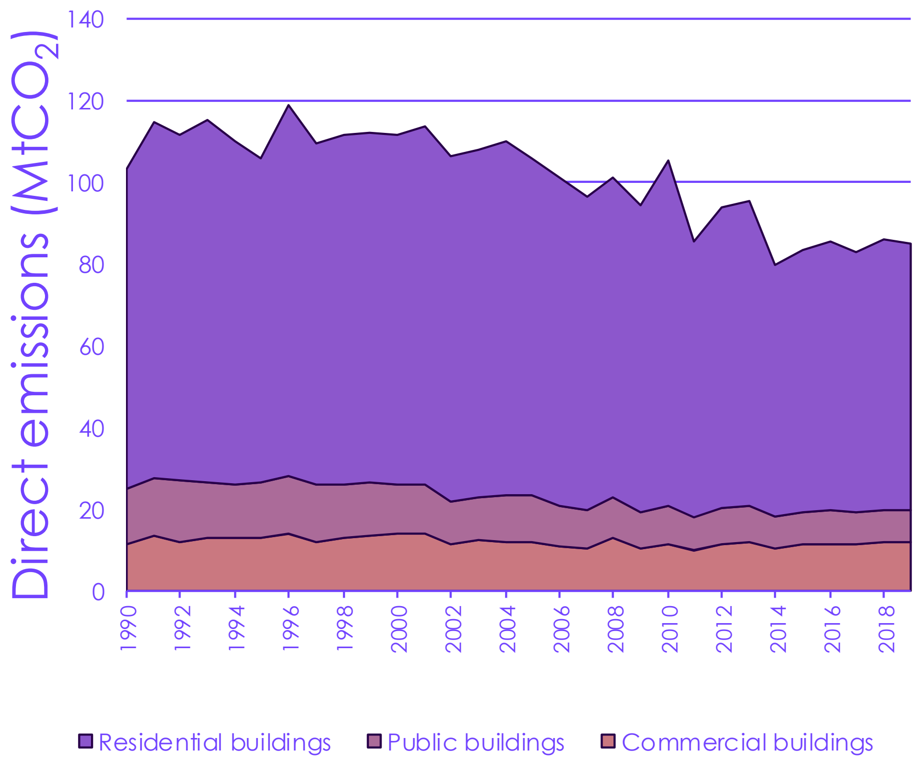
a) Trends and drivers

Direct emissions from buildings fell by 19% from 1990 to 2015 and have remained at a similar level since.

Direct emissions from buildings fell by 19% from 1990 to 2015 and (on a temperature adjusted basis) have remained at a similar level since then. Falls in emissions largely reflect energy efficiency improvements in buildings. Demand for gas and electricity has fallen by 16% and 14% since 2005 (Figure M3.2).[8,9] This means that despite energy price rises, household energy bills in 2016 were, on average, £115 cheaper (in real terms) than when the Climate Change Act was introduced in 2008.[10]

Indirect emissions from buildings have been falling at an average rate of 10% per year since 2009, due to both reductions in demand and the decarbonisation of electricity generation.[11]

Figure M3.2 Direct CO_2 emissions from the buildings sector since 1990



Source: National Atmospheric Emissions Inventory (2020) *Breakdown of UK GHG emissions by source and greenhouse gas.*

Opportunities to reduce emissions exist in four main areas: behaviour change, fabric energy efficiency, energy efficiency of lighting and appliances and switching away from fossil-fuel based heat.

In the buildings sector, there are opportunities for emission reductions in four main areas: behaviour change, increasing the energy efficiency of the building stock, improving the energy efficiency of lighting and electrical appliances, and switching away from fossil-fuel based heat.

In general, switching to efficient electric systems now delivers the largest readily available savings. These savings will grow steadily as the power sector continues to rapidly decarbonise.

a) Behaviour change

i) Residential buildings

There is significant potential to deliver emissions savings, just by changing the way we use our homes. Our Balanced Pathway for residential buildings finds that behaviour change can deliver operational cost savings in the region of £0.4 billion a year by 2050 (Box M3.1) and greater savings may well be possible.

Where homes are sufficiently well insulated, it is possible to pre-heat ahead of peak times, enabling access to cheaper tariffs which reflect the reduced costs associated with running networks and producing power during off-peak times. This means that pre-heating in particular can play an important role when switching to smart, flexible electric heating such as heat pumps with smart controls. If all homes with heat pumps pre-heated their homes, it would save an estimated £2 billion a year in a highly electrified scenario.[§]

Our analysis includes new evidence on pre-heating homes, smart heating management, hot water use and new business models such as heat-as-a-service propositions.

Box M3.1
Behaviour change evidence and assumptions in homes

There is a range of steps we can take to reduce and manage energy use in our homes, saving on both emissions and bills. We examine the following range of measures across our scenarios:

- **Turning off lights**: We assume that turning off lights when not in use can deliver annual electricity savings of 0.4 TWh by 2035. However this is dwarfed by the 5.4 TWh saved by deploying more energy efficient lighting in our scenarios relative to today.
- **Pre-heating**: Where homes are sufficiently well insulated, it is possible to pre-heat ahead of peak times. This enables access to cheaper tariffs which reflect the reduced costs associated with producing power off-peak and reducing requirements for network reinforcement to manage peak loads. Our scenarios assume that all new homes and between 25-50% of post-1952 homes can pre-heat, shifting their space heating consumption up to 4 hours ahead of peak and enabling access to cheaper energy prices as a result.[12]
- **Smarter heating management and use**: We assume a 3-6% reduction in heat demand can be achieved through more informed and smarter management of heating in existing homes. Smart meters and real time displays have been found to result in energy savings of around 3%, driven by associated actions such as turning the thermostat down or reducing the amount of time the heating is on.[13]

[§] CCC analysis drawing on Imperial (2018) *Analysis of alternative heat decarbonisation pathways* and based on the electrification scenario. We have made a conservative assumption in our Balanced Pathway and only assume that 25% of eligible existing homes (post-1952 homes) pre-heat. The number of homes with potential to pre-heat would be expected to be higher after insulation is applied.

- There is evidence that **multizone control** can drive higher savings – we make a conservative assumption that 6% heat demand savings can be realised through multizone control on the basis of analysis undertaken by the Energy System Catapult.**14 However, there is evidence to suggest the savings could be much higher.††,15 Public Health England recommend that homes should be heated to a minimum temperature of 18°C, with Age UK recommending the main living space in a home is heated to 21°C.[16]
- **Low-flow shower heads**: We assume widespread use of low flow shower heads across our scenarios, delivering a 5% reduction in heat demand.[17] These are also an important adaptation measure to prepare for the impacts of climate change, which will increase water stress in the UK.
- **Hot water temperature**: For the majority of our scenarios we assume a constant 60°C hot water temperature in existing homes. In our Widespread Engagement scenario, we assume a 50°C water temperature in homes with heat pumps, with allowance for a daily legionella cycle of one-hour duration. The Health and Safety Executive is currently undertaking work with the Chartered Institution of Building Services Engineers to look at guidance for low-temperature systems to manage legionella risk.
- **Water softening**: Build-up of limescale in a home's central heating system due to hard water can reduce the efficiency of heating systems. We therefore include measures for water softening in our scenarios.[18]
- **Heat as a service**: The Energy Systems Catapult has published evidence suggesting that guarantees around comfort levels and costs of heating could increase the consumer acceptability of low-carbon heat.[19] 'Heat as a service' delivery models can provide this, and involve consumers purchasing service bundles or 'outcomes' from providers (such as a certain number of warm hours) in place of kWhs of fuel. In our Widespread Innovation and Tailwinds scenarios, we assume that the heat-as-a-service delivery model proliferates in existing homes. Based on engagement with a range of stakeholders, we assume that this delivery model can be associated with 3% financial savings20 and a 15% increase in heat pump efficiency resulting from better installation and operation. We also assume that it is associated with a 7.5% commercial cost of capital and a 5% increase in energy consumption (reflecting losses associated with shifting time of use).[21]

Source: CCC analysis; Element Energy for the CCC (2020) Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget.

ii) Public and commercial buildings

Evidence for both behaviour change and energy efficiency potential for non-residential buildings has been drawn from the Building Energy Efficiency Survey (BEES).[22] These two categories of measures have not explicitly been separated in our analysis. BEES includes a number of measures with a strong behavioural aspect, for example, improved energy management, awareness campaigns and training and procurement practices.

** The majority of UK homes rely on a single room thermostat, located in a hall or living room, to control the temperature in the home. This often overrides local control by thermostatic radiator valves, causing underheating or over-heating. Multi-zone control uses digital wireless technology to enable temperature to be controlled using a thermostat and managed radiator control in each individual room, facilitating improved temperature management.

†† Research by the Energy Systems Catapult suggests gas usage reductions of up to 20% are possible, and research by Loughborough University suggests an aggregate saving of around 12% for the UK.

b) Efficiency

i) Residential buildings

Our scenarios examine the role a wide range of energy efficiency measures can play in reducing energy use in homes. We look at the potential for savings resulting from improving the efficiency of lighting in homes, and from the purchase of more efficient appliances.
For fabric energy efficiency in new homes, our scenarios build on the recommendations made by the CCC in our 2019 report *UK housing: Fit for the future?*, and assume ultra-high standards of energy efficiency in new homes from 2025 at the latest, delivered through measures such as triple glazing and high levels of airtightness.[23] We note that Government has signalled that they will bring forward the date of introduction to 2023, in line with our advice.[24]

For existing homes, we deploy measures such as loft, floor and wall insulation across our scenarios, as well as modelling low cost measures such as draught proofing and hot water tank insulation. Our Sixth Carbon Budget analysis is based on a comprehensive update of evidence, to underpin our modelling of energy efficiency retrofits (Box M3.2). This starts with the real-world performance of measures in homes, adjusted to reflect some closure of the performance gap.[‡‡] Previously, our Fifth Carbon Budget analysis was based primarily on a modelled assessment of performance, with adjustment factors applied.[25]

Measures to address thermal efficiency, overheating, indoor air quality and moisture must be considered together when retrofitting or building new homes. We therefore also examine illustrative cost ranges for shading and ventilation measures in addition to our scenarios. See Chapter 3 of our Advice Report for further discussion.

[‡‡] Regulations and monitoring metrics are focussed substantially on the modelled performance of dwellings as designed, rather than their actual performance 'as-built'. There is a large body of evidence which points to a substantial gap between the two. This is the 'performance gap'.

We also draw on new evidence of the technical potential, costs and performance of efficiency measures in the home. This is based on the National Energy Efficiency Database which looks at the impact of measures which have been installed to date.

Box M3.2
New evidence on fabric energy efficiency in existing homes

We have updated our energy efficiency assumptions in four key areas, relative to our previous work: technical potential, range of measures, costs, and savings. Our updated assumptions around costs and savings draw on a comprehensive assessment of the latest available evidence, undertaken by University College London.[26]

- **Technical and economic potential:** We have updated our assessment of the technical and economic potential for fabric energy efficiency measures in the UK housing stock, based on the latest Government statistical releases, data from housing surveys, and research on the prevalence of non-standard cavity walls and lofts.[§§,27] Despite some progress having been made in insulation installations, the assessment has led to an overall increase in the assumed technical potential for lofts and cavities relative to the Fifth Carbon Budget. Amongst other changes, the latest assessment reflects new evidence from the National House Building Council that 72% of homes built from 1991-1995 were built with unfilled cavity walls (previously assumed to be insulated).[28] While technical potential for cavities and lofts has increased, our assessment of economic potential has remained broadly similar (Table B3.2). Our assessment of economic potential is informed by new evidence on the prevalence and cost of treating non-standard cavity walls and lofts.
- **Range of measures**: We have updated the range of energy efficiency measures modelled relative to our work for the Fifth Carbon Budget and Net Zero report. Key changes include the incorporation of new and emerging evidence on the costs and performance of thin internal wall insulation, and a first step in modelling deep whole house retrofits.[29]

We have also separately modelled ranges of costs which could be associated with delivering ventilation and overheating measures to accompany our scenarios, necessary as part of a holistic approach to retrofit (Box 3.2.a, Sixth Carbon Budget Advice Report).

- **Energy savings associated with measures**: UCL's assumptions for the savings associated with measures are drawn primarily from the Government's National Energy Efficiency Data (NEED) Framework.30 The data framework matches gas and electricity annualised meter data, with data on energy efficiency measures installed in homes from the Homes Energy Efficiency Database (HEED), Green Deal, the Energy Company Obligation (ECO) and the Feed-in Tariff scheme. The results are then weighted to produce statistics representative of the whole housing stock. While real world performance data are expected to improve the accuracy of modelling, they are representative of past and current practice and therefore have the potential to underestimate the future performance of measures where improvements are delivered in installation practices and use. Our scenarios are predicated on best-practice delivery and we therefore assume some uplifts to savings associated with closing the performance gap, modelled as uplifts based on in-use factors.[31]
- **Costs associated with measures**: UCL's cost assumptions draw on the latest available evidence, including the 'What does it cost to retrofit homes?' research undertaken by Cambridge Architectural Research for BEIS, and research from the Energy Savings Trust on the costs of insulating non-standard cavities and lofts.[32] This has been supplemented with evidence on supplementary costs such as scaffolding and survey and design, and by additional evidence from field trials, case study data and discussions with retrofit professionals (Table B3.2).

While assumptions draw on the best available evidence, there remains uncertainty over the costs and savings associated with measures. Importantly, energy efficiency must be viewed in the context of the substantial wider benefits which can be delivered (discussed further in Chapter 3 of the Sixth Carbon Budget Advice Report).

§§ Technical potential represents the number of measures which could technically be applied across the UK stock. Economic potential represents a subset, examining only those measures deemed to be deliverable at reasonable cost. We generally excluded measures from our economic potential where costs came in above £700/tCO_2e for a typical home (assumed to be a medium semi-detached home, scaffolding and design costs not included in calculations for economic potential). Some non-standard lofts and cavities were excluded on this basis and our economic potential includes only the following non-standard categories: standard lofts with access issues, cavity walls in concrete dwellings, cavity walls with conservatories, narrow cavities, and high cavity walls. Glazing is not modelled, apart from in deep retrofits, but current rates of upgrade would be assumed to continue.

These factors have led us to model a range of energy efficiency uptake levels across our scenarios.

Table B3.2
Energy efficiency assumptions for key measures in existing homes

	Technical potential (millions of homes)	Economic potential (millions of homes)	Costs for a semi-detached home (£)	% reduction in space heat demand for a semi-detached home
External wall insulation	7.4	7.4	8590	18%
Internal wall insulation			7320	15%
Cavity wall insulation (easy to treat)	5.9	3.1	630	10%
Cavity wall insulation (hard to treat)			2480	
Loft insulation (easy to treat)	13.3	10.8	440	4%
Loft insulation (hard to treat)			740	

Notes: Economic potential represents measures modelled. Costs are in £2019 and rounded to the nearest 10. Costs do not include scaffolding (assumed to be incurred for external wall insulation) or design and planning costs (assumed to be incurred for all solid wall insulation). We assume costs of £986 and £1352 respectively in a semi-detached home. NEED savings have been adjusted to be set against a space heat demand baseline (after accounting for behavioural measures, but before any performance gap adjustment) and will differ from published percentage savings in NEED (which are calculated against total gas demand). Loft savings are based on the average savings in NEED, representing a combination of virgin loft insulation and top-ups. For a semi-detached dwelling with loft insulation of <100mm, savings are assumed to be 7.6%, while for a dwelling with 100-199mm of existing insulation a top-up is assumed to deliver 1.9% savings.

Source: CCC analysis; UCL (2020) Analysis work to refine fabric energy efficiency assumptions for use in developing the Sixth Carbon Budget; Element Energy for the CCC (2020) Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget.

ii) Public and commercial buildings

Evidence for energy efficiency potential in public and commercial buildings is drawn from BEES. This includes measures such as improved fabric efficiency, upgrades to lighting and cooling equipment, controls and metering. Our analysis excludes abatement potential in BEES from industrial buildings (which fall outside the scope of this sector) and abatement potential associated with upgrading space heating plant which we consider may overlap with our analysis of heat decarbonisation. We also exclude some of the highest cost measures (see Box 3.6).

c) Low-carbon heat

i) Residential buildings

There is broad scope for variation in the overall heat mix, and in the precise mix of technologies deployed.

Analysis for our 2018 report *Hydrogen in a low-carbon economy* found that a range of pathways for heat decarbonisation, based on low-carbon hydrogen and/or electrification, have similar costs. On this basis we model a range of pathways for decarbonising heat, with the key objective being to develop a balanced emissions trajectory which can be met in different ways, but which drives sufficient progress in the next decade to keep options open.

There is broad scope for variation in the overall heat mix, and in the precise mix of technologies deployed. Our scenarios include illustrative mixes of a wide range of technologies, including low-carbon district heat networks (Box M3.4), air source heat pumps (ASHPs) and ground source heat pumps (GSHPs), resistive and storage heating, solar thermal, and hydrogen technologies including hydrogen boilers and hydrogen hybrid heat pumps. We also model thermal storage in homes.

Our assessment of the economy-wide best use of biomass indicates that use in buildings should be minimised as far as possible.[33] Some scenarios exclude a role for biofuels. Others include a limited role, restricted to use in hybrid configurations alongside heat pumps in the hardest-to-heat off-gas homes, such that biofuels provide a back-up role in meeting peak demands on the coldest winter days.***

Our analysis for homes makes use of the latest available evidence to inform techno-economic assumptions, tested with experts from industry and Government.

We have used the latest available evidence, and input from BEIS and a range of industry stakeholders, to update our assumptions on technology sizing, costs and lifetimes (Table M3.1). We have expanded the range of technologies modelled relative to our previous work. We have refined our modelling of ground source heat pumps and included a greater variety of hybrid heating configurations (including solar thermal). We have also tested the impacts of widespread deployment of high temperature heat pumps in our Widespread Innovation scenario. Finally, we have extended the analysis to improve our representation of differing levels of flexibility in homes.

Table M3.1
Heat technology assumptions used in our residential analysis for existing homes in 2020

	Efficiency	Lifetime (years)	Fixed cost (£)	Variable cost (£)	Opex (£/year)
Air source heat pumps*	300%	15	4,430	370	100
Ground source heat pumps*	326%	20	9,070	530	100
Hybrid heat pumps**					
With hydrogen	See respective components		5,940	370	160
With biofuels			6,370	370	220
Hydrogen boiler	80%	15	2,960	N/A	100
Biofuel boiler	84%	15	3,130	N/A	100
Electrification (storage heater)	100%	15	N/A	780	100
Gas boiler	87%	15	2,860	N/A	100
Oil boiler	84%	15	3,130	N/A	100

Notes: Costs are in £2019 and rounded to the nearest 10. Boiler costs presented for a 24kW boiler. * Heat pump efficiencies represent the combined SPF assumed for 2020 at 40°C flow temperature (the weighted average flow temperature for heat pumps in our Balanced Pathway). ** While both GSHP and ASHP hybrids were tested in the modelling, ASHP hybrids were found to be more cost effective and are therefore the variant we present here.

*** Our scenarios include a simplified representation and use liquid biofuels in place of solid biomass on the basis that the former is expected to be more conducive to functioning in a hybrid heat pump configuration. Solid biomass combustion can also have negative air quality impacts relative to biofuels.

ii) Public and commercial buildings

Our Sixth Carbon Budget scenarios explore a range of decarbonisation routes for public and commercial buildings, with a varying balance between electrification and hydrogen. We see low-carbon district heat networks providing a significant share of public and commercial heat demand and serving as key anchor loads for networks. This is equivalent to around 22% by 2035 and 42% by 2050 in the majority of our scenarios. Our analysis of district heating is based on a refresh of evidence commissioned for our Fifth Carbon Budget analysis (Box M3.4). Our Widespread Innovation scenario explores lower district heat deployment, with a higher share of building level technologies.

Our analysis of building level heat is based on an illustrative selection of technologies including air-to-air heat pumps, low temperature air-to-water heat pumps, resistive electric heating and hydrogen boilers. Our energy and cost analysis uses air source heat pumps as an illustrative example, but in practice a wider range of technologies is available and could represent a part of the mix, for example ground source heat pumps, high temperature air-to-water heat pumps, hybrid heat pumps with biofuels, or in some limited cases, biomass boilers making use of local biomass sources or biogenic wastes. As a principle however, we have not included biomass boilers as a replacement technology for public or commercial buildings over the Sixth Carbon Budget period, based on our view that biomass resources could be better used as part of engineered removals or in other sectors where alternatives are limited. This is a slightly different approach than in homes, where there is a greater need for hybrid-based solutions, based on stakeholder feedback.

Our assumptions on heat technology technical potential, efficiencies, lifetimes and costs are primarily drawn from new research commissioned by BEIS for non-residential buildings in England and Wales (Box M3.3). We apply the evidence drawn from this study to UK heat demand in our analysis. Assumptions on capacity and load factors are mainly drawn from our Fifth Carbon Budget analysis.

We have drawn on new evidence commissioned by BEIS on the performance, cost and technical suitability of heating options in public and commercial buildings.

Box M3.3
New evidence on Heating, Ventilation and Air Conditioning (HVAC) technologies in non-domestic buildings

This study was commissioned by BEIS to determine the potential across England and Wales to reduce carbon emissions by implementing low-carbon space heating, hot water, ventilation and cooling (HVAC) technologies in non-domestic buildings. The study provides an evidence base on the applicability and cost effectiveness of low-carbon heat measures.

This study is based on data gathered in BEES on HVAC systems currently in the stock. A framework for reinterpreting the BEES data and predicting the HVAC servicing arrangements for each building within the BEES dataset was developed; resulting in the records being categorised into a set of building 'archetypes' with common HVAC characteristics.

Information on low-carbon HVAC system costs and performance was gathered through a literature review (involving detailed review of 52 sources) and industry engagement (including supply chain interviews and eight sub-sector deep dive interviews) to validate the data collected and fill gaps. The evidence gathered was used in modelling to quantify the potential to save carbon emissions from switching to low-carbon HVAC technologies, mapping potential options to archetypes.

A validation process tested the findings with external experts, including engaging a panel of experts through a project approach review workshop and commissioning an industry expert for a detailed review of the modelling inputs and outputs.

Our assumptions on technical potential are taken from data drawn from the study. This indicates the heat demand that can be met by each potential technology for each BEES sub-sector, split by whether the existing heating system is deemed 'abated', 'wet' or 'dry'. We use the BEES sub-sectors to map the technical potential against our public/commercial split of demand.

Table B3.3 shows the efficiency, lifetime and cost assumptions we have used in our analysis which are predominately drawn from the evidence base generated in this study. The main exception is that we have used a 15-year lifetime for hydrogen boilers, rather than 12 years as indicated in this study, for consistency with gas boilers and our view on hydrogen boilers in our residential analysis.

Table B3.3
Heat technology assumptions used in our analysis

	Efficiency*	Lifetime (years)	Capex (£/kW)	Opex: excluding fuel (£/kW)
Air-to-air heat pump	283%	20	772	9.6
Air-to-water heat pump (low temperature)	283%	20	1,530	6.2
Hydrogen boiler	86%	15	414	6.0
Electrification (direct heat)	100%	15	206	3.0
Biomass boiler	78%	20	666	12.9
Gas boiler	86%	15	200	6.0
Oil boiler	86%	20	238	6.1

Notes: * In situ performance coefficient. Evidence was taken from provisional assumptions of the forthcoming study. The cost base year is 2019. Opex includes routine maintenance, but not fuel which is accounted for separately. The capex figures stated are used for 2020 and reductions are applied to some technologies from this point (see Section 1.3.c). Our capex assumption for biomass boilers is drawn from the renewal costs provided within the HVAC study, rather than for new installations, since we only include it as a counterfactual technology and there is a large difference between new and renewal costs in this study.

Sources: CCC analysis; Verco for BEIS (forthcoming) Low carbon Heating, Ventilation and Air Conditioning (HVAC) technologies in non-domestic buildings.

Box M3.4
Low-carbon district heat

In 2015 we commissioned a consortium led by Element Energy, and including Frontier Economics and Imperial College London, to undertake detailed analysis of the cost-effective potential of low-carbon heat networks in the UK to 2050.[34]

The work included a review of district heating, thermal storage and district cooling, along with considering the transition over time to both low-carbon and low-temperature heat networks. Scenarios were developed for our Fifth Carbon Budget advice based on detailed spatial analysis of supply options, combined with spatial analysis of demand.

These scenarios have been refreshed for the purposes of the Sixth Carbon Budget:

- We have updated the supply mixes to ensure they are Net Zero compatible. For the majority of scenarios, we model a fully electrified heat supply mix dominated by water- and sewage-source heat pumps and waste heat from industrial sources. Recent examples of large-scale heat pump solutions include London, Glasgow and the whole town of Drammen in Norway.[35] For our Headwinds scenario, we model an electrified supply mix which retains gas peaking capacity – transitioning to hydrogen over time.
- The majority of current district heat networks use gas Combined Heat and Power (CHP) to generate heat. These heat networks are expected to transition to low-carbon heat sources over time. Our deployment, energy and emissions scenarios take a simplified approach of modelling district heat deployment only at the point at which it becomes low-carbon. Heat network deployment in our scenarios is therefore more limited in early years than is expected in reality, with additional deployment being seen in later years to represent the point at which legacy CHP schemes convert to low carbon sources.
- For the purposes of calculating investment costs over time, we reapportion some network capex to reflect better the fact that a proportion of heat networks are expected to be built with gas CHP in the near-term. For the purposes of calculating costs, we have also updated the timeframe over which network capex is incurred from 20 years to 40 years. After this point, renewals would be expected.
- We assume that the pace of deployment over the next five years is slower than in our Fifth Carbon Budget scenarios. However, similar to the Fifth Carbon Budget, we assume that approximately 18% of homes are assigned to district heat by 2050 (representing the homes in areas of highest heat density). Public and commercial buildings have lower levels of uptake, reflecting new heat demand projections. We assume that from 2025 all new district heat connections are low-carbon, and that legacy gas CHP schemes convert to low-carbon sources between 2033 and 2040.
- In commercial and public buildings, we include a stylised scenario with lower deployment of district heat in our Widespread Innovation scenario; where district heat makes up 14% of heat demand by 2035 and 27% by 2050, compared to 22% by 2035 and 42% by 2050 in our Balanced Pathway.

Source: Element Energy, Frontier Economics, Imperial College for CCC (2015) *Research on district heating and local approaches to heat decarbonisation*; Element Energy for CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget.*

Our scenarios explore a range of future worlds, including ones with higher levels of innovation and behaviour change.

Our starting point for the analysis is the 2019 Net Zero report, which showed that the Net Zero target means eliminating buildings emissions by 2050.

We have used bottom-up analysis to produce a set of pathways to zero emissions from buildings in 2050.

Our starting point is current Government policy. We then look at the impacts of a range of additional policy levers, including phase-out dates for fossil fuel boilers.

We use the scenarios to explore a range of different futures, including ones with higher levels of innovation and behaviour change. We work on the basis of an underlying aim to minimise costs and disruption for households and businesses, working with technology lifetimes to minimise scrappage. In determining the pathways, we have also tested a range of regulatory policy levers as well as new business models. Our starting point is current Government policy. We then look at the impacts of a range of additional policy levers, including phase-out dates for fossil fuel boilers. Our scenarios aim to simulate what can be achieved under an ambitious and effective wide-ranging policy package that deals decisively with the various barriers to action.

Our analysis is split by residential and non-residential buildings, with low-carbon heat network pathways based on buildings-wide analysis produced for the Fifth Carbon Budget, which has been refreshed.

The following sections cover the analytical methodology behind our scenarios, our approach to deriving pathways for the devolved administrations and our approach to uncertainty (including impacts of COVID-19).

a) Analytical methodology

i) Residential buildings

Our 2019 analysis demonstrated that getting to very low levels of emissions in residential buildings is possible. For the purposes of the Sixth Carbon Budget, we have modelled paths which reach zero by 2050.[†††]

We commissioned new modelling of pathways for existing homes, and produced in-house analysis covering new homes and electrical efficiency measures.

Our Sixth Carbon Budget scenarios for residential buildings are composed of five analytical workstreams, looking at decarbonisation pathways for heat in existing homes, heat in new homes, appliance efficiency, the decarbonisation of gas cooking, and the decarbonisation of household and garden machinery. The modelling for the decarbonisation of heat in existing homes draws on a project by Element Energy (Box M3.5), while the latter four analytical workstreams draw on in-house analysis.

For energy efficiency and heat in existing homes, we started by looking at different 2050 mixes, where we explored balances of behaviour change, fabric efficiency, and fuel-switching. We then determined pathways for decarbonisation, starting with current Government policy and considering additional levers on top of this. Our analysis was designed to respect the limits of feasibility and desirability for consumers (considering plausible ranges of behaviour change and technology uptake) and to allow time for supply chains and skills to ramp up (incorporating assumptions for deployment constraints amongst other things).

[†††] There remain a very small volume of emissions in all of our scenarios (<1Mt) associated with limited use of biofuels, house fires, and non-aerosol household products.

Boiler lifetimes of around 15 years imply a need to scale up markets and supply chains for low-carbon heating to cover all new installations by the mid-2030s at the latest, if the Net Zero target is to be met. The pace of decarbonisation across our scenarios is therefore led by dates for regulated phase out of new fossil fuel boilers, in areas not designated for hydrogen or district heat conversion.

Box M3.5
The development of trajectories for residential heat decarbonisation in existing homes

We commissioned Element Energy to develop scenarios for the deployment of energy efficiency and decarbonised heat in existing homes, to inform our Sixth Carbon Budget advice. This work represents an update to, and extension of, the work they undertook for the CCC in 2019 to inform our advice on setting a Net Zero target.[36]

Element's modelling is based on an improved and updated building stock model of the UK, built around regional national housing survey data for England, Scotland, Wales and Northern Ireland, Energy Performance Certificate Data, and a range of other statistics and datasets.

As discussed in section 2, the modelling is underpinned by comprehensive updates to assumptions relating to energy efficiency and low-carbon heat, where new evidence has become available. It is aligned with Green Book assumptions on cost of capital and discount rates, with a 3.5% cost of capital applying for most scenarios, and 7.5% applying where heat-as-a-service is modelled.

The modelling uses a baseline calibrated to 2018 emissions and energy use data and takes into account improvements in boiler efficiency over time. The baseline has been adjusted to account for a 6.6% reduction in heat demand to 2030, in order to reflect near-term projections for the impacts of climate change in the UK (see Box 3.8 for further discussion).

The model was used to calculate end states for 2050 across scenarios, comprising of behavioural measures, energy efficiency measures and a low-carbon heating system for every home in the UK. The end states in our scenarios are informed by a number of considerations. These include:

- **Cost effectiveness.** We tested those mixes of energy efficiency and low-carbon heat which could deliver lowest lifetime costs, on a net present value basis, over a 20-year time horizon. This differs from the definition used for our Fifth Carbon Budget scenarios, which used target consistent carbon values to evaluate the point at which technologies would become 'cost-effective' relative to these carbon values.[‡‡‡]
- **Wider benefits**. We considered wider benefits when determining what mix of measures and technologies to deploy. In particular, across all scenarios we deployed additional energy efficiency measures in order to help address fuel poverty, and in a number of our scenarios (including the Balanced Pathway) we deployed additional energy efficiency beyond this to reflect wider benefits including to comfort and health.
- **Consumer preferences.** We tested a range of behavioural measures, heating mixes and household flexibility levels across scenarios, reflecting variations in consumer and societal preferences.

Deployment trajectories were then developed. Uptake trajectories have been bounded by assumptions on deployment constraints for all key technologies. These constraints were developed using the latest available evidence and tested with industry experts.

Beyond these constraints, the trajectories are based around a regulated approach, reflecting feedback in our call for evidence that regulation is a key pillar for delivery. We

[‡‡‡] Carbon values represent a cost of carbon to the economy, and are used as part of HMT Green Book appraisal. The CCC Fifth Carbon Budget carbon values are based on a rising cost of carbon over the next decades, increasing to over £200/tCO2e by 2050. For further detail, see CCC (2015) *The Fifth Carbon Budget*.

took our starting point as current Government policy – in particular the plans to improve the energy efficiency of all buildings over the next 10-15 years, and the plans to phase-out the installation of new high-carbon fossil fuels in the 2020s.
We then modelled additional levers on top of this, testing a range of phase-out dates for the installation of fossil fuel boilers. These phase-out dates drive uptake of electrified technologies on and off the gas grid.

Separate trajectories were developed for uptake of hydrogen and low-carbon district heating. For hydrogen, an uptake trajectory was developed to reflect hydrogen grid conversion, led by use of hydrogen in industrial clusters. For low-carbon district heat, our Fifth Carbon Budget scenarios were used as a basis, and updated to reflect slower progress in the early years, with CHP phase out for new low-carbon heat networks in 2025, and conversion of all legacy schemes to low-carbon sources by 2040 (Box 3.4).

Source: CCC analysis; Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget*.

Our scenarios for the decarbonisation of heat and energy efficiency measures in new homes build on the recommendations made in our 2019 report *UK housing: Fit for the future?*, and assume that from the mid-2020s at the latest, no new homes are connected to the gas grid and instead are built with ultra-high energy efficiency standards and heated through low-carbon sources (either heat pumps or district heat). Our scenarios draw heavily on analysis undertaken for the CCC by Currie Brown and Aecom in 2019.[37] The following key assumptions underpin the new build analysis:

- We assume that build rates profile up to meet Government new build commitments of 300,000 homes per year by the mid-2020s in England, with rates held constant for the devolved administrations. Projections thereafter follow a profile developed by Element Energy for the Fifth Carbon Budget.
- We assume that any homes built between now, and the date at which regulations on low-carbon heat come into force, must be retrofitted with low-carbon heat at the point of heating system renewal.
- All new build homes are assumed to pre-heat and therefore be capable of accessing lower electricity costs.
- We model costs on the basis of modelling undertaken by Currie & Brown which uses a 7.5% cost of capital for one year.[38] We take a simplified approach of modelling costs in representative years for ten different house types, including homes and flats using different low-carbon heating systems and at different levels of energy efficiency.

Our Sixth Carbon Budget scenarios for lighting and appliance efficiency in homes draw on analysis undertaken for the Fifth Carbon Budget, updated to better align with evidence on the heat replacement effect and to reflect updated assumptions on electricity costs and the rate of decarbonisation.[§§§]

We separately model the decarbonisation of gas cooking appliances (2.1% of residential direct emissions), and household and garden machinery (0.6% of residential direct emissions).

We assume that gas cooking appliances are replaced with electric appliances in most scenarios. Our calculations conservatively assume the efficiency levels of conventional electric hobs, although induction hobs are increasingly popular, and

§§§ The heat replacement effect occurs because as lighting and other electricity products become more efficient, they produce less waste heat. Our assessment allows for a small amount of additional heating requirement.

provide superior performance and greater efficiency savings where suitable. In Headwinds we assume that gas cooking appliances are mainly replaced by hydrogen appliances.
Hydrogen cooking appliances are expected to provide similar performance to gas cookers and could be used wherever the gas grid is converted. The timeframes for cooking decarbonisation are aligned with the dates of phase out for new gas boiler sales and with hydrogen switchover trajectories in the Headwinds scenario.

We assume that the phase out of petrol and diesel household and garden machinery (such as lawnmowers, garden tractors, and hedge trimmers) is aligned with the phase out of petrol vehicles in the transport sector (i.e. all new sales are zero-carbon from 2032 at the latest in our Balanced Pathway).

ii) Public and commercial buildings

All our non-residential scenarios are based on buildings reaching near-zero emissions ahead of 2050.

All our scenarios are based on non-residential buildings reaching near-zero emissions ahead of 2050. As in our Net Zero analysis, the main source of remaining emissions in 2050 is N_2O used for anaesthesia, which seems relatively costly to abate by replacement. We note the NHS now has a target to reduce these emissions by 40% by 2050 as part of its strategy for delivering a Net Zero emission health service.[39] We plan to undertake further work in this area in the future.

Our baseline energy demand is primarily based on BEIS' Energy and Emission Projections.[40]. These are stylised and do not take account of any potential changes in trends associated with increased home-working resulting from the COVID-19 pandemic (see Box 3.7).

As in our Net Zero analysis, the main source of remaining emissions in 2050 is N_2O used for anaesthesia, which seems relatively costly to abate by replacement.

Our scenarios are grounded in current policy. For example, we use expected dates for the phase out of high-carbon fossil fuel heating such as oil, based on policy. We assess our rollout profile of energy efficiency against relevant commitments such as the Government's goal to enable businesses and industry to improve energy efficiency by at least 20% by 2030 and its aim to reduce public sector emissions by 50% by 2032 against 2017 levels.

We then develop a pathway based on the pace of hydrogen conversion of the grid, district heat development and boiler stock turn over for buildings assumed not to convert to hydrogen or district heat. We apply different dates where no new gas boilers would be installed across our scenarios reflecting the potential for regulated phase out of fossil fuels. Each of these ensures that gas is fully phased out before 2050 through natural replacement cycles.

The non-residential buildings analysis was approached by reducing baseline emissions in the following sequence: subtracting energy savings from behavioural measures and energy efficiency, allocating a share of remaining heat demand to district heating, then analysing fuel-switching and improved system efficiency for remaining building-level heat and catering and other fossil fuel demands.

The level of energy savings reached at maximum deployment from behavioural measures and energy efficiency is held constant across scenarios. We vary the profile over which the savings develop according to scenario and the value of the savings varies across scenarios according to different energy prices. Our method of deriving energy savings from BEES and our cost methodology for energy efficiency is described in Box 3.6.

Hydrogen rollout aligns to the pace in homes and is informed by our industrial analysis.

After accounting for reduced heat demand following energy efficiency and uptake of district heating, we consider the mix of technologies for the remaining heat demand.

- We align the uptake of hydrogen boilers in public and commercial buildings to the share of on-gas homes (excluding district heat) that convert to hydrogen in the residential analysis. We assume that grid conversions radiate out from industrial clusters.

- For the share of remaining buildings not assigned to convert to hydrogen, we model uptake of heat pumps and resistive electric heating based on turnover from our assumed phase-out dates.

- Our interpretation of the HVAC study technical potential implies all wet-based systems (gas, oil and biomass boilers) convert to air-to-water heat pumps, while dry systems (resistive electric heating) convert to air-to-air heat pumps, and localised gas heating systems such as found in storage facilities convert to a mixture of air-to-air heat pumps and resistive elective heating.[41]

- The costs of providing heat output with each technology are shown in Table M3.2. This is the smoothed cost over the technology lifetime for an installation in a given year, incorporating our assumptions on capex, opex, fuel costs and efficiencies of each technology.

Table M3.2
Levelised cost of energy for heat technologies installed each year

	Public (£/MWh)		Commercial (£/MWh)	
	2030	2050	2030	2050
Air-to-air heat pump	42	39	48	44
Air-to-water heat pump (low temperature)	77	69	95	85
Hydrogen boiler	85	85	90	90
Electrification (direct heat)	80	74	82	76
Biomass boiler	57	57	64	64
Gas boiler	42	42	44	44
Oil boiler	63	64	66	68

Notes: Cost of capital of 3.5% assumed for public sector and 7.5% assumed for commercial.

After applying energy efficiency, we model the gradual replacement of fossil fuels for catering and other uses.

- We assume that fossil-fuel appliances are replaced with alternatives on reaching the end of their life. Assuming a 15-year lifetime, fossil-fuel appliances are therefore phased out at a linear rate over 15 years following the phase-out date for each fuel.

- Natural gas is replaced by a mix of electricity and hydrogen, which varies between scenarios. Other fossil fuels are assumed to be replaced by electrification.

- We assume that the efficiency of hydrogen and gas appliances is identical. We apply an efficiency saving for converting to electric catering equipment, based on the efficiencies of different types of appliance, weighted by their current aggregate annual consumption.

- Other uses mainly involve the heating of water (e.g. for swimming pools and hospital steam systems). We make the conservative assumption that these are replaced by resistive electric heating (in practice, heat pumps are used increasingly as a source for swimming pools globally).
- Cost estimates for converting catering and other fossil fuel uses are based on fuel costs alone. We assume that other running costs and capital expenditure are identical to fossil fuel equipment.

We use evidence from BEES to assess the potential energy savings and costs associated with behavioural and energy efficiency measures.

Box M3.6
Using the Building Energy Efficiency Survey

The Building Energy Efficiency Survey (BEES), commissioned by BEIS, reports on the energy use and potential for reduction in energy use in non-residential buildings in England and Wales in 2014-15. Abatement potential for a 39% reduction from current energy consumption was identified.

Our analysis excludes abatement potential in BEES from industrial buildings (which fall outside the scope of this sector) and abatement potential associated with upgrading space heating plant which we consider may overlap with our analysis of heat decarbonisation.

Since the BEES data are for England and Wales only, we scale the abatement potential and baseline energy consumption in BEES upwards to reflect inclusion of Scotland and Northern Ireland in our analysis. We do so with a scaling factor derived from sub-national energy consumption data for electricity and gas (which is applied to non-electric energy).

We compared the adjusted baseline energy demands from BEES with the baseline energy developed for our analysis which is based on BEIS' *Energy and Emission Projections (EEP)*: [42]

- This showed the adjusted BEES baseline energy demand was significantly lower that our baseline for 2018, particularly for non-electric energy consumption.
- The disparity grows through time with static BEES data and generally an upward trend to EEP, so the difference would be larger by the time we assume the savings are delivered (some point in the early 2030s).****
- We have applied uplifts of 35% and 20% to commercial and public non-electric abatement potential respectively. This makes up for only a share of the baseline discrepancy which we judge to be a conservative approach reflecting that not all the abatement potential identified might be representative of all non-residential energy demands (e.g. in other locations) and that growth in baseline demand over time will be driven by a range of factors (including new build).

We have excluded some of the most expensive measure categories in BEES from our analysis based on cost:

- We have excluded humidification, small appliances, ventilation, air conditioning and cooling, and building services distribution systems. This reduces non-electrical energy savings marginally and electrical energy savings by around 23%.
- We consider that where electrical energy savings would have a high abatement cost over the carbon values, this may be better dealt with through the electricity supply side where electricity will be very low carbon in later years.

**** The projections show strong growth in commercial electricity consumption and public gas consumption, slight growth in commercial gas consumption and declining public electricity consumption.

- We have made exclusions based on cost only at the category level, so we may be excluding some measures within this that would not be prohibitively expensive (i.e. over around £150/tCO_2e in 2030).

We include 51.6 TWh of energy savings per year from the date when energy efficiency measures are fully deployed in our modelling.

This represents a 27% reduction compared to our 2018 baseline. In our Balanced Pathway this translates to a reduction in commercial energy consumption of 26% in 2030 relative to 2018. This exceeds the overall commercial and industry goal of 20%, since we understand the commercial sector is likely to take on a larger share of this effort due to greater abatement potential. The level of savings drawn from different measure categories is shown in Table B3.6.

We estimate capex and opex associated with energy efficiency measures at BEES measure category level (e.g. building fabric, lighting) and use a representative lifetime for each category informed by the BEES data, weighted by category of measure (Table B3.6). We then estimate abatement costs for each of the segments of energy efficiency abatement in our analysis by using the measure category costs weighted by the share of energy savings it contributes to our abatement segment. Investment costs are based on the total capex for each measure category spread across its assumed lifetime and assigned across relevant abatement chunks. We make the conservative assumption that annual investment costs associated with energy efficiency continue throughout the period of our analysis to reflect renewals.

Table B3.6
Energy efficiency savings and costs using our analysis

	Annual electricity savings (GWh/year)	Annual non-electric savings (GWh/year)	Capex for initial deployment (£ million)	Opex for initial deployment (£ million)	Lifetime (years)
Building instrumentation and control	1,800	10,360	3,000	100	6
Building fabric	1,160	7,840	7,630	-	20
Carbon and energy management	5,100	8,110	1,820	60	3
Lighting	9,500	-	4,550	190	10
Refrigeration	2,390	-	1,410	-	7
Swimming pools	130	780	430	1	5
Space heating	400	3,890	1,070	15	7
Hot water	60	140	110	-	10
Total	**20,520**	**31,120**	**20,020**	**365**	

Notes: Figures may not sum to totals due to rounding.
Sources: CCC analysis; BEIS (2016) *Building Energy Efficiency Survey*.

b) Deriving the paths for the devolved administrations

The pathways for the devolved administrations have been derived using a combination of top down approaches with a detailed bottom-up assessment for heat and energy efficiency in existing homes.

The pathways for the devolved administrations have been derived using a combination of top-down approaches based on key metrics, and some more detailed workings for existing homes. Northern Ireland sees a faster decarbonisation pathway as a result of the higher proportion of homes off the gas grid (Figure 3.3).

For heat decarbonisation in existing homes, our analysis is based on a building stock model of the UK which incorporates regional national housing survey data for England, Scotland, Wales, and Northern Ireland providing an estimate of the breakdown of physical attributes and existing heating systems across each of those three administrations.

Our scenarios do not differentiate between the devolved administrations in terms of the regulatory levers applied, although it remains the case that there is scope for higher levels of ambition to be pursued. The remainder of our modelling for homes uses 2018 statistics on the number of dwellings to infer a split of decarbonisation across the devolved administrations.

For non-residential buildings, the emissions and energy baselines and pathways for the devolved administrations are based on current shares of non-residential direct emissions. At the level of individual measures and fuels the method is a simplification since the current shares for individual fuels may deviate from aggregate emissions for a sector.

- Differing shares were applied for the public and commercial sectors.
- Emissions, energy demand, direct and indirect abatement, and investment costs are split across the devolved administrations using the same method.
- Costs per tonne of abatement are assumed to be identical across devolved administrations.

Figure M3.3 Comparison of residential buildings emissions pathways for the UK, Scotland, Wales and Northern Ireland

Source: CCC analysis; Element Energy for the CCC (2020) Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget.

c) Approach to uncertainty

We use our exploratory scenarios to test a range of uncertainties.

In developing our advice, we have sought to consider the key uncertainties which could influence the path for buildings decarbonisation in the UK. We explore these uncertainties primarily through our use of scenario analysis:

- The exploratory scenarios reach Net Zero emissions by 2050 in quite different ways, illustrating the range of ways in which it can be achieved. We use these scenarios to guide judgements on the achievable and sensible pace of decarbonisation in the face of uncertainty, and to understand how less success in one area can be compensated for elsewhere.
- The Tailwinds scenario assumes considerable success on both innovation and societal/behavioural change and goes beyond the Sixth Carbon Budget Pathway to achieve Net Zero before 2050. This scenario is intended to be at the limits of feasibility.
- Our Balanced Pathway is designed to drive progress through the 2020s, while creating options in a way that seeks to keep the three 'exploratory' scenarios open.

The key sources of uncertainty we test through our Buildings scenarios include:

This includes uncertainties around energy costs, levels of behaviour change, techno-economic assumptions for energy efficiency, heat mixes, techno-economic assumptions for heating, and the pace of action.

- **Energy costs**. We use differing assumptions for economy-wide changes in grid carbon intensity and energy costs across scenarios. We additionally explore the impacts of higher bound hydrogen prices in our residential Headwinds scenario for the purposes of determining energy efficiency uptake in homes. For further discussion on uncertainties in energy costs, see Chapter 1.
- **Behaviour change.** We test varying levels of behaviour change across our scenarios for homes. For existing homes, this includes varying levels of pre-heating and demand reduction, as well as considering the heat-as-a-service delivery model in some scenarios (Table M3.3).
- **Energy efficiency.** We explore a wide range of energy efficiency uptake levels across our scenarios for homes. We also vary our assumptions on costs of different low-carbon measures, and the level of closure of the performance gap which might be achieved across scenarios. For public and commercial buildings, we vary the rates at which measures are rolled out (Table 3.3).
- **Heat mixes**. We explore a range of routes to decarbonising heat across our scenarios, ranging from a fully electrified heating mix in our Widespread Engagement scenario, to a hydrogen-heavy heating mix in our Headwinds scenario. A number of our scenarios, including the Balanced Pathway, represent a hybrid system (Table M3.3).
- **Heating technology costs, lifetimes and sizing**. We explore different levels of technology cost reductions across our scenarios. We also vary the assumed technology lifetimes and sizing for heat pumps across scenarios for homes (Table M3.3).
- **Heat technology efficiency.** In line with our Fifth Carbon Budget analysis, we assume improvements in heat pump Seasonal Performance Factors (SPF) of 0.5 between 2020 and 2030. For the Widespread Innovation and Tailwinds

scenarios, we assume a further 15% efficiency uplift for all years. For homes, this is based on a heat-as-a-service delivery model.

- **Pace of action.** We vary the dates of regulatory levers across scenarios, and the pace of uptake within deployment constraints, to test varying rates of progress.

Table M3.3
Assumption ranges tested through our scenarios

	Balanced Pathway	Range
Residential buildings		
Pre-heating	**25% of eligible existing homes, and all new homes**	25-50% of eligible existing homes, and all new homes
Reduction in space heat from smarter heating management and use*	**3%**	3%-6%
Hot water temperature in homes*	**60°C**	50°C (with daily legionella cycle) to 60°C
Cost of capital for building scale investment	**3.5% for existing homes, 7.5% for new build**	3.5%-7.5% for existing homes (where heat-as-a-service assumed), 7.5% for new build
Degree of closure of the performance gap*	**Uplift equivalent to one third closure of in-use factors**	Uplift equivalent to between one third and one half closure of in-use factors
Heat demand savings as a result of energy efficiency and behaviour change*	**12%**	11%-22%
Percentage of homes using hydrogen by 2050	**11%**	0%-71%
Heat pump efficiencies in 2020*,**		
Air source heat pump combined SPF	**2.54 at 50°C flow, 3 at 40°C flow**	2.92 at 50°C flow, 3.45 at 40°C flow
Ground source heat pump combined SPF	**2.84 at 50°C flow, 3.26 at 40°C flow**	3.27 at 50°C flow, 3.75 at 40°C flow
Heat pump cost reductions*		
Unit and installation	**20% reduction to 2030, 30% reduction to 2050**	20-30% reduction to 2030, 30-40% reduction to 2050
Ground source heat pump groundworks	**30% reduction to 2030**	30-40% reduction to 2030
Heat pump lifetime assumptions*		
Air source heat pump	**15 years**	15-17 years
Ground source heat pump***	**20 years**	20-22 years
Non-residential buildings		
Energy efficiency fully deployed by		
Public buildings	**2032**	2030-2032
Commercial buildings	**2030**	2030-2035
Percentage of non-residential heat demand using hydrogen by 2050	**5%**	0%-46%
Heat pump efficiency in 2020**	**283%**	283%-325%
Heat pump cost reduction (unit and installation)	**20% reduction to 2030, 30% reduction to 2050**	20-30% reduction to 2030, 30-40% reduction to 2050

Notes: This table represents a non-comprehensive list of the metrics varied between scenarios. * Assumptions relevant to existing homes only. ** An improvement of 0.5 in the combined SPF is assumed by 2030 across scenarios. Heat pump efficiencies at 50°C flow temperature are aligned with our Fifth Carbon Budget assumptions, with higher efficiencies assumed where radiators are upgraded to facilitate lower flow temperatures on average. Efficiency variations between flow temperatures based on MCS emitter guide. Further research is needed to improve the evidence base for these assumptions. *** Ground source heat pump ground works are modelled with a separate lifetime, assumed to be 100yrs across scenarios based on consultation with stakeholders. Evidence on the lifetime of ground loops remains limited and would benefit from further research.

We have not explicitly modelled the impacts of COVID-19 on demand and note that the longevity of any impacts remains highly uncertain. Any long-term shift to home working would lead to a shift in emissions from non-residential to residential buildings, particularly during the heating season. This could imply an increase in emissions in aggregate due to the loss in efficiency of having people working in a greater number of spaces which all need heating during working hours. Research undertaken by the International Energy Agency suggests there may be some net gains from a shift to homeworking where this displaces a commute by private car. However, the net impacts remain highly uncertain (Box M3.7).

Box M3.7
Modelling of the impacts on building emissions of a shift to homeworking

The COVID-19 pandemic has driven a substantial increase in homeworking. In April 2020, 46.6% of the labour force did some work at home.[43] It is currently unknown to what extent this may lead to a long-term shift.

The aggregate impacts on emissions from an increase in homeworking are uncertain and complex.

At a household level, working from home results in increased residential energy demand, and reduced transport energy demand. According to analysis undertaken by the IEA, the net impact of these changes is a reduction in energy demand where private vehicles are the main means of commuting.

However, a shift to homeworking would have wider effects on energy consumption:

- Reduced demand for office space would reduce energy consumption and emissions from non-residential buildings. However, offices may be more efficient workspaces than households (i.e. due to greater concentrations of people; newer buildings). In the UK, offices include a greater share of electric heating suggesting they could also be lower emission.
- Changes to where people live may result in increased travel distances or shifts away from public transport.

The impact on emissions depends on the net effects of increases in energy consumption in residential buildings and decreases in non-residential buildings, their relative efficiency, as well as secondary impacts on patterns of living and travel.

Source: IEA (2020) *Working from home can save energy and reduce emissions. But how much?*; O'Brien, W. and Aliabadi, F. (2020) Does telecommuting save energy? A critical review of quantitative studies and their research methods, *Energy and Buildings, 15 October 2020.*

i) Residential buildings

Remaining uncertainties specific to our residential modelling include projections for electricity use from lighting and appliances and for new build, energy savings associated with solid wall insulation, heat pump efficiencies, the performance of hybrids and the performance gap.

While it has been possible to test a range of uncertainties through the scenarios, with sensitivities undertaken alongside, the analysis is necessarily limited by the number of scenarios developed, and by the availability of evidence to inform assumptions. In particular, updated evidence or analysis in the following areas could be expected to impact aspects of the results:

- **Projections of fuel use and new homes.** Projections of baseline fuel use to 2050 remain highly uncertain. This includes projections for electricity use in homes (and achievable savings from lighting and appliance efficiency) where we have conservative assumptions leading to high levels of modelled electricity consumption in 2050. Long-term new build projections are also uncertain and would impact overall energy demand. Finally, we make assumptions about the impact of climate change on future heat demand, and the demand for cooling which remain uncertain (Box M3.8).

- **Solid wall insulation.** While the evidence base on the potential energy savings associated with fabric energy efficiency measures has improved relative to previous work, achievable savings remain highly uncertain in some cases. In particular, evidence used to inform our assumptions indicates lower cost effectiveness for solid wall insulation than has been suggested by previous work. This could in part be a function of U-values of solid uninsulated walls being lower than has been assumed historically, leading to lower observed savings from insulation in the NEED data.[44] However, there are also known uncertainties in the NEED data in relation to the number of partial wall installations in the sample (which would be expected to suppress savings). On this basis the savings we assume are expected to be an underestimate to some degree.

- **Heat pump efficiency.** Our Fifth Carbon Budget assumptions on heat pump efficiency were informed by field trials and monitoring for the Renewable Heat Premium Payment (RHPP) scheme, leading to conservative assumptions in the near term. While deficiencies in this data are widely acknowledged, in the absence of large-scale new published evidence, our Sixth Carbon Budget assumptions have used these conservative assumptions as a starting point. Our assumptions have then been updated to seek to reflect the higher efficiencies that might be achieved at lower flow temperatures, where radiators are replaced. The evidence for these assumptions remains limited and subject to uncertainty.[45] The Metering and Monitoring Service Package data is expected to provide an updated and expanded evidence base on in-situ heat pump performance which will support future analysis.

- **Hybrid heat pumps.** There remains uncertainty over how hybrid technologies will perform in-situ. Based on work undertaken by Imperial College London our base assumption is that hybrid heat pumps can operate in heat pump mode up to 80% of the time.[46] Other trial data (e.g. from Passiv Systems, when combined with smart controls) supports the Imperial assumptions. Trials undertaken by the Energy Systems Catapult have shown that performance can be highly variable and dependent on household heating behaviours.[47] We test the impacts of this through sensitivities on our scenarios.

- **The performance gap**. Our new-build modelling does not include a representation of the performance gap and is therefore likely to underestimate near-term fuel consumption to some degree. We include a representation of some closure of the performance gap for retrofit energy efficiency measures in existing homes. In both cases there is a high level of uncertainty over the precise scale of the performance gap, although a large body of evidence points to it being substantial.

Box M3.8
The impacts of climate warming

Changes in the UK's climate will impact on the energy demand of buildings between now and 2050. Our scenarios for homes have been designed to reflect a number of expected dynamics resulting from the changing climate:

- We assume that increasing winter temperatures result in reduced demand for heating. Based on the average from an ensemble of UK regional climate projections, we assume that increases in average winter temperatures to 2030 result in a 6.6% reduction in heat demand. We hold this reduction constant from 2030 to 2050.[††††, ‡‡‡‡]
- We assume that increasing summer temperatures result in additional demand for cooling. We allow for an additional energy demand of 5TWh annually by 2050. This is aligned with the Energy Systems Catapult's projections, based on an increase in energy demand for cooling calibrated to levels for households in EU countries which currently experience similar levels of Cooling Degree Days to those predicted for the UK in 2050.[48]
- We have separately examined the costs associated with retrofitting shading and ventilation measures in homes to manage overheating risk. This is discussed further in Chapter 3, Box 3.2.a.

The precise impacts of the changing climate on energy demand are uncertain, as they depend on behavioural responses to changes in summer and winter temperatures. We do not model the impacts for public and commercial buildings on the basis that these buildings are expected to be subject to more complex trade-offs between heating and cooling demand that it has not been possible to capture through our Sixth Carbon Budget analysis. Further analysis on energy demand will be covered in the next UK Climate Change Risk Assessment Evidence Report, due to be published by the Adaptation Committee in summer 2021.

Sources: Met Office analysis; CCC analysis; Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget;* Robert Sansom for Energy Systems Catapult (2020) *Domestic heat demand study.*

ii) Public and commercial buildings

Remaining uncertainties specific to our non-residential modelling include energy efficiency costs, heat technology costs and baseline projections.

There are a number of further uncertainties and limitations associated with the non-residential analysis that could impact results:

- **Energy efficiency costs**. We have taken a conservative approach to the estimation of energy efficiency abatement and investment costs, which is likely to overestimate costs.
    - We have used the full capex value derived from BEES (for the scope of abatement that we have included). This would mean that all the cost is additional to what would have been incurred in the baseline, whereas in practice we anticipate that a share of the measures would be in place of business-as-usual investment (e.g. replacing lighting or refrigeration equipment). If replacements take place near the end of a product's natural life

†††† Our residential heat analysis is based on an assessment of end state technology mixes in 2050, which are then deployed over the trajectory to 2050. While further warming after 2030 is expected, we hold the heat demand reduction constant to ensure that the technologies deployed in our modelling are able to meet the heat demands expected from 2030 onwards.

‡‡‡‡ Based on Met Office analysis of Heating Degree Day data derived from the 2018 UK Climate Projections, calculated for a 15.5 degree threshold and based on the RCP8.5 pathway – note that the outputs are similar for any emissions scenarios before 2050 (Riahi et al 2007).

then there may be no additional capital cost, or possibly even some cost saving.

  – We also assume renewal costs continue throughout the appraisal period. With some very short measure lifetimes (e.g. less than five years), this means the costs are repeated several times. If the benefits of some measures could be maintained (e.g. the impact of training or procurement practice) without reinvesting, then costs could be considerably lower than our estimates.

We have taken a simplified approach to modelling both hot water and heat technology mixes in the analysis and note modelled potential for abating emissions resulting from the use of anaesthetics in health care.

- **Heat and hot water.** We have taken a simplified approach of modelling heat and hot water demands together which is likely to slightly underestimate demand and costs.
  – Suitability and uptake are driven by space heating demand, which are applied to hot water demands. This is an oversimplification. For example, hot water makes up 7% of baseline electrical heat and hot water demand that is converted to air-to-air heat pumps, whereas a supplementary technology would be necessary for the hot water.
  – Our costs for delivering all heat and hot water demands are based on costs for generating heat which is likely to lead to an underestimation of costs.
- **Heat technology mixes.** We have modelled all 'wet' based systems that convert to heat pumps using low temperature air-to-water heat pumps, and 'dry' systems converting to air-to-air heat pumps. A wider range of technologies are available which would have different energy requirements and costs. It may also be feasible for buildings with 'wet' systems to convert to lower cost air-to-air heat pumps instead of air-to-water heat pumps and take on additional work in converting distribution systems.
- **Heat technology costs.** Our cost inputs (£/kW) are drawn from the HVAC study commissioned by BEIS. Our cost methodology pairs these with capacity and load factor assumptions drawn primarily from our Fifth Carbon Budget analysis. Capacity and load factors are difficult to assess. We believe we have based our analysis on the best information available but recognise the potential for incompatibility between these data sources and the relatively large impact changing any of these assumptions can have on heat costs.
- **Baseline projections.** There are discrepancies between data sources on commercial and public energy consumption for 2018. We understand a revision to reallocate 18TWh of oil from industry to other final users has resulted in higher energy consumption for public and commercial buildings in Energy Consumption in the UK (ECUK) than is reflected in inventory data or BEIS Energy and Emission Projections (EEP). [§§§§,49,50] Due to a closer mapping to inventory data, we have grounded our analysis on EEP data for 2018 and scaled this slightly to align fully to inventory data. The balance between public and commercial sub-sectors and fuel types varies by data source, so introduces a few elements of uncertainty. Projections of energy use to 2050 are clearly uncertain. Our baseline projections are generally based on BEIS' EEP which shows a strong growth in commercial electricity consumption to 2035, which leads to a 77% increase in commercial electricity from 2018 -2050 in our analysis. Taking this baseline is a cautious

§§§§ Other final users include the public sector, commercial buildings and agriculture.

approach which may be leading to more low-carbon electricity generation requirements than may be necessary.

- **N_2O emissions from anaesthetics.** In line with our Net Zero analysis, we have not modelled the potential for abating 0.6MtCO_2e of N_2O emissions arising through use in anaesthesia. A recent NHS report suggests these emissions can be reduced by up to 75% by 2050. [51] This abatement and associated costs are not included in our analysis.

Our scenarios and analytical approach have been deliberately designed to explore and test the implications of uncertainties, allowing us to develop a balanced assessment of achievable carbon savings which might be met in a range of ways. While uncertainties will inevitably remain, the analysis undertaken provides a solid basis on which to proceed.

Endnotes

[1] CCC (2020) *The Sixth Carbon Budget – Methodology Report.* Available at: www.theccc.org.uk

[2] National Atmospheric Emissions Inventory (NAEI) (2020) *Breakdown of UK GHG emissions by source and greenhouse gas.*

[3] Department for Business, Energy & Industrial Strategy (BEIS) (2020) *DUKES, Electricity: commodity balances (DUKES 5.1).*

[4] NAEI (2020) *Breakdown of UK GHG emissions by source and greenhouse gas.*

[5] BEIS (2020) *Energy Consumption in the UK (ECUK, End uses data tables*, Table U2.

[6] BEIS (2020) *DUKES, Electricity: commodity balances (DUKES 5.1).*

[7] NAEI (2020) *Breakdown of UK GHG emissions by source and greenhouse gas.*

[8] BEIS (2020) *DUKES*, Natural gas: commodity balances (DUKES 4.1).

[9] BEIS (2020) *DUKES, Electricity: commodity balances (DUKES 5.1).*

[10] CCC (2017) *Energy Prices and Bills – impacts of meeting carbon budgets.*

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[12] See Figure 4-5: Imperial College London for the CCC (2018) *Analysis of Alternative UK Heat Decarbonisation Pathways.*

[13] Aecom (2011) *Energy Demand Research Project: Final Analysis.*

[14] Energy Systems Catapult (2019) *Pathways to Low Carbon Heating: Dynamic Modelling of Five UK Homes.*

[15] Energy Systems Catapult (2020) *Achieving energy savings using zonal control*; Beizaee, A. Allinson, D. Lomas, K. J. Foda, E. and Loveday, D. L. (2015) *Measuring the potential of zonal space heating controls to reduce energy use in UK homes: The case of un-furbished 1930s dwellings.* Energy and Buildings, vol. 92, pp. 29-44, 2015.

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[18] Battelle Memorial Institute (2009) *Final report study on benefits of removal of water hardness (calcium and magnesium ions) from a water supply*; Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget.*

[19] Energy Systems Catapult (2019) *Smart Energy Services for Low Carbon Heat*; Energy Technologies Institute (2018) *How can people get the heat they want at home, without the carbon?*

[20] Energy Systems Catapult (2019) *Heat as a Service Case Study.*

[21] Values for financial savings and energy consumption increase were taken from nominal results by Energy Systems Catapult: Energy Systems Catapult (2019) *Smart Systems and Heat Phase 2 D10 - D14: Market Transformations Report*. These findings are sensitive to assumptions regarding future market structures and service propositions. Assumptions on cost of capital in scenarios using heat-as-a-service are conservative, on the basis that the 7.5% cost of capital is applied to all low-carbon heat and energy efficiency in existing homes.

[22] BEIS (2016) *Building Energy Efficiency Survey.*

[23] CCC (2019) *UK housing: Fit for the future;* Currie & Brown and Aecom for the CCC (2019) *The costs and benefits of tighter standards for new buildings.*

[24] CCC (2020) *Letter: Future Homes Standard and proposals for tightening Part L in 2020.*

[25] SAP methodology was used to calculate energy savings from measures, and in-use factors applied to correlate better the modelled data with real-world performance. For further detail see Element Energy and the Energy Saving Trust for the CCC (2013) *Review of potential for carbon savings from residential energy efficiency*.

[26] UCL (2020) *Analysis work to refine fabric energy efficiency assumptions for use in developing the Sixth Carbon Budget.*

[27] Energy Saving Trust (2016) *Quantification of non-standard cavity walls and lofts in Great Britain*; Energy Saving Trust (2019) *Determining the costs of insulating non-standard cavity walls and lofts.*

[28] Referenced in Energy Saving Trust for DECC (2016) *Quantification of non-standard cavity walls and lofts in Great Britain.*

[29] Assumptions for thin internal wall insulation based on forthcoming research by Leeds Beckett University for BEIS, Thin Internal Wall Insulation (TIWI) Project. Assumptions for deep whole house retrofits informed by evidence provided by Energiesprong. It should be noted that our modelling of deep retrofits differs from the Energiesprong model in a number of important ways; notably we do not model onsite generation or counterfactual maintenance costs which are core to the Energiesprong business case. For further discussion of the benefits of the Energiesprong retrofit model see CCC (2018) *UK housing: Fit for the future?*

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[38] Currie & Brown and Aecom for the CCC (2019) *The costs and benefits of tighter standards for new buildings.*

[39] NHS (2020) *Delivering a 'Net Zero' National Health Service*.

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[44] BRE (2016) *Solid wall heat losses and the potential for energy saving*.

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[46] CCC calculations based on Imperial College (2018) *Analysis of alternative heat decarbonisation pathways* (Hybrid heat pump 10 Mt scenario).

[47] Energy Systems Catapult for BEIS (2019) *D8 Decarbonising Heat: Understanding how to increase the appeal and performance of heat pumps.*

[48] Robert Sansom for Energy Systems Catapult (2020) *Domestic heat demand study.*

[49] BEIS (2019) *Energy Trends: June 2019, special feature article - Change to method of estimating sector demand for oil products*.

[50] BEIS (2019) *Energy Consumption in the UK (ECUK)*.

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Chapter 2

Emissions pathways for the buildings sector

Introduction and key messages

The following sections are taken directly from Chapter 3 of the CCC's Advice Report for the Sixth Carbon Budget.[52]

Our pathways reduce emissions in buildings to zero by 2050 at the latest, whilst adapting to a changing climate.

Direct buildings emissions were 87 $MtCO_2e$ in 2019. Progress in delivering emissions reductions has broadly flatlined since 2015, when comparing on a temperature adjusted basis.

Our pathways to 2050 aim to reduce emissions in buildings to zero by 2050 at the latest, based on the findings of our Net Zero report. They also aim to ensure buildings of the future are comfortable, healthy spaces to be year-round, which are resilient to overheating and other climate risks.

Our Balanced Net Zero Pathway reflects four priorities over the coming decade or so:

- Deliver on the Government's energy efficiency plans to upgrade all buildings to EPC C over the next 10-15 years.
- Scale up the market for heat pumps as a critical technology for decarbonising space heating, while maintaining quality.
- Expand the rollout of low-carbon heat networks in heat dense areas like cities, using anchor loads such as hospitals and schools. Prepare to shift away from using fossil fuel Combined Heat and Power (CHP) as a supply-source towards low-carbon and waste heat by preference from the mid-2020s.
- Prepare for a potential role for hydrogen in heat through a set of trials building on the current innovation programme.

They require a major ramp up in supply chains for insulation, heat pumps and heat networks, which our analysis shows is feasible.

This programme requires a major ramp-up from what is happening today in supply chains for insulation, heat pumps and heat networks. Our detailed analysis demonstrates that this is feasible:

- We commissioned Element Energy to undertake bottom-up modelling of heat decarbonisation for existing homes. Alongside modelling undertaken in house, the assessment indicates that delivering net zero emissions in buildings is feasible.
- This assessment is underpinned by the latest available evidence on the cost and performance of measures, and on deployment constraints, informed by a literature review and through evidence gathering from expert stakeholders.
- The installation rates for insulation measures such as lofts and cavity walls are within the range previously achieved under the supplier obligations in the early 2010s. Solid wall installation rates are more ambitious but considered achievable with strong policy in our testing with stakeholders.

The rest of this section is set out in three parts:

a) The Balanced Net Zero Pathway for buildings
b) Alternative routes to delivering abatement in the mid-2030s
c) Impacts of the Scenarios – costs and benefits

1. The Balanced Net Zero Pathway for buildings

Buildings shift on to low-carbon heat networks, high efficiency and flexible electrification, along with some hydrogen near industrial clusters.

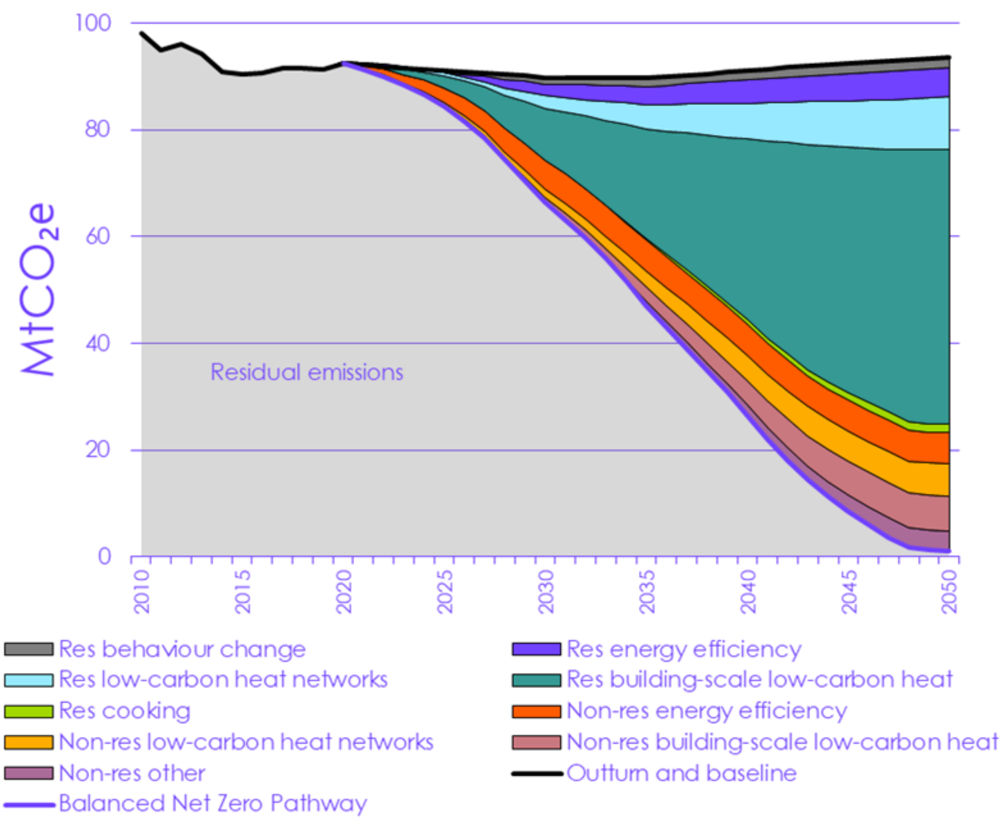
Across all buildings, around 34% of abatement to 2030 comes from energy efficiency measures, with a growing share of abatement from low-carbon heating, which dominates the picture from 2028 on (Figure A3.2.a). Buildings shift on to low-carbon heat networks, high efficiency and flexible electrification, along with some hydrogen near industrial clusters from 2030.

Our pathways take Government policy as their starting point: including the major programme to improve the efficiency of buildings and phase out oil and coal heating.

Our Balanced Net Zero Pathway takes Government policy priorities as its starting point – in particular the plans to improve the energy efficiency of all buildings over the next 10-15 years, to phase-out the installation of new high-carbon fossil fuels in the 2020s, and to expand heat networks through to 2050. We have assessed what additional levers are required in order to remove all remaining fossil fuel emissions from buildings, while minimising costs and disruption:

- Minimising costs and disruption means working as much as possible with existing technology lifetimes – particularly the heating technology stock.
- At the same time, we want to move quickly enough to be able to reach Net Zero without scrapping existing heating systems.

Figure A3.2.a Sources of abatement in the Balanced Net Zero Pathway for Buildings



Source: BEIS (2020) *Provisional UK greenhouse gas statistics 2019*; Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget*; CCC analysis.
Notes: Residential low-carbon heat includes some efficiency associated with new homes. Non-residential energy efficiency also includes some behavioural measures. Non-residential other includes catering and other non-heat fossil fuel uses.

We look at a set of additional policy levers: a phase out date for the installation of natural gas boilers in 2033, along with new standards on mortgage lenders and at point of sale to drive efficiency renovations in the 2020s and 2030s.

Given boiler lifetimes of around 15 years, we have looked at phasing out the installation of fossil fuel boilers, in advance of 2035. We adopt a central date of 2033 for gas boilers across buildings, with public buildings moving faster:

- For homes, we pick a central phase out date of 2028 for high-carbon fossil fuel boilers not connected to the gas grid, and a phase out date of 2033 for gas boilers.
- The key date of 2033 balances the need to scale up heat pump supply chains sustainably, while allowing for a small amount of headroom over a typical 15-year boiler stock turnover before 2050.
- In non-residential buildings we use 2025 for high-carbon fossil fuel boilers in public buildings and 2026 in commercial buildings, based on the feasibility and benefits of moving faster. We use phase out dates for gas boilers of 2033 in commercial buildings and 2030 in public buildings in the Balanced pathway. The faster pace in public buildings allows the Government to meet its targeted 50% reduction in emissions by 2032.
- These dates operate alongside the deployment of low-carbon heat networks and a regional rollout of hydrogen conversion of the gas grid, informed by our industry scenarios. This means that the phase-out does not apply in any areas designated for these alternatives.

The other key dates are then based on the need to build critical supply chains and skills, and prepare the building stock for the transition to low-carbon heating, with most of the energy efficiency programme completed by the time fossil fuel boiler installations are phased out from 2033 (Table A3.2.a).

This energy efficiency programme is also underpinned by a timetable of standards –rented homes achieve EPC C by 2028 in line with new Government proposals, with social homes aligned to the same timetable.

We test two new policy proposals for the two-thirds of homes which are owner-occupied, and therefore not covered by existing proposals outside of Scotland. This includes a requirement on lenders to first report on and then improve the average efficiency of their mortgage portfolios, covering just under half of the owner-occupied stock. A further subset are captured by regulations at point of sale, drawing on proposals published by the Scottish Government.

Table A3.2.a
Implications in the Balanced Pathway for buildings

	Balanced Net Zero Pathway date	Scenario implications
Efficiency		
All new buildings are zero-carbon	2025 at the latest	100% of buildings built with high-levels of energy efficiency and low-carbon heating (e.g. heat pumps or low-carbon heat networks).
Rented homes achieve EPC C	2028	Rented homes to achieve EPC C by 2028, such that all practicable lofts and cavities are insulated alongside other low-regret measures, with solid wall insulation deployed where this supports low-carbon heat and wider benefits.
Standards for lenders targeting EPC C across the housing portfolio	2025 - 2033	Homes with mortgages achieve EPC C by 2033, such that all practicable lofts and cavities are insulated alongside other low-regret measures, with solid wall insulation deployed where this supports low-carbon heat and wider benefits. This covers just under half of all owner-occupied homes.
All homes for sale EPC C	2028	No dwellings can be sold unless they meet the minimum standard. At the current housing turnover of once every ten years for mortgagors and once every 24 years for outright owners, regulations at point of sale would be expected to result in a further 15% of owner occupied homes meeting the required standard by 2035 (with further upgrades driven by the standards on lenders, totalling at least 60% of owner-occupiers overall).
All commercial efficiency renovations completed	2030	All energy efficiency improvements are made by 2030 to meet the Government's target of reducing business and industrial energy consumption by 20%.
Heating		
All boilers are hydrogen-ready	2025	By 2025 at the latest, all new gas boilers are hydrogen-ready.
Oil and coal phase out (outside of any zones designated for low-carbon district heat)	2028	100% of heating system sales off the gas grid are low-carbon from 2028, with exemptions for any buildings in zones designated for low-carbon district heat. Earlier dates may be possible in public and commercial buildings.
Natural gas phase out (outside of zones designated for low-carbon district heat or hydrogen-conversion)	2033	100% of heating system sales are low-carbon from 2033, with exemptions for any buildings in zones designated for low-carbon district heat or hydrogen-conversion. We assume an earlier date of 2030 in public buildings so as to achieve the Clean Growth Strategy target of 50% emission reduction by 2032.
CHP phase out for low-carbon district heat	2025	Currently, around 93% of district heat networks use a fossil fuel-based primary fuel source. We assume that all new district heat network connections from 2025 are low-carbon. All heat networks supplied by legacy CHP schemes convert to low-carbon heat sources by 2040.

Notes: The fossil phase-out dates drive uptake of building-scale low-carbon heating – predominantly heat pumps, with some flexible resistive electric heating such as storage heating and panels.

Energy efficiency in the Balanced Net Zero Pathway

Our assumed household energy efficiency programme over the next 10-15 years is broadly in line with Government ambition.

The household energy efficiency programme in our Balanced Net Zero Pathway corresponds to a similar level of ambition as the Government's EPC C targets:

- It entails £55 billion of investment in home energy efficiency to 2050.

- BEIS's published estimate of £35-65 billion to achieve the EPC C standard implies a broadly consistent level of ambition.
- It remains important that EPCs are reformed to ensure they drive the energy efficiency measures needed, as detailed in our accompanying Policy report.

15 million homes get one of the main measures (wall/roof/floor insulation).

In total, 15 million households receive one of the main insulation measures (loft/wall/floor) and a further 8 million benefit from draught-proofing. Most homes with hot water tanks benefit from hot water tank insulation. All fuel poor homes receive a high efficiency upgrade:

- We deploy low-cost measures such as draft proofing and hot water tank insulation in all homes, as well as insulating all practicable cavities and lofts (including top-ups where existing insulation is below 200mm).
- Our assessment is that this leads to the deployment of around 3 million cavity insulation measures and 11 million loft insulation measures to 2050.
- We include solid wall insulation in just under half of all uninsulated solid-walled homes (3.4 million in total) including all those in fuel poverty.

We conservatively estimate heat efficiency savings of 12% based on evidence of how measures currently performed when installed.

Energy efficiency and behavioural measures in our Balanced Pathway deliver a 12% reduction in heat demand to 2050 (compared to a 22% reduction in our Tailwinds scenario).* This is a conservative estimate which reflects how measures are currently performing when installed in existing homes (further detailed in the accompanying Method report). Higher savings are possible with greater improvements in tackling the performance gap, innovation and public engagement.

There remains uncertainty over the balance of costs and benefits for wall insulation in solid walled homes in particular, as well as levels of public support. This includes uncertainty over the energy savings which can be achieved and the potential for innovative new approaches which minimise cost and disruption (detailed in the separate Methodology report). Further research is needed here to inform deployment. To the extent there is any under delivery of solid wall insulation relative to our scenarios, the abatement would need to be delivered in other ways e.g. through increased uptake or performance of other energy efficiency measures, or through a faster rate of heat pump deployment.

Public willingness to adopt solid wall insulation is highly uncertain, as are the costs and benefits. Our Balanced Pathway insulates 3.5 million solid walls (out of a total of 8 million).

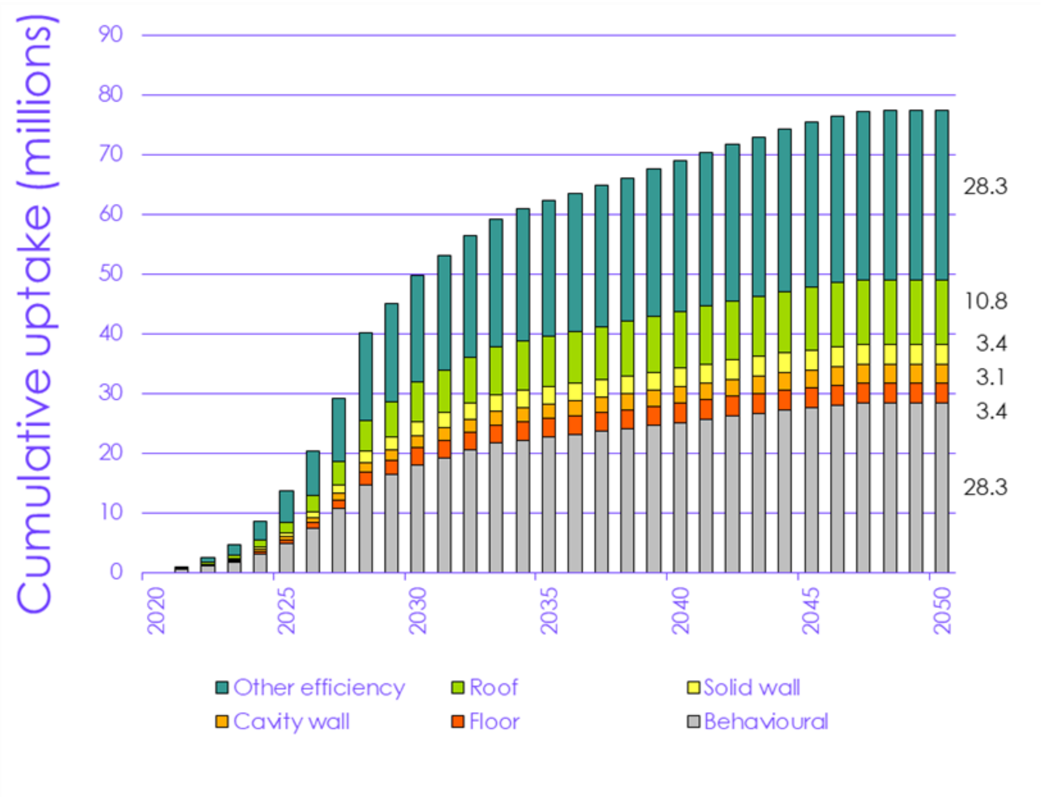
The timetable associated with our Balanced Net Zero Pathway allows for rapid scale-up of supply chains for critical insulation measures (Figure A3.2.b):

- Total loft insulations rise rapidly from just 27,000 lofts insulated in the past year to back to over 700,000 installations per year by 2025. This compares to 1.6 million which were insulated in 2012 under the supplier obligations.
- The rate of cavity wall insulation rises from 41,000 cavities to over 200,000 a year by 2025.
- Solid wall insulation measures also increase to just over 250,000 a year by 2025 from just 11,000 in the past year. This puts us on track for insulating 3.4

* This represents an aggregate reduction in heat demand across the stock, taking into account technical and economic potential, and is not reflective of the savings which might be delivered in an individual home which has minimal existing insulation. A typical household in our Balanced Pathway which installs cavity wall insulation, loft insulation, and floor insulation sees heat demand savings of 30%, while very deep retrofits might deliver savings in the region of 57% (Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget*). The lower stock-level heat demand savings relative to our Net Zero analysis reflect a number of factors, including updated savings assumptions based on data from the National Energy Efficiency Database, and the latest evidence on costs and technical and economic potential. These factors lead to lower deployment relative to Net Zero, but similar deployment to that modelled for the Fifth Carbon Budget.

million by 2050, or just under half of the total UK stock of solid wall buildings.

Figure A3.2.b Uptake of heating efficiency measures in existing homes



Source: Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget*.
Notes: This does not include measures which save other electrical demand such as LEDs, wet and cold appliances. Behavioural measures include multi-zonal heating controls and pre-heating (i.e. turning heating on early, off-peak).

Public and commercial buildings benefit from around 25% energy efficiency savings.

Our non-residential building scenarios include a 27% reduction in energy consumption compared to our 2018 baseline. In our Balanced Pathway, commercial energy efficiency is fully deployed by 2030 in line with the Clean Growth Strategy target and public sector measures are fully deployed by 2032 to contribute to the Government's emission reduction target.

Low-carbon heating in the Balanced Net Zero Pathway

By 2030, most heating installations are low-carbon – predominantly heat pumps.

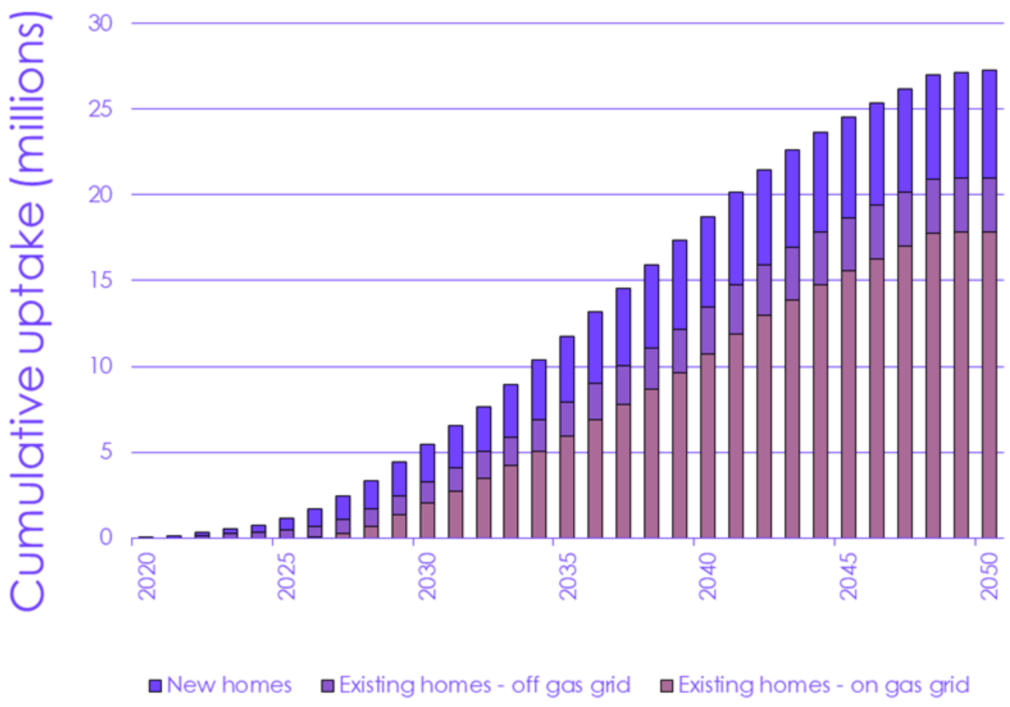
Our Balanced Net Zero Pathway implies that by 2030, low-carbon heat installations in homes could represent up to around 80% of sales.† Of these low-carbon heat installations, 75% are heat pumps (including hydrogen hybrids), 19% are low-carbon heat networks, and 5% are other flexible electric heating with space heat storage or solar thermal.

- By 2030, heat pump sales reach just over 1 million per year in new and existing homes of a total market of 1.8 million boiler installations currently. There are a total of 5.5 million heat pumps installed in homes by 2030, of which 2.2 million are in new homes (Figure A3.2.c).

† Based on low-carbon heat installations in existing homes in 2030 of 1.2m, low-carbon heat installations in new homes of 0.3m, and current annual boiler sales of 1.8m per year.

- Hydrogen trials are scaled up rapidly in the 2020s to enable rapid grid conversion from 2030 onwards (as detailed in the separate Policy report).
- Low-carbon heat networks are built through 2020-2050, with scaling up through to 2028, from which point around 0.5% of total heating demand is converted per year. By 2050, around a fifth of heat is distributed through heat networks.

Figure A3.2.c Uptake of heat pumps in residential buildings



Source: Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget.*

Public buildings move at a faster pace, leading to higher levels of low-carbon heat in non-residential buildings by 2030. A greater share of demand is met through heat networks than for homes.

By 2030 37% of public and commercial heat demand is met by low-carbon sources. Of this low-carbon heat demand 65% is met by heat pumps, 32% district heating and 3% biomass. By 2050 all heat demand is met by low-carbon sources of which 52% is heat pumps, 42% is district heat, 5% is hydrogen boilers and around 1% is new direct electric heating.

We explore a range of scenarios which achieve 45-65% reduction in emissions by 2035, against current levels.

All buildings scenarios achieve close to zero emissions by 2050. The Tailwinds and Widespread Engagement pathways are faster than the Balanced Pathway, reducing to close to zero by 2044 (Figure A3.2.d).[‡] By 2035, the pathways achieve reductions of 45% - 65%, relative to current emissions.

We explore different contexts by varying the key timings, costs and performance assumptions and by exploring the impact of innovation such as new business models (Table A3.2.b):

- **Widespread Engagement**. Households and businesses are prepared to undertake renovations at scale through the 2020s, with high levels of pre-heating and other behaviour change in homes.[§] They also support earlier regulatory approaches.
- **Innovation**. Power sector innovation drives down electricity costs. Households adopt smart, flexible electric heating including hybrid heat pumps, as well as high-temperature heat pumps (which are able to operate at higher temperatures, reducing the need for radiator upgrades).[53**] New business models such heat-as-a-service and new financial models for deep retrofits become common, delivering high performance solutions. High levels of cost reduction through learning, and increases in performance over time.
- **Headwinds**. People change behaviour and new technologies develop, but there are no widespread behavioural shifts or innovations that significantly reduce the cost of green technologies ahead of current projections. Alongside strong electrification, there is widespread use of hydrogen, led by the conversion of industrial clusters.
- **Tailwinds**. Households and businesses support early regulatory approaches, and minimise their use of energy through behaviour change and the highest uptake of energy efficiency measures. At the same time, innovation drives down costs (with 40% reductions in heat pump costs to 2050) and drives up performance.

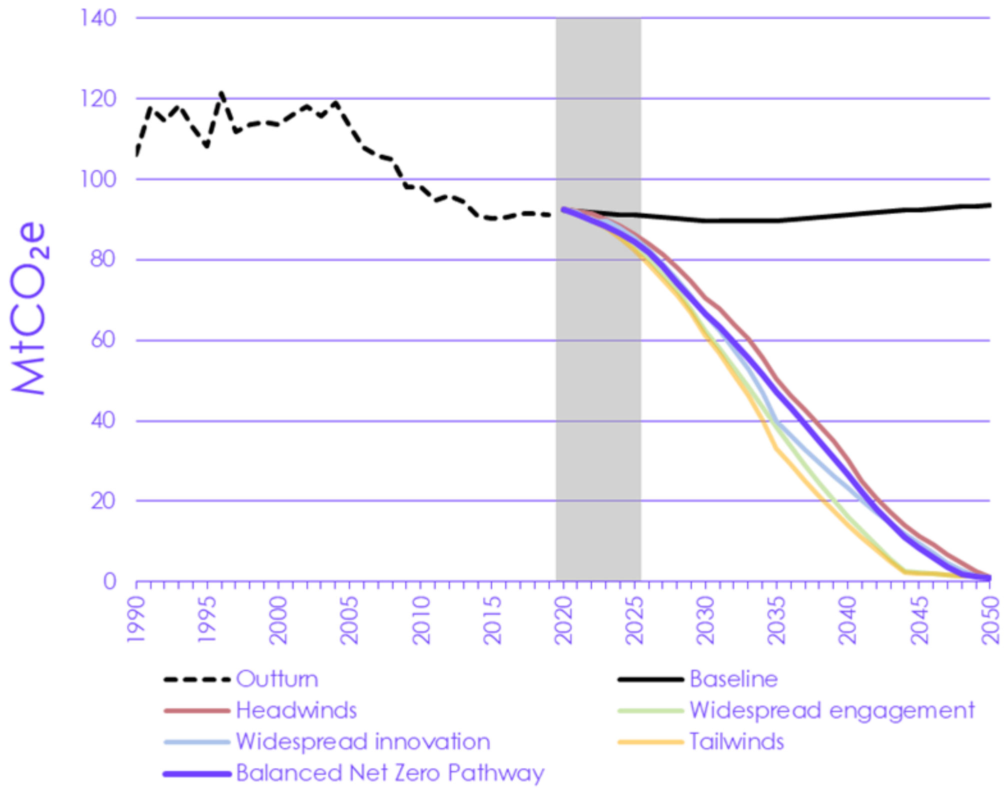
Availability of hydrogen in Headwinds is increased at an ambitious rate in the 2030s, implying that some possible hydrogen-dominated pathways could lead to lower emissions in the budget period. However, as a result this scenario has considerably higher overall hydrogen demand, creating a substantially bigger challenge to source sufficient volumes of low-carbon hydrogen. In turn, this is likely to lead to more use of fossil gas reforming with carbon capture and storage (CCS), increasing residual emissions from hydrogen production and increasing reliance on CCS and fossil gas imports (see section 5). While higher buildings demands could be conceived of, they are not included in our scenarios due to these supply challenges and residual emissions.

‡ Some additional rollout of low-carbon heat networks occurs to 2050.

§ Where homes are sufficiently well insulated, it is possible to pre-heat ahead of peak times, enabling access to cheaper tariffs which reflect the reduced costs associated with running networks and producing power off-peak. Other behavioural measures are summarised in table 3.2.a.

** While high temperature heat pumps are specifically designed for high temperature operation, the designs of 'conventional' heat pumps are increasingly being improved to reach 60-65°C at reasonable efficiency. We assume that radiator upgrades could be avoided where flow temperatures of 65-70°C are reached. An efficiency penalty is associated with operation at these higher temperatures, although discussions with manufacturers suggest efficiency benefits relative to resistive heating are maintained even in very cold weather.

Figure A3.2.d Emissions pathways for the buildings sector



Source: Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget;* CCC analysis.

Table A3.2.b
Summary of key differences in the buildings sector scenarios

	Balanced Net Zero Pathway	Widespread Engagement	Widespread Innovation	Headwinds	Tailwinds
Behaviour change and demand reduction	**Moderate levels of behaviour change (homes).** **25% of eligible households pre-heat, 3% reduction in space heat demand from smarter heating management and use, low-flow shower heads.**	High levels of behaviour change (homes). 50% of eligible households pre-heat, 6% reduction in space heat demand, 50°C hot water temperature with daily legionella cycle,[††] low flow shower heads	High levels of behaviour change (homes). 50% of eligible households pre-heat, 6% reduction in space heat demand, heat-as-a-service delivering higher performance, low flow shower heads	Moderate levels of behaviour change (homes) 25% of eligible households pre-heat, 3% reduction in space heat demand, low flow shower heads	High levels of behaviour change (homes) 50% of eligible households pre-heat, 6% reduction in space heat demand, heat-as-a-service delivering higher performance, low flow shower heads

[††] Legionella bacteria are widespread in natural water systems and can cause Legionnaires' disease where conditions are conducive e.g. where water is maintained at a temperature high enough to encourage growth. Legionella bacteria can multiply where temperatures are between 20-45°C, but do not survive above 60°C. HSE is currently undertaking work with CIBSE looking at guidance for low-temperature systems to manage legionella risk.

Efficiency	**Moderate energy efficiency uptake in homes. Loft and wall insulation for all fuel poor.** **Fast commercial uptake; Moderate-paced public uptake.**	Moderate-high energy efficiency uptake in homes. Loft and wall insulation for all fuel poor. Fast uptake of energy efficiency in other buildings.	Lower energy efficiency uptake in homes. Loft and wall insulation for all fuel poor. Innovation drives down energy efficiency costs and delivers high performing deep retrofits. Moderate-paced uptake in other buildings.	Lower energy efficiency uptake in homes. Loft and wall insulation for all fuel poor. Slow commercial uptake; moderate-paced public uptake.	High energy efficiency uptake in homes (full economic potential). Loft and wall insulation for all fuel poor. Fast uptake of energy efficiency in other buildings.
Low-carbon fuels/ technology	**Hybrid hydrogen scenario in homes, with 11% of homes using hydrogen for heat. Limited use of biofuels in homes.** **Heat networks fully electrified.**[‡‡] **Non-residential buildings heat and catering demands mainly electrified with some hydrogen.**	Fully electrified scenario (including heat networks). No biofuels in homes.	Hybrid hydrogen scenario in homes, with 10% of homes using hydrogen for heat. Widespread uptake of high-temperature heat pumps and flexible technology. No biofuels in homes. Heat networks fully electrified. Lower levels of low-carbon heat networks in non-residential buildings. Non-residential buildings heat and catering demands mainly electrified with some hydrogen. Higher efficiency of heat pumps and greater reduction in cost over time.	Widespread network conversion to hydrogen, with 71% of homes using hydrogen for heat. Smaller role for heat pumps across all buildings; 13 million in homes. In homes, hydrogen boilers in north and heat pump-hydrogen hybrids in south. Limited use of biofuels. Heat networks supplied by hydrogen and large-scale heat pumps. Catering and cooking demands predominantly met with hydrogen.	Buildings fully electrified, except for areas around industrial clusters which use H_2 boilers. 11% of homes using hydrogen for heat. No biofuels in homes. Higher efficiency of heat pumps and greater reduction in cost over time.

[‡‡] Dominated by water- and sewage-source heat pumps and waste heat from industrial sources.

Table A3.2.c
Critical dates and scenario metrics in the Balanced Net Zero Pathway

	Balanced Net Zero Pathway date	Range
All new homes are zero-carbon	2025 at the latest	2024-2025
Rented homes achieve EPC C	2028	2027-2030
Standards for lenders targeting EPC C across the housing portfolio	2025 - 2033	From 2025 to 2030/2035
All homes for sale EPC C	2028	2025-2030
Commercial energy efficiency complete	2030	2030-2035
Public sector energy efficiency complete	2032	2030-2032
Oil and coal phase out (outside of any zones designated for low-carbon district heat)	Residential: 2028 Commercial oil: 2026 Public oil and all coal: 2025	Residential: 2026-2028 Commercial: N/A Public: N/A
Natural gas phase out (outside of zones designated for low-carbon district heat or hydrogen-conversion)	Residential: 2033 Commercial: 2033 Public: 2030	Residential: 2030-2035 Commercial: 2030-2033 Public: 2030-2033

3. Impacts of the scenarios: costs, benefits and co-impacts on society

The Balanced Pathway requires investment at an average rate of around ~£12 billion per year to 2050, offset by reductions in fuel costs of ~£5 billion per year.

In our 2019 *Net Zero* report, we identified buildings as one of the most costly challenges across the economy, with in-year costs in 2050 of around £15 billion per year and uncertainty around the total costs throughout the period to 2050. Our updated Sixth Carbon Budget pathways estimate these full costs.

The Balanced Pathway requires investment across all buildings (residential and non-residential) at an average rate of around ~£12 billion per year to 2050, offset by reductions in operating costs of ~£5 billion per year:

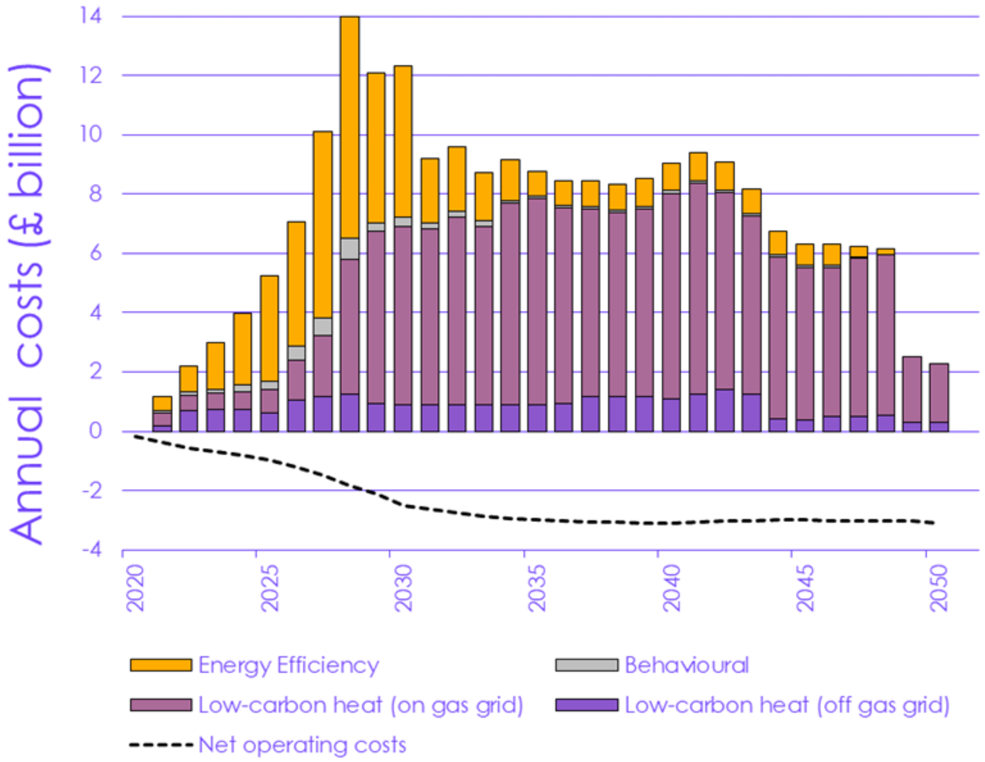
- Total investment costs are £360 billion to 2050, of which around £250 billion is for the programme of upgrading homes (Figure A3.2.e) and £110 billion in public and commercial buildings.
- Total investment in the programme of efficiency in existing homes in this scenario is around £45 billion to 2035 with a total spend of £55 billion by 2050. This compares to BEIS's published estimate of £35-65 billion to achieve the EPC C standard.[54]

Total investment costs are less than £10,000 per household.

- Total investment costs are less than £10,000 per household on average in our Balanced Pathway. 63% of homes need spend no more than £1000 on retrofitting energy efficiency measures.
- The deployment of all energy efficiency potential in public and commercial buildings entails £2 billion per year of commercial investment to 2030 and £0.5 billion per year of public sector investment to 2032. Annual operating cost savings of around £1.5 billion and £0.5 billion result for commercial and public buildings respectively.
- Including low-carbon heat increases this to £2.8 billion per year investment in commercial buildings and £0.9 billion in public buildings through the 2030s and 2040s. This is associated with total operating cost savings of £3 billion per year across public and commercial buildings.

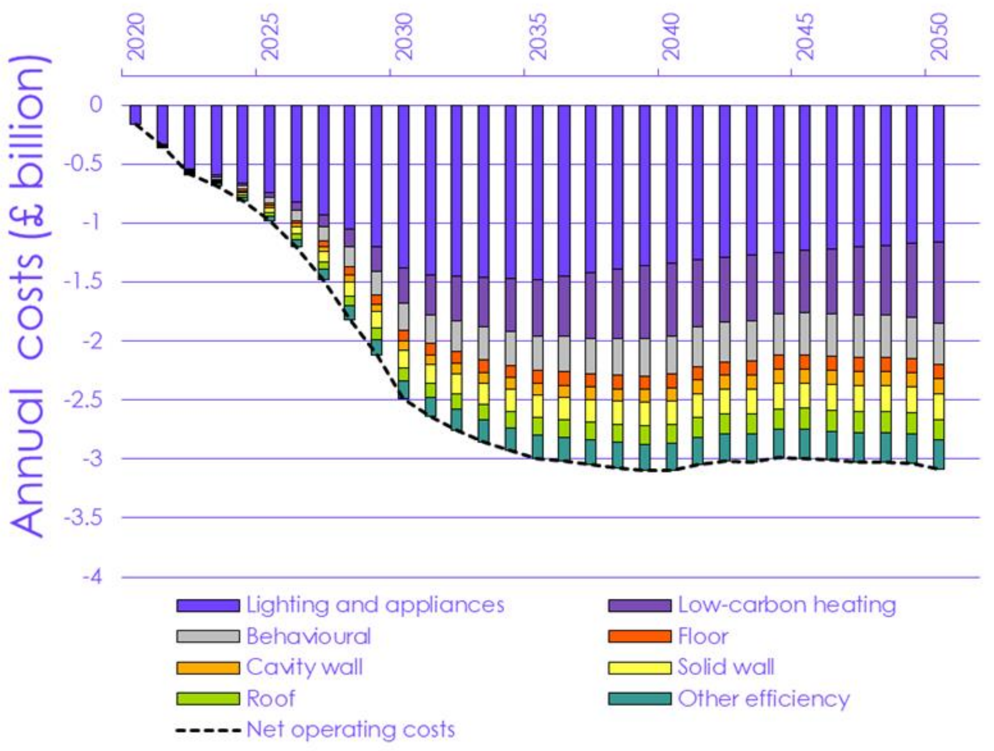
Energy efficiency is projected to deliver ongoing operating cost savings (Figure A3.2.e), resulting in lower overall bills for households in all scenarios apart from Headwinds. Behaviour change in our Balanced Pathway is estimated to contribute around £0.4 billion of savings per year by 2050.

Figure A3.2.e Household investment and operating costs for existing homes, Balanced Net Zero Pathway



Source: Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget;* CCC analysis.

Figure A3.2.f Operating costs in existing homes, Balanced Net Zero Pathway



Source: Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget;* CCC analysis.
Notes: Opex not calculated for transition to low-carbon cooking or for decarbonisation of household and garden machinery.

Reduction of costs – through learning by doing and by incentivising flexibility – is essential.

This major investment programme can act as an economic stimulus and create over 200,000 new jobs.

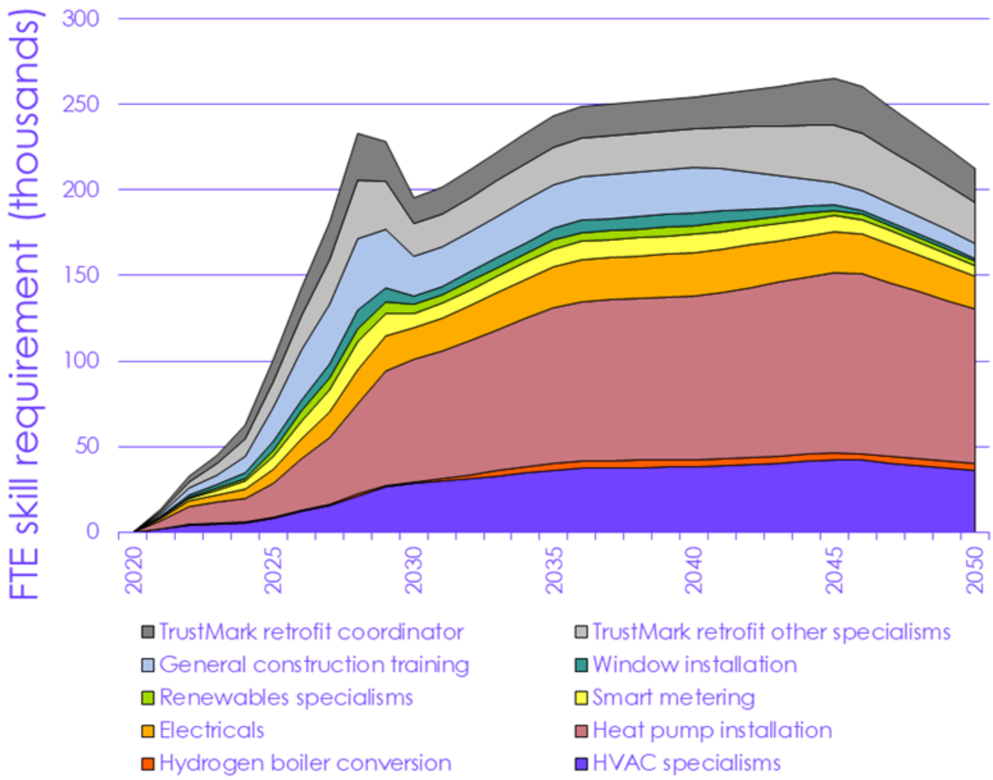
This is a major investment programme which, if managed well, can have strong economic benefits. In particular, the investment can act as a stimulus and create skilled employment throughout the UK, with the Construction Industry Training Board (CITB) estimating over 200,000 new jobs in this scenario (Figure A3.2.g). There is strong reason to believe these jobs would be additional to the current workforce. Energy efficiency retrofits are expected to provide new jobs and have already been recognised as an important part of the green recovery. Low-carbon heat installations, while replacing fossil fuel installations, are expected to drive additional jobs due to the additional labour required for more complex installations and household conversion.[§§]

[§§] Recently published evidence from BEIS suggests that the labour costs for installing an air source heat pump are roughly double those for a conventional gas boiler, with the costs being around three times higher for a ground source heat pump (Delta EE for BEIS (2020), *Cost of installing heating measures in domestic properties)*. These increased costs are representative, in part, of the increase in effort required. While there is potential for labour differentials to be more limited for hydrogen boilers and heat network connections to homes, the need for regional conversions could drive additional jobs relative to the installations which might otherwise be associated with natural replacement cycles.

Wider benefits include improved health outcomes, levels of comfort and adapting to a changing climate.

Upgrading the building stock will deliver a significant set of wider benefits in terms of improved comfort and health, particularly for the fuel poor. The current estimated cost to the NHS from poor quality housing is £1.4-2 billion per year, in England alone.[55] Energy efficiency – done alongside ventilation and shading upgrades – can improve comfort levels year-round and guard against damp (Box A3.2.a). The retrofit of homes to both address and adapt to climate change has potential to deliver regeneration benefits. More widely, the shift to electrification and heat networks can also deliver improved energy security and improved air quality. There is some evidence to suggest that there could also be air quality benefits from switching to hydrogen heating in terms of reduced NO_x emissions, although further research is needed.[56]

Figure A3.2.g Additional FTE requirements for each qualification level and specialist skill



Source: CITB (2020) Building Skills for Net Zero (draft report); CCC analysis.
Notes: Figures adjusted to represent a 2-year rolling average. 'TrustMark retrofit other specialisms' includes retrofit designers, installers, advisers and assessors. FTE equivalent by skills do not sum exactly to equivalent numbers by trade due to mapping.

Box 3.2.a
A holistic approach to retrofit

Measures to address thermal efficiency, overheating, indoor air quality and moisture must be considered together when retrofitting or building new homes.

There are zero cost actions householders can take now to better ventilate and shade their homes, including shutting curtains during the day to limit solar gains, and opening windows to improve ventilation.[***] There are also home upgrade measures which can improve overheating and ventilation further.

- Shading measures can include high specification blinds (e.g. with reflective backing) and/or external shading or awnings. We estimate that installing moderate cost measures to the most at-risk property types would add £4-£5 billion of total investment costs to 2050.[†††57]
- Ventilation measures (which can also help mitigate overheating risk) include extract fans, mechanical extract ventilation (MEV) and mechanical extract ventilation and heat recovery (MVHR). Installing extract fans is estimated to cost around £550 per home, while MEV or MVHR could add between £1,700-£4,100 per home.[58]

Wider adaptation needs, such as water efficiency and flood resilience, should be considered as part of retrofit needs but have not been costed as part of this work.

Sources: CCC and Element Energy analysis.

[***] Windows should be opened when room temperatures reach 22 degrees, but should remain closed if outdoor temperatures rise above indoor temperatures. Overheating and ventilation can both be improved by opening windows during the night to purge heat.

[†††] This assumes all flats within the housing stock install high specification blinds designed to reflect solar gain and/or allow for windows to be open during use. These costs would be additional to those presented in Figure 3.2.e.

Endnotes

[52] CCC (2020) *The Sixth Carbon Budget – The Path to Net Zero*. Available at: www.theccc.org.uk

[53] For further discussion see The Carbon Trust and Rawlings Support Services for BEIS (2016) *Evidence Gathering – Low Carbon Heating Technologies* and Delta EE for BEIS (2018) *Technical feasibility of electric heating in rural off-gas grid dwellings*.

[54] Government response to BEIS Select Committee's recommendations.

[55] Nicol S. et al. (2015) *The cost of poor housing to the NHS.*

[56] Gersen, S. Darmeveil, H. Van Essen, M. Martinus, G.H. and Teerlingc, O.J (2020) *Domestic hydrogen boilers in practice: enabling the use of hydrogen in the built environment*. These findings are supported by testing currently being undertaken by Worcester Bosch.

[57] Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget*

[58] UCL (2020) *Analysis work to refine fabric energy efficiency assumptions for use in developing the sixth carbon budget*; Currie & Brown (2019) *The costs and benefits of tighter standards for new buildings*; Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the sixth carbon budget*.

Chapter 3

Policy recommendations for the buildings sector

Introduction

The following sections are taken directly from [Chapter [2] of the CCC's Policy Report for the Sixth Carbon Budget.[59]

This chapter sets out the Committee's recommendations in buildings for delivering the Sixth Carbon Budget, building on the recommendations put forward in the CCC's 2020 Progress Report to Parliament (Table P3.1). The pathways set out in our *Advice Report* see buildings emissions fall by just under 50% from 2019 to 2035, on the way to reaching near-zero by 2050. By 2033, all of the UK's buildings should be energy efficient and all boiler replacements should use low-carbon technologies such as heat pumps – or be designated as part of a zone for district heating, or possibly hydrogen.

Table P3.1
Summary of policy recommendations in buildings

Heat and buildings strategy	Produce a robust and ambitious heat strategy which sets the direction for the next decade, with clear signals on the phase out of fossil heating and commitments to funding. This must include a clear set of standards; plans to rebalance policy costs while making low-carbon more financially attractive; plans to introduce green building passports, and a role for area-based energy plans.
Standards for existing buildings	Bring forward the date to reach EPC C in social homes to 2028, in line with the Private Rented Sector (PRS) proposals, and finalise the delivery mechanism. Implement PRS proposals for homes and non-residential buildings in line with new proposals and implement improvements to the EPC framework, including ensuring they drive the energy efficiency measures needed. Develop options to cover the regulatory policy gap for owner-occupied homes, looking at trigger points at point of sale and through mortgages. Publish proposals for standards to phase out liquid and solid fossil fuels by 2028, and in-use standards in commercial buildings.
Newbuild standards	Implement a strong set of standards – with robust enforcement – that ensure buildings are designed for a changing climate and deliver high levels of energy efficiency, alongside low carbon heat. Publish a robust definition of the Future Homes Standard and legislate in advance of 2023.
Green recovery and supply chain development	Provide a stable long-term policy framework to support sustained growth at sufficient scale (i.e. 600,000 heat pumps per year in existing homes by 2028). Ensure continuing support for non-residential heat pump installations beyond 2022, including low-carbon heat sources for district heating schemes. Create a level-playing field for hybrid heat pumps by continuing to support new business models off the gas grid both financially and by ensuring hybrid heat pumps are an integral part of PAS2035 retrofit coordinator advice.
Hydrogen development	BEIS and Ofgem should undertake a programme of research to identify priority candidate areas for hydrogen, along with areas which are unlikely to be suitable, to inform development and network investments. Undertake one or more hydrogen trials at a representative scale in the early 2020s (e.g. 300-3000 homes), to inform decisions on low-carbon zoning from 2025. All new boilers to be hydrogen-ready by 2025 at the latest. Continue further pilots in the late 2020s, where valuable to inform large-scale take-up.

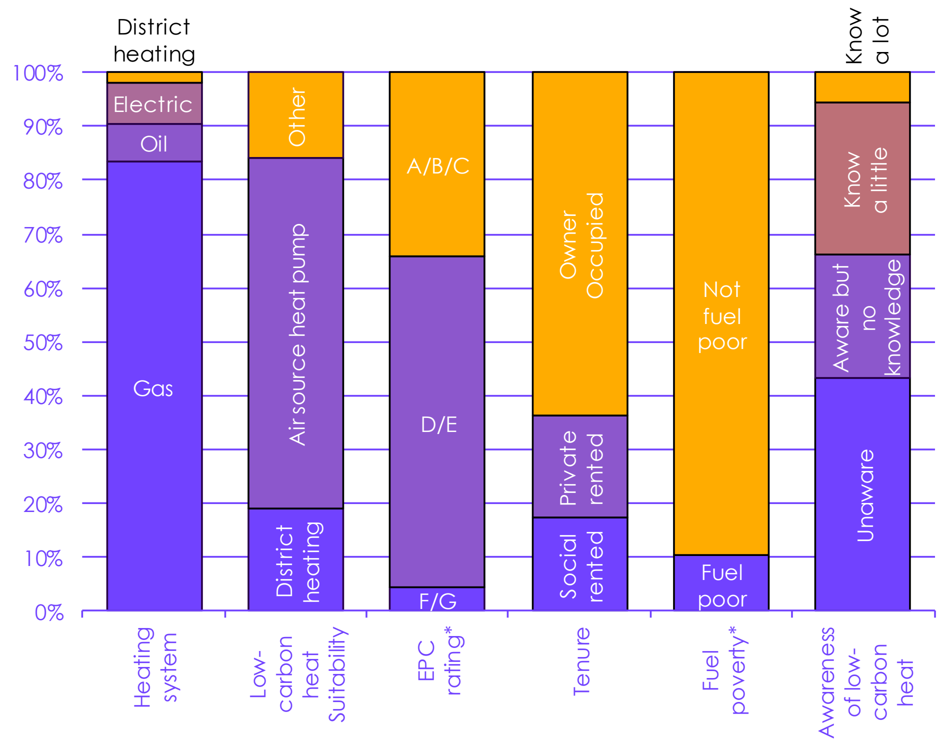
Low levels of public engagement and higher upfront costs of low-carbon heating make buildings particularly challenging to decarbonise.

Buildings is a particularly challenging sector to decarbonise.

- Progress has been slow to date, with emissions remaining flat or rising for the last five years.
- The implementation of key measures remains at very low levels, with weak supply chains for key measures such as insulation and heat pumps, and hydrogen use still in a development phase.
- Levels of public engagement are low - in particular, there is low awareness of the need to shift to low-carbon heating.

- This is compounded by the low cost of gas heating and balance of policy costs between electricity and gas, which make low-carbon options uncompetitive.
- Finally, the UK housing stock is both diverse and relatively inefficient, which means that a range of approaches is necessary (Figure P3.1). This includes a range of ownership – council, housing association, private-rented, owner occupiers with mortgages, owner occupiers without mortgages – as well as both freeholders and leaseholders.

Figure P3.1 Overview of the housing stock according to key metrics



Sources: Heating System: Element Energy (2020) for CCC; Low-carbon heat suitability: Element Energy and UCL for CCC (2019);[60] EPC Rating: MHCLG (2019);[61] Tenure: MHCLG (2020),[62] Scottish Government (2018),[63] Stats Wales (2020),[64] Department for Communities (2019)[65]; Fuel Poverty: BEIS (2020a);[66] Awareness of low-carbon heat: BEIS (2020b)[67]

Notes: *EPC and fuel poverty statistics shown for England only. Low-carbon heat suitability reflects assessment undertaken for Net Zero advice, and reflects the portion of the stock deemed suitable for air source heat pumps, net of those suitable for district heating.

However, our understanding of public support has developed, along with a growing consensus on the way forward. In particular, the UK Climate Assembly has shed new light on public support for different heating solutions and priorities for the transition, which can help shape Government's strategic approach:

- On low-carbon heating, Assembly Members back the use of hydrogen, heat pumps and heat networks, stressing that local areas should be able to choose the options best suited to their needs.

- On home retrofits, they emphasised the need to minimise disruption in the home, put in place support around costs and offer flexibility and choice to householders.

Government's Heat and Buildings Strategy aims to address these challenges and is due shortly. This advice supports that strategy development.

BEIS and MHCLG are currently developing a Heat and Buildings Strategy for imminent publication, following on from the 2018 evidence assessment.[68] This aims to address the challenges and set the policy direction through the next decade. We have worked up a set of policy recommendations based on evidence of what works,[69] insights from our pathways work and significant stakeholder input, to support the development of the strategy. This was presented at an Autumn Ministerial roundtable and is set out in the following section. Further detail on how we have developed our scenarios is set out in the Method report.

The following sections cover:

1. Current policy commitments
2. Key changes required

1. Current Government policy commitments

The Government plans to get all homes to EPC C over the next 10-15 years.

The UK Government has developed plans to improve the energy efficiency of all buildings over the next 10-15 years, and plans to phase-out the installation of new high-carbon fossil fuels in the 2020s:

- **Home efficiency**. In the 2017 *Clean Growth Strategy*, the Government committed to getting all fuel poor and rented homes to EPC C by 2030, and other owner-occupied homes by 2035. In September 2020 it published proposals to bring forward the date for private-rented homes to 2028.
- **Rented commercial and public buildings.** Existing regulations require all privately-rented properties in England and Wales to be at least EPC E by April 2023. In October 2019 the Government published proposals for all non-residential private-rented buildings in England and Wales to meet EPC B by April 2030 where cost-effective, based on meeting a seven-year payback test. BEIS estimate 64% of the stock will meet the EPC B target, 20% to fail but meet EPC C cost-effectively and 17% to be unable to meet EPC C cost-effectively.[70]
- **New buildings.** Under the proposed Future Homes Standard, no new buildings will be built with fossil fuel heating. UK Government is looking to introduce this in advance of 2025 in England and Wales, with the Scottish Government aiming for the same outcome from 2024.
- **Commercial efficiency**. In the Clean Growth Strategy, the Government set a goal to enable businesses and industry to improve energy efficiency by at least 20% by 2030.
- **Public buildings**. Government is aiming to reduce public sector emissions by 50% by 2032 against 2017 levels.

There are plans to phase out liquid and solid fossil fuels but no current proposals to phase out natural gas.

- **High-carbon fossil fuel phase out**. The commitment here is to phase out the installation of new coal and petroleum appliances in the 2020s, on which a consultation is due shortly. This covers 11% of the current energy consumption for heating and hot water[71].

Energy efficiency funding is targeted at the fuel poor, at social homes and public buildings at a UK level.

This regulatory timetable is supported by £9.2 billion of funding targeting public sector buildings, social homes and the fuel poor, on top of at least £4 billion committed under the ECO programme. An additional £2.0 billion of funding for homes has recently been announced through the Green Homes Grant, now extended until the end of the 2021/22 financial year.[72]

The UK Government's 2020 *Ten Point Plan* includes a number of further commitments. It is aiming to achieve sales of 600,000 heat pumps a year (across all homes) by 2028, and investing in hydrogen development, including a 300 home trial in Fife.[73]

The Scottish Government has a more ambitious programme in place in some areas. It has published proposals for point-of-sale standards to require all owner-occupied homes to meet EPC C, to be introduced from 2024, with a cap of £15,000 per home. This means that any homes which are below an EPC C efficiency rating will need to be upgraded before they can be sold. This is supported by £1.6 billion of funding to 2025 across buildings heat and efficiency. Smaller amounts of funding are available in Wales and Northern Ireland.

15.5 million 'owner-occupied' homes are not currently covered by proposed efficiency standards in England, Wales and Northern Ireland.

The main regulatory policy gaps are efficiency standards for 15.5 million owner-occupiers (of which over 65% are below EPC C), owner-occupied commercial buildings and plans for phasing out natural gas heating:

- There are currently about 29 million homes in the UK, of which 19 million are below EPC C. Of the 29 million, 18 million are owner-occupied, of which around 1.5m are fuel poor*. Accounting for the Scottish Government proposals, this means that there are 15.5 million potentially 'able-to-pay' properties not currently covered by proposed standards.
- Commercial buildings which are owned rather than leased are likewise not covered by current policy proposals.
- Around 85% of existing homes and 63% of public and commercial heating is met through natural gas which is not currently covered by regulatory proposals to phase out natural gas.

In the next section, we set out what more is required to address this regulatory policy gap as part of a broader policy package which creates employment and delivers a broad set of wider benefits in terms of comfort, health and ongoing energy bills savings.

* Calculated from percentage for England, in: BEIS (2020) 'Table 18: Fuel poverty detailed tables 2020', *Fuel poverty statistics report for 2020*. Department for Business, Energy & Industrial Strategy.

We have developed a four-point policy package in consultation with a broad set of stakeholders, covering: a clear direction; making low-carbon financially attractive; enabling measures such as green passports and skills strategy, and getting on with it - using planning and other tools.

We have developed a policy package in consultation with stakeholders which draws on the sixth carbon budget pathway analysis. In the following sections, we set out the four core components of the policy package along with the supporting evidence (Figure P3.2).

Figure P3.2 Buildings heat – high-level Sixth Carbon Budget policy package

Source: CCC

a) A clear direction

By the start of the Sixth Carbon Budget in 2033, all UK buildings should be energy efficient, the heat pump industry should have scaled up to be able to manage over a million installations a year in homes, heat networks should be fully low-carbon and being rolled out at scale and there should be a clear plan for the role of hydrogen in UK buildings.

Our pathways in this report factor in rapid progress in a set of low-regrets options for decarbonising buildings, including widespread energy efficiency, tackling newbuild, heat pumps in buildings off the gas grid, low-carbon heat networks and biomethane.[†]

[†] Further detail on the role of these is included in Chapter 3 of *The Sixth Carbon Budget - The UK's path to Net Zero* and the 2019 *Net Zero* report.

Government needs to give clear signals – electrification is of primary strategic importance; hydrogen provides flexibility and could play a role in regional grids, particularly in areas near industrial clusters.

i) The importance of electrification

Our Balanced Pathway is informed by the following judgements regarding the gas grid:

1. Efficiency is a fundamental first step, or the scale of the problem gets too big.
2. Low-carbon heat networks are a competitive and flexible solution in heat dense areas such as cities.
3. System costs are not a major differentiator between electrical and hydrogen heat for remaining homes on the gas grid,[74] so public support is likely to determine the shape of our decarbonised future. With coordination, solutions can vary by region, depending on local resources, infrastructure and consent.
4. Full hydrogen conversion is unwieldy due to the low system efficiency which poses a significant supply-side challenge (Chapter 2, Advice Report). As a worked example, 800 TWh of hydrogen would require 100-150 GW of gas reforming with CCS; or 300 GW offshore wind capacity if just using electrolysers. On this basis we do not recommend planning on a full hydrogen conversion. Full electrification would be challenging (though not impossible) as it requires considerable flexible supply and possibly an element of boiler scrappage if delays in building supply chains persist. This means it is sensible to plan for a range of solutions.

This implies electrification is of primary strategic importance for Net Zero; crucially, this strategic importance remains true even where hydrogen grid conversion is widespread (as illustrated in our Headwinds Pathway). Hydrogen is particularly valuable where it can provide flexibility – either at a system-level within the power sector, or at a buildings level through hybrid heat pumps. It could also play a supporting role through targeted regional gas grid conversion, where there is public support and an underlying technical case (for example, due to co-location with an industrial hydrogen cluster). Hybrid heat pumps offer a number of benefits and should be covered by the policy package (Box P3.1).

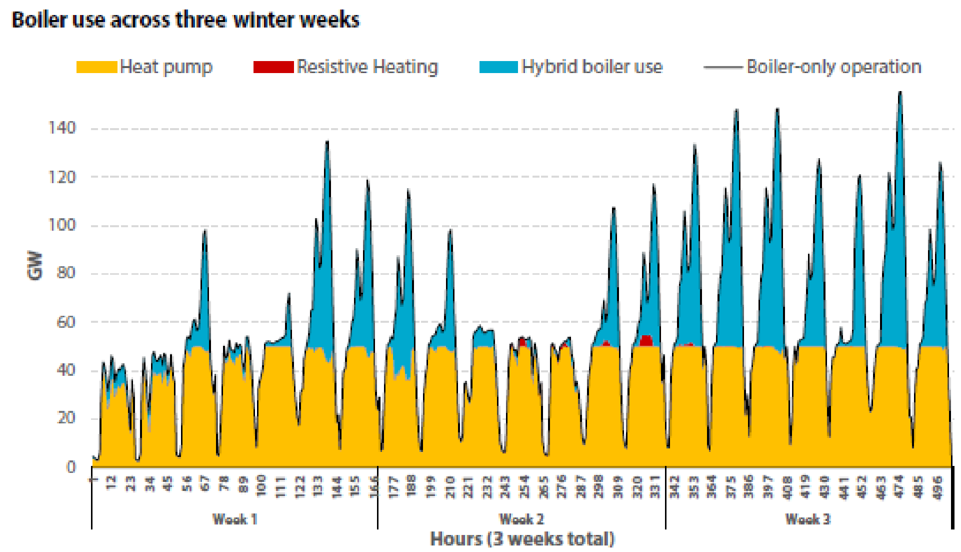
It is essential that the Government sets a clear commitment to electrification through the 2020s, including a stable and long-term support framework to build the heat pump supply chain to sufficient scale to deliver near term emissions reductions and keep full electrification on the table (1 million heat pumps a year in homes by 2030) (Box P3.2).

Box P3.1
Role of hybrid heat pumps

There is optionality over how hydrogen is used, including its role in the power system, the balance of use between heat pump-hydrogen boiler hybrids and hydrogen boilers at buildings level, and the extent of any regional conversion. In a system which uses high volumes of hydrogen, the use of hydrogen hybrid heat pumps can offer a number of benefits. These include:

- **A much lower reliance on CCS and imported natural gas**. Our net zero analysis suggested that very high amounts of CCS would be likely be required (>175 $MtCO_2$/year) even with constrained use of hydrogen alone in buildings. This constraint is potentially binding.
- **Lower residual GHG emissions**. Gas reforming with CCS is low-carbon rather than zero carbon, providing lifecycle emissions savings of 60-85% relative to natural gas use in boilers. If hydrogen from gas with CCS is deployed in very large quantities, the emissions savings may be insufficient to meet stretching long-term emissions targets.
- **Potentially competitive economics**. The evidence suggests that the majority of the costs involved with a full hydrogen scenario come from the cost of the hydrogen itself which remains considerably higher than the upfront costs of converting the gas grid and making changes inside the home. This remains true even given the higher capital costs of hybrid heat pump solutions.
- **System level flexibility benefits**. Hydrogen hybrid heat pumps would enable heating systems to respond to economic signals around the relative prices of fuels and to infrastructure constraints (e.g. ensuring electricity demand does not exceed local grid capacity).

Figure B3.1 Hybrid heat pumps and hydrogen can help deliver a flexible, low-cost solution



Source: CCC (2018) *Hydrogen in a low-carbon economy*, based on Imperial College (2018) *Analysis of alternative UK heat decarbonisation pathways*
Notes: Chart shows aggregate heat demand for both domestic and non-domestic premises. Pattern of use could be expected to be similar on individual premises. Chart is for heat output, rather than energy input. 'Boiler only operation' is shown as a comparator, and is not expected to be in addition to the boiler in a hybrid system.

Hybrid heat pumps have potential to offer a number of broader benefits in the near-term:

- **Advantages in public acceptability.** Unlike a shift straight to an electric heat pump, a switch to hybrid heat pumps would enable people to experience unchanged characteristics of the heating service they receive and avoid disruption (e.g. by replacing radiators), while increasing familiarity with the technology.

- **Scope for accelerated near term deployment and emissions reductions**. Hybrid heat pumps can be installed alongside existing systems such that distressed purchases need not be a barrier, and installation is more viable in advance of boiler end of life. It can also be installed alongside, rather than following improvements to the energy efficiency of buildings.
- **Suitability in hard-to-decarbonise properties, particularly in homes off the gas grid.** There are estimated to be around 1.3 million heritage homes, including 400,000 listed buildings. Homes off the gas grid are larger on average. For a portion of hard-to-decarbonise homes, hybrid solutions and cascading heat pumps will be more cost-effective than extensive efficiency upgrades with a large single heat pump.[75]
- **Reducing reliance on single set of government-led decisions in mid 2020s**. By taking the first part of the decision (i.e. on a move to hybrid heat pump-boiler systems) over how to decarbonise heat fully for on-gas properties now, the second part – on how to reduce emissions from the considerably lower residual natural gas use – could potentially follow in the second half of the 2020s.

In the context of the benefits that hybrid heat pumps have potential to provide, it remains that there are risks and uncertainties which would also need to be overcome. While hybrid heat pumps can offer a host of benefits, in order to achieve these it is important that hybrids are used effectively in homes. Based on work undertaken by Imperial College London our base assumption is that hybrid heat pumps can operate in heat pump mode up to 80% of the time.[76] Other trial data (e.g. from Passiv Systems, when combined with smart controls) supports the Imperial assumptions. However there is also evidence of homes using heat pump components of hybrids much less.[‡] A sensitivity conducted on our scenarios suggests that hybrid heat pumps which only operate in heat pump mode 50% of the time (relative to 80% of the time in the baseline case) are significantly less cost effective.

In order to overcome challenges of this kind, standards on smart heating controls and operation, and rebalancing of gas and electricity prices, would be important parts of any policy package.

Sources: CCC analysis; Energy Systems Catapult for BEIS (2019); Element Energy and UCL for CCC (2019)[1]

Box. P3.2
Heat pump deployment in homes over the coming decade

Our Balanced Pathway includes deployment of 5.5 million heat pumps in homes to 2030, of which 2.2 million are in new build homes, with a large proportion of the remainder expected to be installed off the gas grid. This is consistent with deployment rates reaching just over 1 million a year in homes by 2030, compared to just 26,000 a year currently.

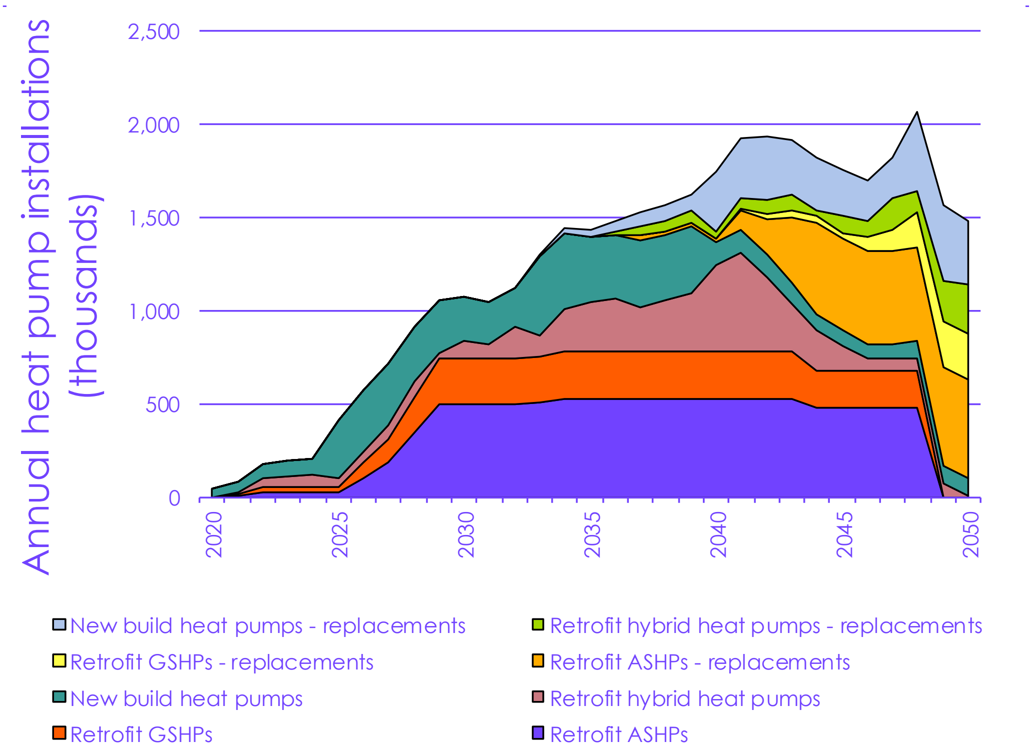
The deployment trajectory for heat pumps in our Balanced Pathway reflects our assessment that there remains a strong case for delivering growth of this scale, regardless of the heat mix chosen post-2030:

- **Clear market signals.** A commitment to strong near-term uptake provides the policy certainty necessary to support the levels of electrification across scenarios (with Headwinds also reaching deployment of 1 million heat pumps a year by the early 2030s).
- **Preparing supply chains to keep options open for full electrification.** For full electrification, boiler lifetimes imply a need to scale up markets and supply chains to cover all new installations by the mid-2030s at the latest, representing up to 1.8 million heat pumps a year in existing homes. Supply chains must grow steadily to accommodate not only first-time heat pump installations in existing homes, but also new build installations (including retrofits for those homes being built now with gas) and replacements (Figure B3.2).
- **Further benefits of early deployment.** These include driving down near-term emissions (reducing the scale of the challenge to 2050), increasing consumer familiarity ahead of further widespread adoption and driving down the costs through learning by doing.

Our analysis finds that deployment at this scale is achievable. The level of deployment remains well within the deployment constraints developed in discussion with stakeholders, assumed to reach around 1.3 million heat pumps by 2030. There is also evidence to suggest that this level of deployment may not be contingent on significant retrofit, with nearly 7 million homes in our scenarios receiving no or low energy efficiency packages. Where deployment comes in the form of hybrid heat pumps, early deployment is likely to be possible across a wider variety of homes.

‡ The Energy Systems Catapult conducted a trial where the performance of hybrid heat pumps was shown to be highly dependent on household heating behaviours, with heat pumps operating as part of hybrid heating systems delivering between 6% and 63% of the heating in different homes.

Figure B3.2 Annual heat pump deployment in homes



Source: CCC analysis, Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget*

Source: CCC analysis; Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget*.

ii) Phase-out dates and standards

A clear timetable is needed, backed by standards. We have set out an indicative timetable based on extending the current regulatory approach and working as much as possible with existing technology lifetimes to minimise costs and disruption.

The second element to setting direction is a clear timetable, backed by standards. We have set out an indicative timetable based on Government's existing commitments, and extending its current regulatory approach (Table 3.1). This is driven by the need to minimise costs and disruption, which means working as much as possible with existing technology lifetimes, while minimising scrappage. It would be possible to deliver a similar outcome through higher levels of subsidy and later regulation, but our modelling suggests that this is the minimum level of additional regulatory commitment required to deliver the programme of Net Zero buildings in the Sixth Carbon Budget pathway. Alternative regulatory approaches could also be possible, where they deliver similar levels of ambition.

Table P3.2
Critical dates and policy implications in the Balanced Pathway for buildings

	Indicative date	Policy implications
Efficiency		
All new buildings are zero-carbon	2025 at the latest	Implement a strong set of standards that ensure buildings are designed for a changing climate and deliver high levels of energy efficiency, alongside low-carbon heat. Commit to publishing a robust definition of the Future Homes Standard which is legislated in advance of 2023.
Rented homes achieve EPC C	2028	This means reforming EPCs to make them fit for purpose, aligning the timetable for social homes to private-rented sector (PRS) proposals, finalising a delivery mechanism for social homes, and legislating the PRS proposals.
Standards for lenders targeting EPC C across the housing portfolio	2025 - 2033	Government to pursue options set out in the Green Finance Strategy for mandatory disclosure by lenders of average efficiency across the mortgage portfolios, and introduce a progressive set of minimum standards.
All homes for sale EPC C	2028	No buildings can be sold unless they meet the minimum standard.§ At the current housing turnover of once every ten years for mortgagors and once every 24 years for outright owners, regulations at point of sale would be expected to result in a further 15% of owner occupied homes meeting the required standard by 2035 (with further upgrades driven by the standards on lenders, totalling at least 60% of owner-occupiers overall).
All commercial efficiency renovations completed	2030	BEIS must accelerate plans for a new in-use performance standard for commercial properties along with plans for SMEs and legislate the private-rented proposals.
Heating		
All boilers are hydrogen-ready	2025	Based on projected additional costs of £100 or less per boiler, and with a view to minimising scrappage, we recommend appliance standards for hydrogen-ready boilers. Should costs prove higher or safety considerations materialise, this should be reviewed. Early commitments and widespread standards would be expected to drive costs down through competition and economies of scale.
Oil and coal phase out (outside of any zones designated for low carbon district heat)	2028	BEIS must now publish long-awaited proposals to phase out the installation of new high-carbon fossil heating. Further support is needed in the near-term to build critical supply chains and to channel investment in networks.
Natural gas phase out (outside of any zones designated for low-carbon district heat or hydrogen-conversion areas)	2033	A decision-making framework spanning national, regional and local levels, and informed by regional and local area planning, is needed to facilitate decisions on the future of heat. A programme of area-based energy planning can provide a locus for meaningful public engagement. In areas not designated as areas for hydrogen or heat networks, standards phasing out the installation of gas appliances will allow low-carbon heating to become widespread by 2050.
Gas CHP phase out for low-carbon heat networks	2025	Relative Gas Combined Heat and Power (CHP) carbon benefits reduce as the grid intensity continues to fall through the 2020s. On this basis, we assume that all new district heat network connections from 2025 are low-carbon, requiring emissions performance standards and funding for low-carbon heat sources. All heat networks supplied by legacy CHP schemes convert to low-carbon heat sources by 2040.

Setting a phase out date for natural gas (outside of designated hydrogen or district heat conversion zones) can build on the approach for high-carbon fossil fuels. The UK Citizens Assembly supported a ban on new gas boilers between 2030-2035, with 86% in favour.[77]

§ In Scotland, these requirements are subject to spending caps. Our scenarios also implicitly assume spending limits form part of the minimum standards for all homes – for instance, we exclude measures from our economic potential where the costs are deemed too high, including for some hard-to-treat measures.

Boiler lifetimes of 15 years imply a phase out date for the installation of fossil fuel boilers in advance of 2035. Our Balanced Pathway picks a central date of 2033.** This in turn implies:

- The need to prepare the building stock for low-carbon heating in advance of this, through an approach which completes the majority of energy efficiency installations by the time the full-scale transition occurs. Our Balanced scenario assumes 76% of fabric energy efficiency measures in homes are deployed by 2033 and that 100% of public and commercial energy efficiency measures included in the scenario are complete. ††
- The need to build low-carbon heat supply chains in the near term, such that they are able to service up to around 1.8 million homes by 2033 and 50% of the non-residential heating market.‡‡
- The need to designate areas for low carbon district heat networks and hydrogen conversion well in advance of 2033.
  - This would enable buildings in these areas to be given an exemption from a ban on fossil fuel boilers, such that they need only undergo one low-carbon heating transition and that infrastructure costs can be minimised.§§
  - An exemption could take different forms and could still require new heating systems in these areas to meet certain conditions (such as hybrid heat pump configurations) even where some continued role for fossil fuels is permitted beyond 2033.

Moreover, keeping hydrogen in play means progressive steps building through the 2020s to develop an integrated approach across buildings, CCS, industry and transport (Figure P3.3).

- Where electrification remains the primary route to decarbonise buildings, it is expected that decisions on the future of the gas grid are most likely to comprise of a series of decisions on hydrogen zoning, informed by cross sectoral considerations.
- Decisions on those areas which will not be converted will be of equal importance, with early designation enabling effective targeting of electric heating and district heating, and associated infrastructure upgrades.
- This approach to decision-making can help minimise the risk of remaining uncertainties holding up progress on decarbonisation.
- It also implies the need for careful consideration of how the distributional implications of staggered low-carbon heat conversions might be managed.

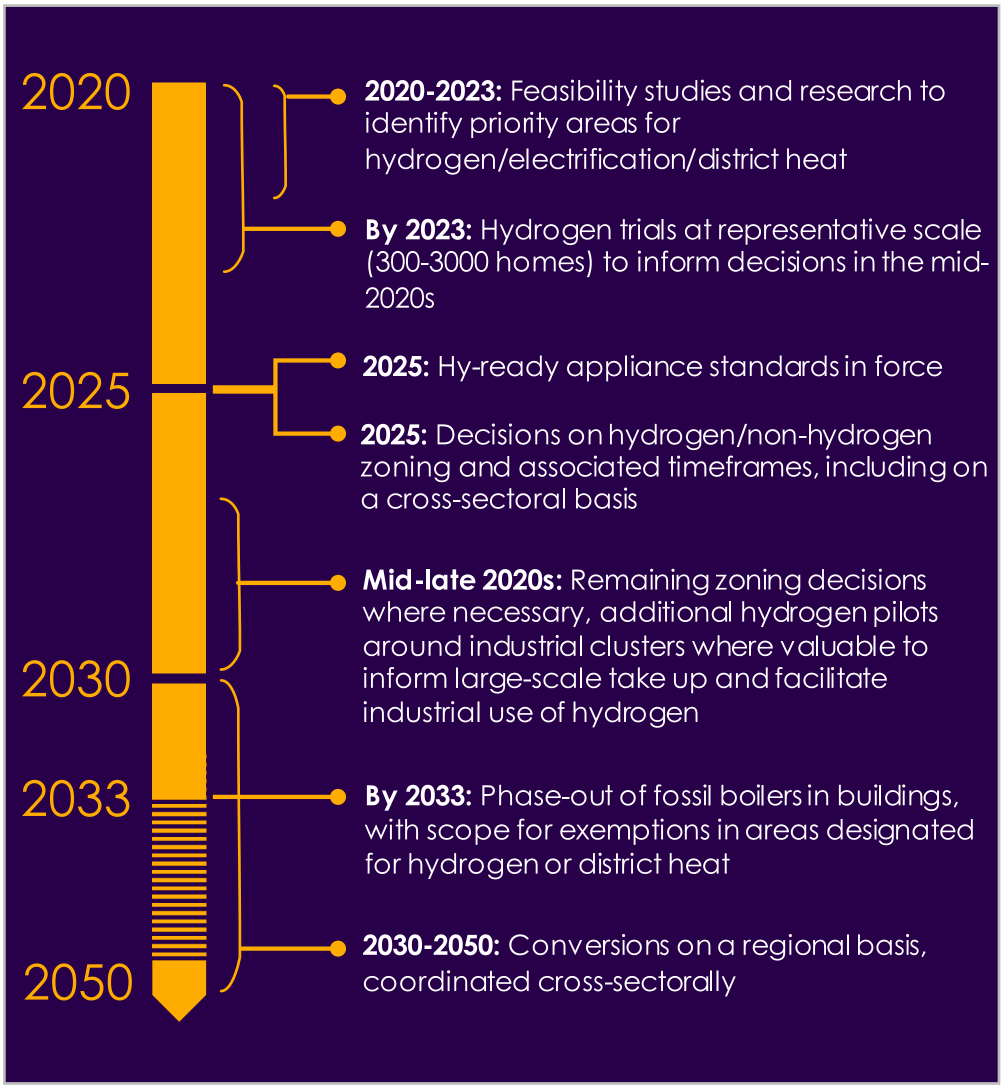
** Phase out regulations on the gas grid are envisaged to prevent the installation of new fossil fuel boilers in areas not designated for hydrogen or low carbon heat network conversion. An earlier date of 2030 is adopted for public buildings in order to achieve the targeted 50% cut in emissions by 2032.

†† See Chapter 3 of the Methodology Report for details of what is included for public and commercial energy efficiency in our scenarios.

‡‡ 1.8 million homes based on current annual boiler sales. Some of these homes would be expected to switch onto district heat, with a small number potentially needing low-efficiency electrified solutions.

§§ For instance, heat density is a key determinant of the costs of low carbon district heat provision. On this basis it is preferable to maximise the number of buildings using low carbon district heat where a heat network is in operation, This suggests the need to minimise alternative heating solutions.

Figure P3.3 Indicative hydrogen development Pathway for buildings



b) Making low-carbon buildings financially attractive

Policy must make low-carbon heat affordable and cost-competitive by targeting cost reduction, rebalancing policy costs and increasing funding for low-carbon heat.

Policy must make low-carbon heat affordable and cost-competitive by targeting cost reduction, rebalancing policy costs and increasing funding for low-carbon heat.

i) Cost reduction

The first step is to minimise costs through fabric efficiency measures, through learning by doing, and by enabling household-level flexibility:

- When installed in energy efficient homes, low-carbon heat can offer running cost savings relative to fossil fuel alternatives
- Innovation provides scope for cost savings over time in both energy efficiency and low-carbon heat, including through innovative roll-out models, modularisation and improved system design[***,78]
- Valuing and enabling flexible loads can cut costs and carbon. We estimate that pre-heating could save up to £2 billion per year.[79]

Government and Ofgem can enable household-level flexibility through implementing their Smart Systems and Flexibility Plan, including rolling out mandatory half-hourly settlement, and supporting cost-reflective charging and smart tariffs. Standards on smart heating could help maximise emissions reductions and minimise the system costs of electrifying heat.

ii) Rebalancing policy costs

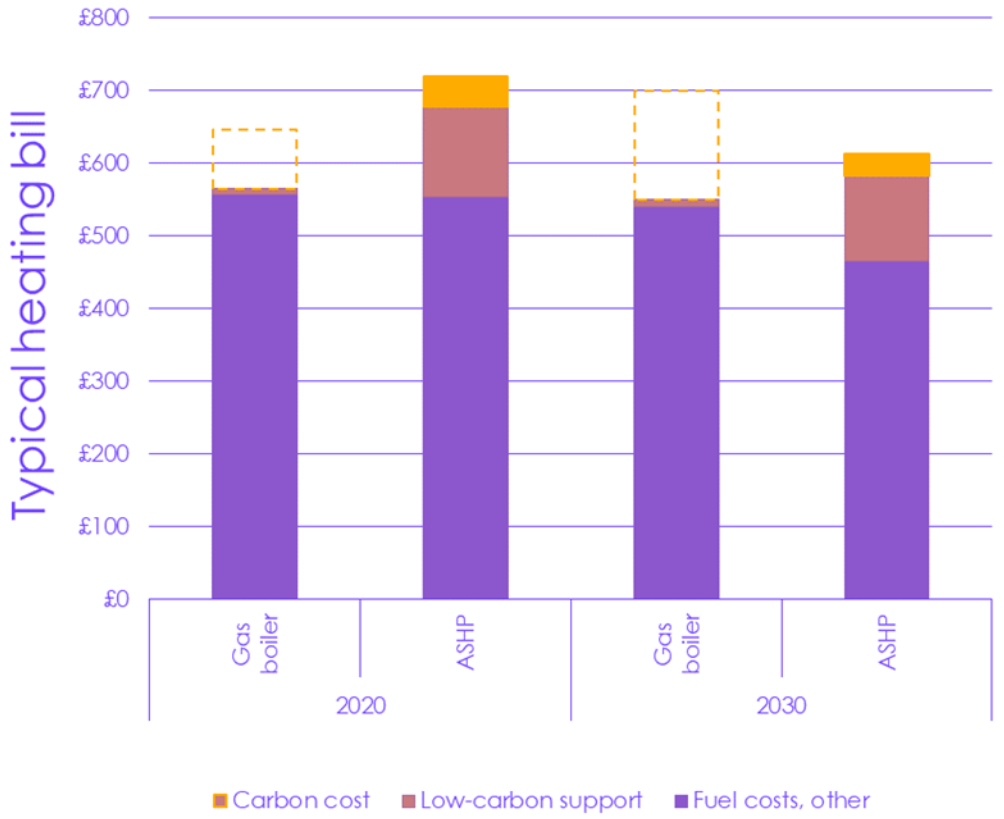
Rebalancing policy costs on electricity and gas is also a critical enabler, cutting running costs for electric heating where it is displacing fossil fuels (Figure P3.4).

A favourable VAT regime – including on the sale and installation low-carbon technology – can also support low-carbon solutions.

More broadly, it will be essential for Government to assess how the costs of all forms of heating – electric, hydrogen, hydrogen-hybrid and heat networks – can be made fair, and protect vulnerable and low-income households. This is particularly important with different solutions emerging in different parts of the country.

[***] This could include a role for area-based approaches to retrofit, making use of the 'mass customisation' model described in a recent report by the Connected Places Catapult and the Housing Innovation Programme. Energiesprong provides an excellent example of an approach which can deliver holistic deep retrofits for groups of homes whilst also offering guaranteed performance.

Figure P3.4 The uneven distribution of policy and carbon costs on electricity and gas penalises low-carbon electric solutions



Source: CCC analysis
Notes: Switching to heat pumps is made more costly by the fact that the carbon costs of gas are not reflected in its price and the distribution of the costs of low-carbon support across fuels. Electricity consumption is subject to a carbon price under the EU Emissions Trading System (ETS) and the Carbon Price Floor in the UK, whereas there is no carbon price on gas consumption. Both electricity and gas prices include a portion which is support for low-carbon and fuel poverty schemes, at 3.5p/kWh on electricity and 2.1p/kWh on gas. Low-carbon support costs are higher on electricity as they include the costs of decarbonising the power sector (through subsidies such as the Contracts for Difference).

iii) Increasing funding for low-carbon heat

The final step consists in addressing the remaining upfront cost barrier, through a combination of private (including 'green') finance and public funding targeted at low-income households and to support the vulnerable, along with other priority areas such as public buildings and social housing:

- The current policy approach aims to leverage private finance where possible, including through landlords and 'able-to-pay' owner-occupiers. For energy efficiency, householders can access low cost finance through mortgage finance, although there are still relatively few 'green mortgage' products on the market. The Green Finance Institute identified digital green passports based on accurate in-situ performance as a key solution to raising finance.

- Public spending should be prioritised for low income households and areas of the economy which do not have recourse to other funding. Additional Exchequer-funding may facilitate the transition (see Chapter 6 of our Advice report).

- Public spend can also act as an economic stimulus as part of the Green Recovery. This has been recognised by the Government in the launch of the Green Homes Grant and Public Sector Decarbonisation scheme.

We have mapped current public commitments against investment projections, and identified three major funding gaps for existing homes: public sector buildings, along with bridge funding for heat pumps and low-carbon heat networks.

We have mapped current public commitments against investment projections for existing buildings. Our assessment is that, by and large, existing public funds are well targeted. However, we have identified three major funding gaps to 2030: public sector buildings, along with bridge funding for heat pumps and low-carbon heat networks (Table P3.3).

In our accompanying Advice report (Chapter 6), we set out an illustrative funding package in 2030 of £5-7 billion/year in 2030, including an additional £0.5 billion/year for low-income households; £0.5 billion/year for social homes and £1 billion/year for public sector buildings.

We also map current funding commitments against investment projections for public and commercial buildings, finding a shortfall in support for public buildings and negligible support for commercial buildings (Table P3.3):

- Funding for decarbonising the public sector currently stands at around £1 billion with a pledge to increase this to £3 billion, including grants under the Public Sector Decarbonisation Scheme in England, the Public Sector Low Carbon Skills Fund and additional funds in Scotland and Wales.[80,81] We estimate costs of delivering public sector energy efficiency and heat pumps to 2030 of over £5 billion in our Balanced Pathway, suggesting a shortfall which will need to be met by central Government and/or supplemented by public bodies using interest free loans such as Salix or raising other funds.

- A substantial amount of investment in commercial energy efficiency is required in our scenarios, which may need to be largely met by the private sector. BEIS has a BASEE innovation fund to develop new business models that encourage take up of energy efficiency projects by small and medium businesses (SMEs).[82] Implementing in-use performance monitoring of commercial buildings could drive progress and low-cost finance will be needed to facilitate.

There is little planned financial support for low-carbon heat in the commercial sector. The Non-Domestic RHI closes to new applicants on 31 March 2021, with a year extension to submit full applications for accreditation due to COVID 19 disruption; and a new allocation of tariff guarantees to provide certainty to larger, better value for money installations. The proposed Clean Heat Grant for 2022-24 is set to include the smallest commercial businesses as well as homes.[83] With a capacity restriction of 45kW and limited funding, there will remain a significant gap in support to drive commercial low-carbon heat.

Table P3.3
Investment costs to 2030 in our Balanced Pathway alongside committed public expenditure

Segment	Estimated investment costs to 2030	Committed public expenditure to 2030 (estimated)	Comment and RAG rating
Fuel poor owner-occupied homes, energy efficiency	£4.5- 8.9 billion**	UK Govt: ~£5-6 billion across fuel poor homes (ECO, portion of the Home Upgrade Grant, portion of Green Homes Grant) Around £0.5 billion at Devolved Administration level Further funding possible from Scottish Government*	Funding in line with projected costs
Social housing, energy efficiency	£3.1-4.0 billion**	UK Govt: £3.8 billion Further funding from Scottish Government*	Funding in line with projected costs
Other owner-occupied homes, energy efficiency	£10.6 billion	UK Govt: £1-2 billion (a portion of the Green Homes Grant) Further funding from Scottish Government*	Current funding in place to 2022 with a focus on private finance for remainder
Private-rented homes, energy efficiency	£11.1-13.5 billion**	UK Govt: fuel poor funding (see top row) and Green Homes Grant Possible further funding from Scottish Government*	Regulatory approach designed to leverage private finance
Heat pump scale up to 2025, existing homes	Estimated £3.0 billion	UK Govt: Estimated £0.5-2 billion (Clean Heat Grant plus a portion of Green Homes Grant and Home Update Grant) Further funding from Scottish Government*	Additional funding is required to support the scale up of supply chains ahead of the introduction of standards
Heat pumps, 2025-2030, existing homes	£17.7 billion including £2.8 billion in social homes	Negligible	Current gap in social homes – extent of additional gap will depend on funding model
Heat networks (all buildings)	£17.5 billion in total, of which £~5.5 billion to leverage private investment	UK Govt: £0.6 billion, aiming to leverage ~£2 billion private finance Further funding from Scottish Government*	Further funding required, particularly for low-carbon heat sources post-2022
Public sector energy efficiency and heat pumps	£5.4 billion total cost to 2030.	UK Govt: £3 billion Further funding from Scottish Government*	Public funding will be required for the gap
Commercial energy efficiency	£21 billion	UK Govt: £6 million Further funding from Scottish Government*	Proposed standards to leverage private finance Possible gap for SMEs
Commercial heat pumps	£0.5 billion total cost to 2030. £80 million to 2025 if funding heat pumps at 80%.	UK Govt: <0.1bn under Clean Heat Grant for heat pumps <45kW Further funding from Scottish Government*	Additional bridge funding may be required until standards are introduced to build the supply chains

Sources: BEIS (2020),[21,22,23,24,84] The Conservative Party (2019),[85] Scottish Government (2020),[86] Welsh Government (2019),[87] HMG (2020)[13]
Notes: Estimates of committed policy spend are based on limited information and are subject to change. They are approximated based on current Government announcements and involve a number of judgements, particularly regarding how the Green Homes Grant, the Home Upgrade Grant and ECO will be apportioned between segments (reflected in ranges). Rows are not designed to be summed due to overlaps. *The Scottish Government has committed £1.4 billion of funding over the next Parliament, but it is not possible to disaggregate this currently. ** The top end of the range includes floor insulation in all fuel poor homes. This was implemented in Element's modelling by assigning high energy efficiency packages to these homes, and as such floor insulation was also included. In practice, it is likely that deployment of floor insulation may be more limited (particularly where this is more expensive solid floor insulation).

c) Enabling measures: information and skills

i) Information

High quality advice and information is a critical enabling measure.

High-quality advice and information is critical for guiding householders' decisions, and scored highly with the UK Climate Assembly.[88]

EPCs have been a useful source of basic comparable information but they have extensive issues (poor quality/low robustness; modelled rather than actual performance; they do not show benefits of decarbonising electricity or savings possible from smart tariffs; they do not always incentivise the measures needed to support decarbonisation).

There is an urgent need to reform EPCs to ensure they are fit to support near-term progress.

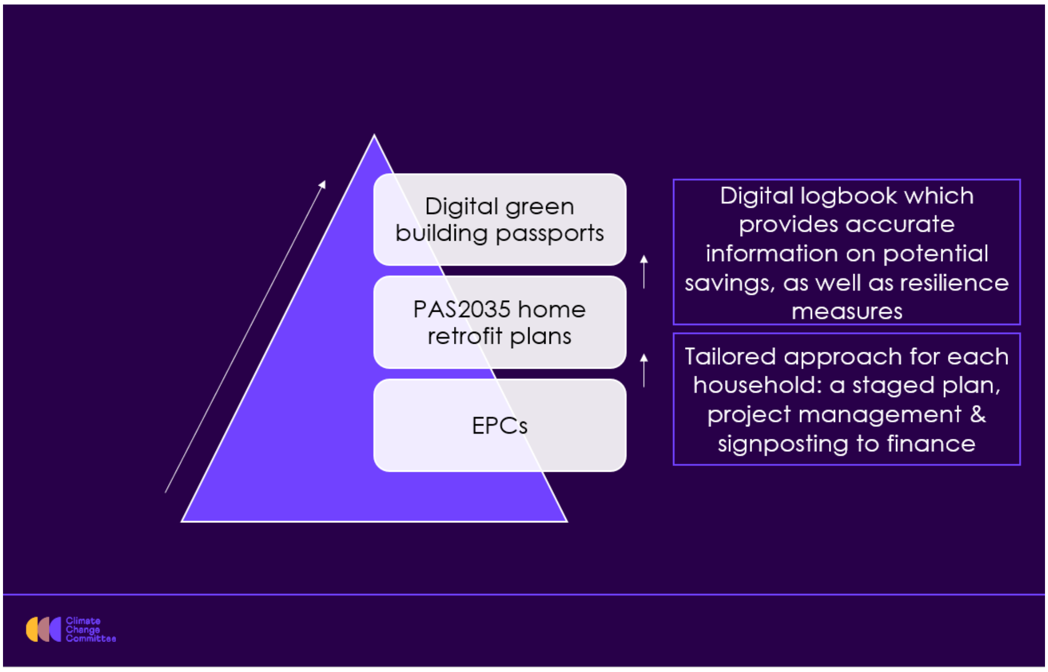
Government has recognised the urgent need to improve EPCs to ensure they are fit to support near-term progress, with a range of improvements proposed in the recent EPC action plan. It is important that alongside this, the methodology is designed to drive deployment of the necessary energy efficiency measures on a holistic basis,[†††] and does not disincentivise low-carbon heat. Onsite generation is not a replacement for energy efficiency or low-carbon heat.

Green Building Passports could provide holistic guidance to householders and unlock green finance at scale.

As a next stage, home retrofit plans are a tailored approach which can bring in wider dimensions of comfort, aesthetics and affordability as well as adaptation needs (Figure P3.5). Combining these with the opportunity of smart meter data in a digital Green Building passport could unlock green finance at scale by providing a robust, quality source of information to raise finance against, track progress and help make standards enforceable. Approaches like this are required to scale up additional finance to the £~8 billion/year on home renovation by 2030 implied by our Balanced Pathway.

††† Measures to address thermal efficiency, overheating, indoor air quality and moisture must be considered together when retrofitting or building new homes.

Figure P3.5 A high-quality source of information at Household-level



Source: CCC analysis

The Government is due to consult shortly on plans to introduce a mandatory in-use energy performance rating scheme for large commercial buildings, aiming to make it simpler for businesses to identify potential to save energy. Such schemes can be effective in driving change given business decisions around energy efficiency are shown to respond to reputation and risk.[89] Performance labelling for buildings allows tenants and owners to choose more efficient buildings, encouraging developers to compete for clients willing to pay a premium for efficient buildings. Well executed building labelling has created higher value for efficient buildings and attracted capital for low-carbon investment to go 'beyond code' (e.g. the Australian NABERS and the US Energy Star Buildings programmes).[90]

ii) Skills

Skills remain a further critical enabling measure. The CITB have identified pace of change as a key challenge, necessitating Government intervention. It is vital that the policy framework also scales up inspections and enforcement activity to ensure householders get what they have paid for.

The other critical element within the enabling measures is to prepare for new skills demand early, with enforcement of standards to drive up quality and drive down costs:

- The analysis of skills needs (Chapter 3, Advice report) shows the impact on activity levels from the major programme of building renovation over the next three decades, which is due to create over 200,000 jobs in home renovation and heating.
- The Construction Industry Training Board's (CITB) assessment of the skills challenges associated with our scenarios identifies the pace of change as a key challenge: current institutions are not equipping enough people with the required skills.

- It is unlikely that the market will develop the requisite skills in time, potentially resulting in poor quality installations (Box P3.3). Government intervention, working closely with installers and others in the private sector and with local government, is required to ensure that the skills that employers need are available at the required scale on a timely basis.

It is vital that the policy framework also prepares to scale up inspections and enforcement activity to ensure householders genuinely get what they have paid for, and see the savings realised through their energy bills.

Box P3.3
Current and future skills needs

There is an urgent need to upskill our workforce, both to meet current building standards, and to meet the immediate-term challenges ahead.

Skills issues exist for the standards and needs we have today. Deficits have been identified in areas such as repair and maintenance, and work on traditional buildings.[91] Skills deficits are expected to be a major contributor to the current performance gap.[92]

On top of this, the sector remains unequipped for the major and immediate-term challenges ahead. The chopping and changing of UK Government policy has inhibited skills development in design, construction and in the installation of new measures. An upcoming report by the CITB identifies low demand for skills and training linked to Net Zero, and finds the current training supply not yet 'Net Zero ready'. A survey undertaken for the CITB revealed that 78% of respondents considered there to be a skills gap in their occupation/profession for decarbonisation. [93]

This is a solvable issue. The same survey found that 90% of respondents would be willing to retrain, with a similar percentage willing to diversify their business offer or profession. External funding to cover some or all of the cost of training, and receiving an accredited qualification, were seen as the most important factors when undertaking decarbonisation retraining or upskilling.[94] Progress in standards has also been seen; a good case study is the PAS 2030 standard which addressed the need to look at ventilation alongside energy efficiency; PAS 2035 also represents a major step forward.

The CITB find that a rapid increase in skills capacity is needed, with large-scale re-skilling of the existing workforce and key structural issues addressed; including build quality, sector reputation and training readiness. All parties - Government, industry and the training sector – have responsibilities to deliver this. Actions for Government identified by the CITB include a clear decarbonisation policy framework; a planned approach to skills provision to balance immediate with future needs (with the recently launched Green Jobs Taskforce being a route to deliver this); requirements on the use of retrofit standards and a redesign building regulations around as-built performance; and support for SME innovation.

Sources: CITB (2020) Building Skills for Net Zero (draft report); CCC analysis.

d) Getting on with it

A mix of solutions displacing gas heating, and in particular any regional role for hydrogen in the gas grid, will not be achievable without a strategic, coordinated and planned approach to deliver heat decarbonisation.

A mix of solutions displacing gas heating, and in particular any regional role for hydrogen in the gas grid, will not be achievable without a strategic, coordinated and planned approach. Institutional frameworks will need to evolve, and national, regional and local decision-making frameworks will need to be determined in order to deliver this. Regional and local area energy planning and engagement can also minimise disruption and inform timely network investment.

While Area-based Energy Planning is not the whole solution, where underpinned by a robust methodology, it can provide better information to facilitate the process and is a hook to engage the public. A coordinated and planned rollout will also ensure that electricity network upgrades can be delivered in time and at reasonable cost (Box P3.4). This is particularly urgent in areas off the gas grid.

The Energy Systems Catapult estimates that the total cost for undertaking detailed-planning across Great Britain is £80-100 million – less than 0.5% of the costs of the transition in buildings.

In the immediate term, a better understanding at a national level of suitable candidate areas for hydrogen – together with areas which are clearly unsuitable – can help target investment in the gas grid better and enable targeted progress on electrification. BEIS and Ofgem would be well-placed to collaborate on a major study to identify prime candidate areas for hydrogen or full electrification, with input from networks on current capacity.[95]

Beyond this, there are a number of options for addressing the governance gap over the next decade and facilitating a set of decisions on the future of the gas grid in different parts of the UK, including Pathfinder Cities and other regional and local demonstrators, a new Heat Delivery and heat zoning:

- **Pathfinder Cities/areas.** Building on the approach signalled in the Ten Point Plan and existing demonstrators, these offer a route to scaling up, engaging the public and improving our understanding of system integration challenges. A BEIS/MHCLG-led process could identify up to three areas for demonstrators 2025-2030 plus pipeline for 2030s. 2025 local council elections are an opportunity to test with the public.

- **Heat Delivery Body.** The CBI and Birmingham University Heat Commission has recommended that a new heat delivery body be established to formalise governance structures and coordinate national, regional and local government.[96]

- **Next set of Local Area Energy Plan pilots, with full rollout after 2025**. Part of the focus will need to be in areas off the gas grid to inform network investment, given more rapid timelines.

- **Zoning for heat networks.** Given the spatial nature of heat networks and the importance of managing demand-risk, a zoning approach supported by policy such as licensing will help provide a robust framework for deployment at scale.

Government should aim to move forward with an equivalent set of proposals in its forthcoming strategy.

Box P3.4

The need for further strategic planning and local evidence to inform infrastructure investments

We surveyed UK Distribution Network Operators earlier this year to understand and gather views on preparedness of distribution networks for Net Zero delivery. All six respondents considered indicative electric vehicle and heat pump pathways to 2035 to be achievable 'if certain conditions are met' (particularly from a regulatory framework perspective) but levels of heat pump deployment in particular were more aggressive than a number have previously been planning for.

DNOs stressed the need for careful coordination and forward planning if this is to be achievable – and to control costs.
It was noted that significant cost savings could be achieved where EV and electric heat rollout is planned and coordinated such that streets only need to be dug once for cable upgrades, with one DNO quoting 85% of the costs of low voltage upgrades being excavations. This is supported by previous analysis from Vivid Economics and Imperial College London.[97] One suggested meeting net zero to be 'impossible' without planned and coordinated approach.

Policy recommendations included: the need for a ten-year strategy (including target heating fuels for different segments and timelines for transition); coordinated/regional rollout including taking a whole energy systems approach; valuing flexible loads; making charging cost reflective; and a focus on fairness/protecting the vulnerable. Network upgrade lead times were reported as ranging from a matter of weeks to up to eight years depending a wide range of factors relating to the specific upgrade needed.

Similar themes around the importance of co-ordination emerged from our Call for Evidence, where respondents argued that an uncoordinated approach to the decarbonisation of heat could put the net-zero target at risk if the different infrastructure requirements are not in place to support different solutions. A piecemeal approach was also seen to risk increasing costs (e.g. reducing economies of scale, and leading to unnecessary investment in multiple infrastructure networks).[98]

Source: CCC analysis

[59] CCC (2020) *Policies for the Sixth Carbon Budget and Net Zero*. Available at: www.theccc.org.uk

[60] Element Energy and UCL for CCC (2019) *Analysis on abating direct emission from hard-to-decarbonise homes*

[61] MHCLG (2019) Annex Table 1.2: Energy efficiency rating bands, by tenure, 2008, 2013 and 2018', *English Housing Survey: Energy efficiency, 2018-19*;

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