Committee on Climate Change

Sectoral scenarios for the Fifth Carbon Budget

Technical report

November 2015

Contents

The Committee

The Rt. Hon John Gummer, Lord Deben, Chairman

The Rt. Hon John Gummer, Lord Deben, was the Minister for Agriculture, Fisheries and Food between 1989 and 1993 and was the longest serving Secretary of State for the Environment the UK has ever had. His sixteen years of top-level ministerial experience also include Minister for London, Employment Minister and Paymaster General in HM Treasury.

He has consistently championed an identity between environmental concerns and business sense. To that end, he set up and now runs Sancroft, a corporate responsibility consultancy working with blue-chip companies around the world on environmental, social and ethical issues. Lord Deben is Chairman of Valpak Limited and the Association of Professional Financial Advisors.

Professor Samuel Fankhauser

Professor Samuel Fankhauser is Co-Director of the Grantham Research Institute on Climate Change and Deputy Director of the ESRC-funded Centre for Climate Change Economics and Policy, both at the London School of Economics. He is a Director at Vivid Economics and a former Deputy Chief Economist of the European Bank for Reconstruction and Development.

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Professor Sir Brian Hoskins, CBE, FRS is the Chair of the Grantham Institute for Climate Change and the Environment at Imperial College London and Professor of Meteorology at the University of Reading. His research expertise is in weather and climate processes. He is a member of the scientific academies of the UK, USA, and China.

Paul Johnson

Paul Johnson has been director of the Institute for Fiscal Studies since January 2011. He is a visiting professor at UCL. Paul has published and broadcast extensively on the economics of public policy including tax, welfare, inequality and poverty, pensions, education, climate change and public finances. He is author of major books on pensions, tax and inequality. He is one of the authors of the "Mirrlees review" of tax system design. Paul has previously worked at the FSA and has been chief economist at the Department for Education and director of public spending in HM Treasury as well as deputy head of the UK Government Economic Service.

Paul is currently a member of the council and executive committee of the Royal Economic Society, a member of the banking standards board and has just completed an independent review of consumer price inflation statistics for the UK Statistics Authority. He has previously served on the council of the Economic and Social Research Council. He was a founder council member of the Pensions Policy Institute and in 2010 he led a review of the policy of auto-enrolment into pensions for the new government.

Julia King, The Baroness Brown of Cambridge

Julia King DBE FREng, The Baroness Brown of Cambridge, is a Fellow of the Royal Academy of Engineering (FREng) and was made a CBE for 'Services to Materials Engineering' in 1999. She was appointed by the Chancellor of the Exchequer in March 2007 to lead the 'King Review' to examine the vehicle and fuel technologies that, over the next 25 years, could help to reduce carbon emissions from road transport.

She is currently Vice-Chancellor of Aston University, and is one of the UK's Business Ambassadors, supporting UK companies in the areas of low carbon and transport. Following on from a career as an academic researcher and lecturer in materials engineering at the Universities of Cambridge and Nottingham, Julia King joined Rolls-Royce PLC in 1994. At Rolls-Royce, she held a number of senior executive appointments, including Director of Advanced Engineering for the Industrial Power Group and Engineering Director for the Marine Business. Julia returned to academia in 2004 as Principal of the Engineering Faculty at Imperial College, London, moving to Aston in 2006.

Lord John Krebs

Professor Lord Krebs Kt FRS FMedSci ML is Emeritus Professor of Zoology at Oxford University. He was Principal of Jesus College, Oxford between 2005 and 2015. Previously, he held posts at the University of British Columbia, the University of Wales, and Oxford, where he was lecturer in Zoology, 1976-88, and Royal Society Research Professor, 1988-2005. From 1994-1999, he was Chief Executive of the Natural Environment Research Council and, from 2000-2005, Chairman of the Food Standards Agency. He is a member of the U.S. National Academy of Sciences.

He was chairman of the House of Lords Science & Technology Select Committee from 2010 to 2014, President of the British Science Association in 2012 and is a member of the House of Lords Energy and Environment Sub-committee of the EU Select Committees.

Lord Robert May

Professor Lord May of Oxford, OM AC FRS holds a Professorship at Oxford University. He is a Fellow of Merton College, Oxford. He was until recently President of the Royal Society, and before that Chief Scientific Adviser to the UK Government and Head of its Office of Science and Technology.

Professor Jim Skea

Professor Jim Skea has research interests in energy, climate change and technological innovation. He has been RCUK Energy Strategy Fellow since April 2012 and a Professor of Sustainable Energy at Imperial College since 2009. He was Research Director of the UK Energy Research Centre 2004-12 and Director of the Policy Studies Institute 1998-2004.

He has operated at the interface between research, policy-making and business throughout his career. He is President of the Energy Institute and was elected co-Chair of IPCC Working Group III in 2015. He was awarded a CBE for services to sustainable energy in 2013 and an OBE for services to sustainable transport in 2004.

Chapter 1: Overview

Introduction and key messages

This Technical Report accompanies *The Fifth Carbon Budget - The next step towards a low-carbon economy*[1], our published advice on the level of the fifth carbon budget (the Advice Report).

A key conclusion of that advice is that the fifth carbon budget should reflect the cost-effective path to the UK's 2050 target to reduce emissions by at least 80% on 1990 levels. That is the best way to balance the various factors in the Climate Change Act that the Committee must consider in reaching its advice.

- **There has been good progress reducing emissions to date.** Emissions in 2014 were 36% below 1990 levels and current policy, if it delivers fully, would lead to a 45% reduction by 2020.
- **A continuation of this rate of emissions reduction would meet the 2050 target.** Our Central scenario is our best estimate of the cost-effective path to the 2050 target and involves a reduction in gross emissions of 61% by 2030 relative to 1990. Emissions across the economy would need to fall by around 13 $MtCO_2e$ (3%) per year on average from 2014 to 2030. Emissions in the 'non-traded' sectors (i.e. outside the EU Emissions Trading System - transport, heat in buildings, agriculture) would need to fall around 6 $MtCO_2e$ (2%) each year.
- **To succeed in maintaining this rate of reduction the UK will have to continue previous good progress alongside making progress in increasingly difficult areas.** For example, our scenarios include:
  - Improvements to **energy efficiency** in: buildings (e.g. improved insulation, including 1.5 million solid walls and 2 million cavity walls in the 2020s, increased use of LED lighting and more efficient appliances), transport (efficiency of conventional vehicles continues to improve from around 125 gCO_2/km in 2014 to 102 g/km in 2020 and 86 g/km in 2030 on a test-cycle basis) and industry (improved energy management and process control, use of more energy efficient plant and equipment, waste heat recovery).
  - In **power**, the carbon intensity of generation decreases from around 450 gCO_2/kWh in 2014 to 200-250 g/kWh in 2020, and to below 100 g/kWh in 2030. This reduction could be delivered by different mixes of low-carbon generation (i.e. renewables, nuclear and CCS).
  - **Electrification of heat and transport**. Heat pumps and heat networks from low-carbon sources provide heat for around 13% of homes and over half of business demand in 2030. Ultra-low emission vehicles increase their share, with deployment of electric vehicles across cars, vans and smaller HGVs (the combination of plug-in hybrids and battery electric vehicles reach 9% of new car and van sales in 2020 and around 60% in 2030). These will require bigger behavioural changes than previous emissions reductions.
  - Development of **carbon capture and storage** (CCS) with deployment in power as part of a portfolio of low-carbon technologies, and in industry with the development of a CCS cluster

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[1] Available at www.theccc.org.uk

Introduction and key messages

allowing use in the iron and steel and chemicals sectors.

  - In **agriculture**, increased take-up of crops and soils measures that mainly target the reduction of N_2O through improved fertiliser use efficiency, livestock measures targeting diets, health, and breeding that reduce methane; waste and manure management.

- **Meeting those challenges will require sufficient lead-time** to improve the cost and performance of the relevant technologies, build markets for these technologies, and develop supply chains and supporting infrastructure. Consumers will also need time to adapt behaviours to support take-up of low-carbon technologies.
- **The scenarios in this report can be delivered at a resource cost of less than 1% of GDP in 2030.**

This Technical Report describes the scenarios used by the Committee to inform its judgements over the cost-effective path. This chapter summarises the scenarios and sets out important assumptions and approaches that are used across the economy. Chapters 2-7 describe the scenarios in each sector:

- Chapter 2: Power
- Chapter 3: Buildings
- Chapter 4: Industry
- Chapter 5: Transport
- Chapter 6: Agriculture and LULUCF
- Chapter 7: Waste and F-gases

This chapter sets out our approach to developing the sectoral scenarios and the assumptions underpinning them, in the following sections:

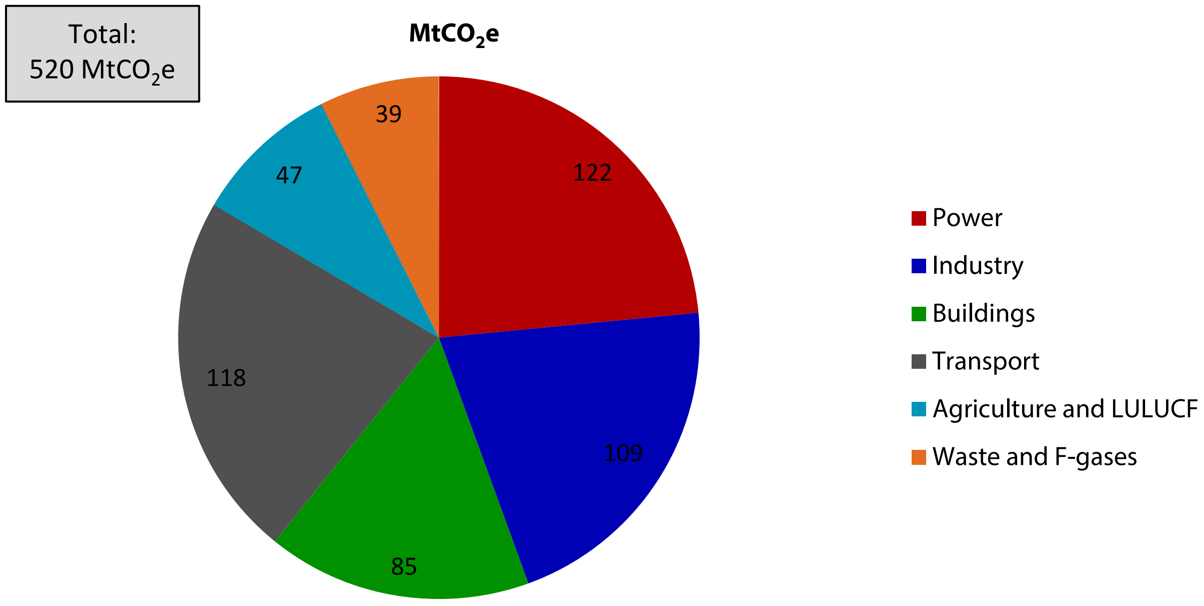
1. Current emissions and changes since 1990
2. Meeting the 2050 target – what this means for the fifth carbon budget
3. Innovation and the role of deployment in meeting the 2050 target
4. The role of bioenergy
5. Approach to developing our scenarios for the fifth carbon budget
6. Assumptions underpinning our scenarios
7. Economy-wide scenarios
8. Differences between the nations of the UK
9. Costs of meeting the fifth carbon budget

1. Current emissions and changes since 1990

UK emissions of greenhouse gases (GHGs) covered by carbon budgets were 520 $MtCO_2e$ in 2014. This excludes emissions from international aviation and shipping, for which 2014 estimates are not yet available but accounted for 41 $MtCO_2e$ in 2013.

UK emissions are split between six sectors (Figure 1.1): electricity generation (23%), industry (21%), buildings (16%), transport (23%), agriculture and land-use, land-use change and forestry (LULUCF) (9%), and waste and F-gases (7%).

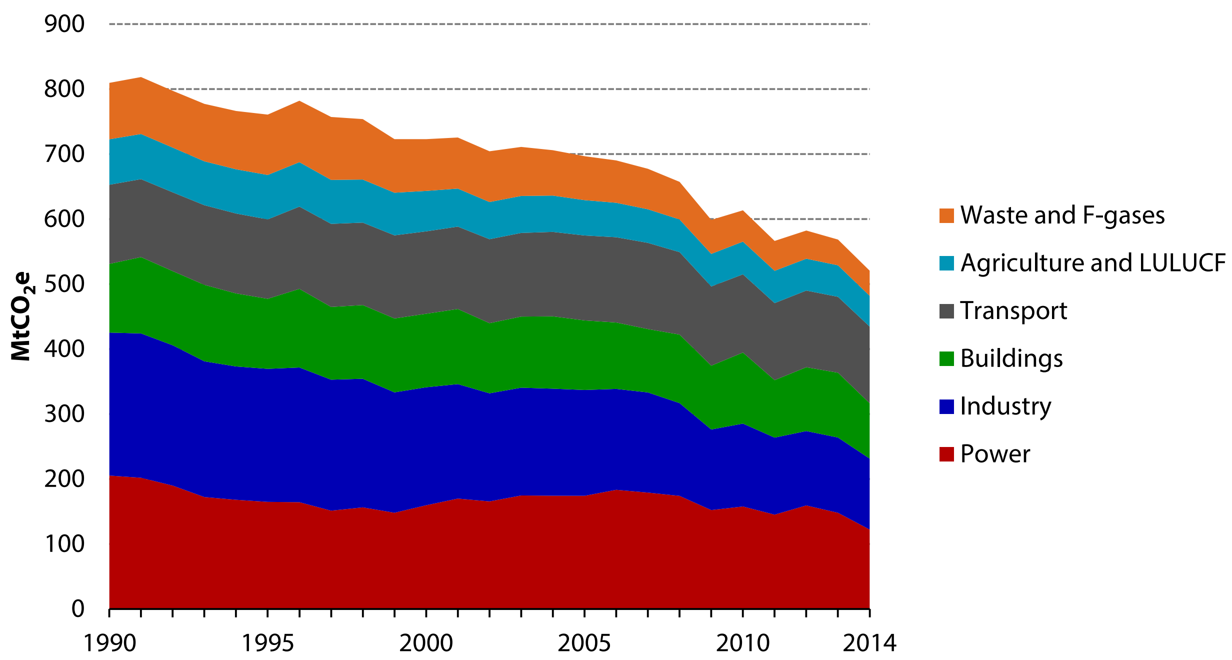
Figure 1.1: Current UK emissions of greenhouse gases (2014)



Source: DECC (2015) *Provisional UK greenhouse gas emissions national statistics*; CCC analysis

UK greenhouse gas emissions in 2014 were 36% below 1990 levels and 25% below 2005 (Figure 1.2). In part this is due to the economic downturn, in particular a 9% reduction in GHG emissions in 2009. However, the reductions since 1990 also reflect some longer-term trends and more recent impacts of policies aimed at reducing emissions.

Figure 1.2: Historical UK emissions of greenhouse gases (1990-2014)



Source: DECC (2015) *Final UK greenhouse gas emissions national statistics: 1990-2013*; DECC (2015) *Provisional UK greenhouse gas emissions national statistics*; CCC analysis

2. Meeting the 2050 target – what this means for the fifth carbon budget

The Committee's advice about the fifth carbon budget depends, in part, upon the progress required for the UK to be on track to meet the statutory 2050 target. This section discusses the analysis and thinking to 2050 that feeds into the fifth carbon budget recommendations.

A number of common themes have emerged from the various approaches:

- **Energy efficiency and behaviour change.** Reducing the level of energy demand through improved efficiency and small changes to consumer behaviour can greatly reduce the cost of meeting the 2050 target. However, it is clear that this alone will not be enough to reduce emissions by 80%, and fuel switching to low-carbon sources will also be needed.
- **Power sector**. Meeting the target is likely to require a power sector with very low emissions in 2050. This is needed to decarbonise existing demands for electricity and to meet new demands in road transport and heat in buildings without increasing emissions (with potential for other applications). The level of electricity consumption in 2050 could be 50% to 135% above the level in 2014.
- **Carbon capture and storage (CCS)** is very important in meeting the 2050 target at least cost, given its potential to reduce emissions across heavy industry, the power sector and perhaps with bioenergy, as well as opening up new decarbonisation pathways (e.g. based on hydrogen). Estimates by the Committee[2] and by the ETI[3] indicate that the costs of meeting

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[2] CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*

the UK's 2050 target could almost double without CCS. At the global level the IPCC has estimated that its absence could increase costs by over 100%[4].

- **Bioenergy**. Sustainable bioenergy can play an important role reducing emissions where alternative options are very limited. However, there are limits to the sustainable supply (e.g. this could provide around 10% of primary energy in 2050), so its role must be supplementary to other measures. It should be targeted at options where it has the largest impact on reducing emissions. Our analysis to date indicates that use should preferentially be as wood in construction or use of bioenergy with CCS and/or displacing coal, with further potential for use where alternative low-carbon options are not available (e.g. aviation). The Committee's estimates of sustainable bioenergy supply suggest that use with CCS would provide an extra emissions reduction of around 20 $MtCO_2e$/year relative to use to displace gas in heat for industry and buildings.
- **Industry**. In addition to opportunities for energy efficiency and CCS, decarbonisation can be achieved through switching from generating heat from fossil fuels to using electricity or hydrogen generated from low-carbon sources. There may also be opportunities to reduce emissions through materials efficiency and product substitution, but it is difficult to estimate the extent of these. Given the costs and challenges associated with decarbonising industry, residual emissions might be around 65 $MtCO_2e$ in 2050.
- **Agriculture**. Agriculture emissions can be reduced by changed farming practices (e.g. on-farm efficiencies, improved animal fertility), reduced food waste and adjustment of diet towards less carbon-intensive foods. However, there is a limit to what is likely to be achievable in reducing agriculture emissions, so residual emissions in 2050 may be around 30 $MtCO_2e$.
- **Aviation**. While UK demand for international aviation is likely to grow considerably, emissions must be limited. Previous analysis by the Committee concluded that, based on the available evidence, aviation should plan for its emissions in 2050 to be no higher than those in 2005. That requires strong efficiency improvements to balance demand growth of about 60%.
- **Buildings and surface transport**. With the developments described above, there may be a small amount of room for residual emissions in buildings and/or surface transport. Where emissions remain should depend on how different low-carbon technologies develop. It is therefore sensible to plan now to keep open the possibility of near-full decarbonisation of both buildings and surface transport by 2050.
- **Infrastructure development**. New infrastructures will be required to support the deployment of low-carbon technologies. As well as CO_2 infrastructure, which is key to commercialisation of CCS, development of heat networks and electric vehicle charging networks will be required, and potentially infrastructure for hydrogen applications. Electricity networks will also need to be strengthened in places, to cope with new demands (e.g. from heat pumps) and increasing generation from low-carbon sources.

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https://www.theccc.org.uk/archive/aws/IA&S/CCC_IAS_Tech-Rep_2050Target_April2012.pdf

[3] ETI (2015) *Building the UK carbon capture and storage sector by 2030 – Scenarios and actions* http://www.eti.co.uk/wp-content/uploads/2015/03/CCS-Building-the-UK-carbon-capture-and-storage-sector-by-2013.pdf

[4] 138%, IPCC (2014) *Fifth Assessment Report – Synthesis Report*. Available at http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf

Our scenarios to 2035, which underpin our advice on the fifth carbon budget, explicitly take account of the considerations set out above to ensure the 2050 target can be met cost-effectively. The scenarios are set out in Chapters 2-7 of this report.

3. Innovation and the role of deployment in meeting the 2050 target

Innovation will be critical in developing and deploying new low-carbon technologies, and improving the cost and performance of existing ones, in order to meet the 2050 target and further reduce GHG emissions beyond 2050. Government must play an active role in the innovation process due to the following factors:

- The greenhouse gas externality: the GHG emissions of a technology are generally not included, or only partially included, in market prices. Even where carbon costs are reflected in market prices, businesses may not be able to rely on this continuing to be the case in future.
- The innovation process is characterised by *spillovers*: the knowledge generated by research and development within an individual firm is likely to be spread, so that the firm carrying out innovation will be unable to appropriate the full benefit from the innovation[5].
- The limited potential for market pull to incentivise innovation in low-carbon technologies, as these essentially replace the service provided by high-carbon technologies, rather than providing new services.

Government involvement is important to ensure limited resources are best allocated across the innovation process to ensure that carbon budgets, the 2050 target and subsequent decarbonisation can be met at acceptable cost. Our 2010 review of low-carbon innovation[6], identified three broad phases of the innovation process:

- **Research and development (R&D)**, involving both basic research and development of specific technologies, culminating in initial demonstration of feasibility.
- **Demonstration**, involving large-scale pre-commercial demonstration of technologies designed to test and improve reliability, improve designs, and establish and reduce operating costs. Technologies currently at this stage include carbon capture and storage (CCS) and hydrogen fuel cell vehicles.
- **Deployment**, leading to technologies considered "commercially proven" and achieving economies of scale. Technologies within this stage include nuclear power, heat pumps, offshore wind and electric vehicles.

While innovation involves progressing through these three phases, it is not a strictly linear process; experience at the demonstration and deployment phases frequently reveals the need for additional basic R&D to overcome barriers to further progress.

Our assessment is that while R&D is important, it is sensible to plan for meeting the 2050 target largely through currently-known technologies:

- R&D will be required to develop new low-carbon technologies, and to improve the cost and performance of existing ones. Many of the benefits of R&D may accrue in the period beyond

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[5] Spillovers are greater for green innovation than conventional innovation. See Antoine Dechezleprêtre, Ralf Martin and Myra Mohnen (2014) *Knowledge Spillovers from Clean and Dirty Technologies*. Centre for Economic Performance, LSE. Available at http://cep.lse.ac.uk/pubs/download/dp1300.pdf

[6] CCC (2010) *Building a low-carbon economy – the UK's innovation challenge*. Available at https://www.theccc.org.uk/publication/building-a-low-carbon-economy-the-uks-innovation-challenge

2050 when, according to IPCC, even deeper reductions in emissions may be required to give a likely chance of keeping temperature increases below 2 degrees.

- Deployment of currently-known technologies at scale will be required to ensure the 2050 target can be met at reasonable cost.

Deployment of currently known technologies is of critical importance to meeting the 2050 target due to the time frame required for developing and scaling up new technologies, risks and uncertainty over new technologies, the role of deployment in the innovation process and the need for supporting infrastructure and supply chains:

- **Time frame to meet the 2050 target**. The fifth carbon budget will be legislated in 2016, 34 years before 2050, a relatively short period of time for the scale of the energy system transition required to meet the target. However, stock turnover means that deployment of the technologies that will meet this target must begin even earlier. To effectively decarbonise power, transport and heat generation by 2050, it will be necessary to decarbonise all new investment by around 2020 for power (with the exception of back-up and balancing plant), 2035 for transport, and 2035 for heat.
- **Time frame to reach deployment at scale**. The development of new technologies takes time. This is highlighted in a recent report by the UK Energy Research Centre (UKERC)[7], which reviewed the available evidence for the time new technological innovations take to reach commercial maturity. They find that, across 16 successful innovations considered, the average time taken from invention to commercialisation is 38 years, with a range between 19 and 70 years, with energy generation technologies taking significantly longer than average. The need to deploy solutions at scale within the next 20 years suggests that the 2050 target could only be met with reasonable certainty through initial deployment of currently known technologies that have moved beyond the research and development phase in the near-term.
- **Risk and uncertainty of early-stage technologies**. Each phase of innovation carries different risks of failure. Technologies at the R&D stage are therefore riskier than those at the deployment stage when the risks of failure at earlier stages have been eliminated. Furthermore, each phase carries different levels of uncertainty – the full set of risks faced by technologies at the R&D phase is largely unknown and unquantifiable, while that faced by those at the deployment phase is much better understood, due to the experience of manufacturers and consumers in the early stages of deployment. This has allowed us to characterise the specific risks faced by offshore wind, electric vehicles and heat pumps, and identify measures to address these risks[8]. We therefore have a reasonable degree of confidence that these technologies can be deployed at sufficient scale to meet the 2050

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[7] UKERC (2015) *Innovation timelines from invention to maturity: A review of the evidence on the time taken for new technologies to reach widespread commercialisation*.

[8] For example, see BVG Associates (2015) *Approaches to cost-reduction in offshore wind*. Available at https://www.theccc.org.uk/publication/bvg-associates-2015-approaches-to-cost-reduction-in-offshore-wind/; Pöyry & Element Energy (2015) *Potential CCS Cost Reduction Mechanisms Report*. Available at https://d2kjx2p8nxa8ft.cloudfront.net/wp-content/uploads/2015/06/P%C3%B6yry-Element-Energy2015-Potential-CCS-Cost-Reduction-Mechanisms-Report.pdf; Element Energy (2012) *Cost and performance of EV batteries*. Available at https://www.theccc.org.uk/publication/international-aviation-shipping-review/; Element Energy et al (2013) *Pathways to high penetration of electric vehicles*. Available at https://d2kjx2p8nxa8ft.cloudfront.net/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf; Frontier Economics & Element Energy (2013) *Pathways to high penetration of heat pumps*. Available at https://d2kjx2p8nxa8ft.cloudfront.net/wp-content/uploads/2013/12/Frontier-Economics-Element-Energy-Pathways-to-high-penetration-of-heat-pumps.pdf

target, given a sensible deployment strategy, supplemented by monitoring and evaluation of costs and technical performance, and measures to address barriers.

- **Role of demonstration and deployment in the innovation process.** Deployment of a new technology at scale provides manufacturers with the necessary experience to successfully identify remaining barriers to commercialisation, so that these can be addressed through product redesign, and if necessary, further R&D to improve the product or reduce its cost. Where technologies face high initial costs, for example as expected for CCS, a level of deployment support may be required to provide the experience and to reach the economies of scale to deliver cost reductions. It is far from clear that currently unknown technologies will face lower costs than currently known technologies, and will not therefore require the same level of deployment support.
- **Requirement for supporting infrastructure, supply chains and developed markets.** Energy technologies require supporting infrastructure to operate, extensive supply chains to deploy at scale, and developed markets to ensure demand is sufficient for the level of deployment. Infrastructure, supply chains and markets all take time to develop, and evolve over time as technology and society change, barriers are identified and solutions emerge. For example, electric vehicles require: public charging infrastructure; a power sector capable of accommodating the vehicles' specific demand profile; sufficient battery and electric motor manufacturing capacity; sufficient supply of raw materials such as lithium and rare earth metals; and consumer familiarity with the vehicles themselves. These factors need to be in place by the time the technology needs to be deployed at scale in the mid-2030s. Early deployment of currently known technologies would allow concurrent development of infrastructure, supply chains and markets.

This underpins our approach to developing our emissions scenarios, and the inclusion of considerable volumes of offshore wind, CCS, electric vehicles and district heating in our scenarios, as set out in Section 7.

4. The role of bioenergy

The role of bioenergy in climate change mitigation is controversial. Specifically, there are questions over the extent to which bioenergy use results in emissions reductions when lifecycle impacts are accounted for, and tensions between use of bioenergy and sustainability objectives (e.g. relating to use of land for growing food, protecting biodiversity and water resources).

We considered these questions in our 2011 Bioenergy Review. The Bioenergy Review conclusions are summarised in Box 1.1.

In developing our decarbonisation scenarios, we have followed the principles set out in the Bioenergy Review, by including deployment of bioenergy where it can contribute most effectively to reducing emissions, while ensuring that total bioenergy use remains within the limit of sustainable supply:

- The Bioenergy Review identified the expected level of sustainable supply to the UK over the period to 2050. We estimated the level of supply to the UK was likely to rise to 2030, before declining as global competition for bioenergy reduced the quantity available to the UK to 2050. Our scenarios are conservative, and include 7 $MtCO_2e$ less abatement from bioenergy than indicated by our assessment of sustainable supply (Figure 1.3).
- Bioenergy displaces fossil fuels across a range of applications over the period to 2030, and is gradually diverted to CCS from 2035 as this provides the greatest reduction in GHG emissions.

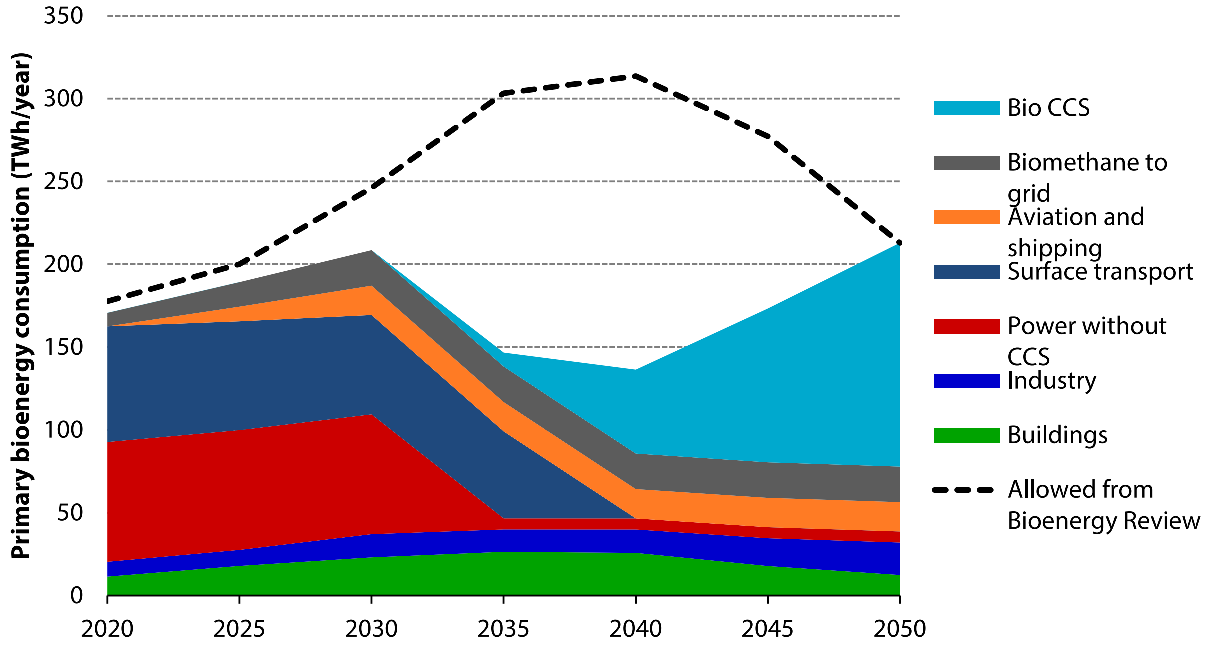
Box 1.1: The Bioenergy Review

The Bioenergy Review provided an assessment of the potential roles for bioenergy given lifecycle emissions and other sustainability concerns, and also considered alternative uses for bioenergy feedstocks (e.g. use of wood in construction). The Bioenergy Review concluded:

- **The need for bioenergy versus its sustainable supply:**
  - It will be difficult to meet the overall 2050 emissions target unless bioenergy can account for around 10% of total UK primary energy (compared to the current 2%) and CCS is a feasible technology. This reflects the fact that there are a small number of economic activities where alternatives to hydrocarbons may either not be feasible (e.g. in aviation) or have not yet been identified (e.g. in iron and steel).
  - Scenarios for global land use which take account of required food production suggest that a reasonable UK share of potential sustainable bioenergy supply could extend to around 10% (200 TWh) of primary energy demand in 2050.
- **Lifecycle emissions.** It is important that the role of bioenergy in low-carbon strategy reflects realistic estimates of total lifecycle emissions for different types of feedstock, including both direct and indirect land use change impacts.
- **Appropriate use of limited sustainable bioenergy supply in the long term.** Given limits to the global supply of sustainable bioenergy, it is important that this is used in an optimal fashion:
  - If CCS is available, it is appropriate to use bioenergy in applications with CCS, making it possible to achieve negative emissions. These applications could include power and/ or heat generation, the production of hydrogen, and the production of biofuels for use in aviation and shipping.
  - If CCS is not available, bioenergy use should be skewed towards heat generation in energy-intensive industry, and to biofuels in aviation and shipping, with no appropriate role in power generation or surface transport.
  - In either case, the use of woody biomass in construction (rather than as an energy source) should be a high priority, given that this generates negative emissions through a very efficient form of carbon capture.
- **Implications of bioenergy availability for overall low-carbon strategy.** Our analysis has revealed that supplies of sustainable bioenergy may only just be sufficient to make meeting the 2050 target achievable, and only then if CCS is available. Policy should therefore place a high priority on developing and demonstrating CCS technology, ensuring that sectors which do not need to rely on bioenergy achieve decarbonisation via other means, and supporting research in areas where it is possible that there could be breakthroughs which will lessen sustainability constraints.

Source: CCC (2011) *Bioenergy Review*. Available at https://www.theccc.org.uk/publication/bioenergy-review/

Figure 1.3: Bioenergy consumption in CCC scenarios



Source: CCC (2011) *Bioenergy Review*, available at https://www.theccc.org.uk/publication/bioenergy-review ; CCC analysis

Notes: Utilisation based on sectoral trajectories subject to the economy-wide bioenergy resource constraint and considerations around steady decarbonisation to 2050. Some potentially available bioenergy resource is underutilised in the medium term, which could in principle increase abatement, although it may imply that bioenergy is used for a short period (e.g. 10 or 15 years) in particular sectors, which may not be cost-effective.

5. Approach to developing our scenarios for the fifth carbon budget

We have developed a set of scenarios for reducing UK GHG emissions based on a bottom-up analysis across the sectors of the economy. These scenarios combine expectations for emissions in the absence of further effort to reduce emissions (the 'baseline', see section 6), with our best assessment of what is required on the cost-effective path to the 2050 target.

In developing our scenarios we have considered:

- The relative cost-effectiveness of different approaches to meeting the 2050 target, and reducing emissions in the period to 2050. Specifically, the scenarios include measures that are available at lower cost than the Government's published carbon values (Box 1.2).
- The wider criteria set out in the Act, including impacts on affordability and competitiveness (see Chapter 4 of the Advice Report, and section 5 in the sector Chapters in this report).
- The need to ensure that measures required to meet the 2050 target are available to be deployed when needed, through demonstration and deployment of key technologies, development of markets, and deployment of supporting infrastructure. The scale of the reduction needed to meet the 2050 target is such that a high level of ambition and significant policy intervention will be required across all the emitting sectors.

- The feasibility of deploying particular solutions. This has included consideration of barriers to deployment and measures that can be taken to address these barriers, supply chain constraints, and rates of stock turnover.
- Actions to which the Government is already committed, largely occurring in the period to 2020 (e.g. standards for new car gCO_2/km). If these deliver as planned then emissions in 2020 would be around 45% below 1990 levels.[9]

The **Central scenario** represents our best assessment of the technologies and behaviours required over the fifth carbon budget period to meet the 2050 target cost-effectively, while meeting the other criteria in the Act.

There is inevitable uncertainty over the rates at which technologies will become available, their future costs and the scale of behaviour change likely to occur. Our scenarios are not prescriptive: it may be possible to meet carbon budgets with lower deployment of some options, provided the increase in emissions is offset by higher deployment of others. The scenarios are also not exhaustive: it is possible that some options that are not currently included in our scenarios become more cost-effective than we currently envisage. The scenarios allow the Committee to determine whether the overall budget is deliverable within the statutory duties placed on it by the Climate Change Act and discussed in Chapter 1 of the Advice Report.

There are many uncertainties over the possible emissions path over the period to 2030 and beyond. These include macro drivers (the level of future economic activity, fossil fuel prices, population), the evolution of cost and performance of options to reduce GHG emissions, consumer acceptance of these options, and the extent of behavioural change people are prepared to make. Our scenarios take a conservative approach to these uncertainties: they assume demand for energy services grows in line with historical experience, and that there is relatively limited scope for radical behaviour change over the near-to-medium term. This approach minimises the risks of a fifth carbon budget set at our recommended level being too tight and excessively costly or otherwise infeasible.

Our scenarios explicitly recognise uncertainty in two ways:

- In addition to the Central scenario, we develop Barriers and Max scenarios in each sector. The **Barriers Scenario** represents unfavourable conditions for key measures (technological barriers, failure to achieve cost reductions, or market barriers). The **Max Scenario** represents higher, but still feasible, deployment of key measures. This demonstrates that there is flexibility in how a given carbon budget could be met with varying degrees of effort across sectors.
- We also develop one or more **Alternative scenarios** in each sector, representing deployment of different measures to those in Barriers, Central and Max. For example, one of the Alternative scenarios in the Buildings sector involves greater levels of district heating and lower take-up of heat pumps than the Central scenario; one of the Alternative scenarios in the transport sector involves widespread take up of hydrogen technologies, rather than battery electric vehicles. This demonstrates some robustness within sectors to uncertainty over the types of abatement options that will ultimately prove to be better-performing and cost-effective.

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[9] DECC interim projections (October 2015).

Box 1.2: Evaluating cost-effectiveness in our scenarios

Abatement costs and cost-effectiveness

The cost-effectiveness of measures to reduce emissions can be evaluated by their abatement cost. Expressed in £/tCO_2e, the abatement cost is the measure's total lifetime cost divided by its total lifetime emissions saving, i.e. the cost per tonne of CO_2 saved over the measure's lifetime. Reducing emissions at lower overall cost generally involves prioritising measures with low abatement costs over measures with high abatement costs. A measure is considered "cost-effective" if its abatement cost is lower than the appropriate carbon value (see below).

Our approach to calculating abatement costs is consistent with HM Treasury's Green Book and DECC's supplementary guidance. Our calculations include the "resource costs" to the UK of deploying the measure. Resource costs express costs incurred by the UK economy as a whole, rather than costs incurred by private agents, which may differ from resource costs due to transfers of money such as taxation or profits of UK companies.

Separate from our cost-effectiveness calculations, we sometimes calculate the private costs borne by households and businesses, in order to evaluate the likelihood of market take-up or the incidence of energy bills (see, for example, Chapter 2: Power, or Chapter 5: Transport).

Target-consistent carbon values

- The Government's carbon values for policy appraisal are designed to be consistent with action required under the Climate Change Act. They reflect estimates in the literature and modelled scenarios and have been peer reviewed by an expert panel. The modelling work includes a top-down global sectoral model for the world energy system under low, central and high projections for global technology costs, fossil fuel prices and global energy demand. The model is used to calculate carbon costs consistent with international action to limit the expected average increase in global surface temperatures to 2°C above pre-industrial levels.
- In a central case the carbon values reach £78/tCO_2e in 2030, growing steadily (around 5% per year) to £220/t in 2050. Low and high values are 50% below and above the central level. We have previously concluded that these values are in line with estimates in the wider literature for the costs of limiting warming to 2°C.
- The UK's 2050 target is aligned to this level of effort globally, and is likely to require some actions at similar carbon cost.[10] Using the Government's trajectory of carbon values as a guide to low-carbon investment would therefore support a steady increase in effort over time.

We use the target-consistent carbon value to assess whether low-carbon investments represent good value. The significantly lower forecasts of market carbon prices in the EU Emissions Trading System (EU ETS) are not target-consistent, and therefore not an appropriate guide to assess the value of low-carbon investments. Figure B1.2 shows the trajectory of carbon values we consider out to 2050.

Expected market carbon price

- The actual carbon price in the market is expected to be lower than the target-consistent carbon values above. Independent forecasters project a carbon price in the EU Emissions Trading System of £24/tCO_2e in 2030. Although this will be topped up in the UK, with the Government's carbon values as the formal target trajectory, the additional UK carbon price support has been frozen at £18/t. That implies a total market price of £42/t in 2030 for the UK power sector.

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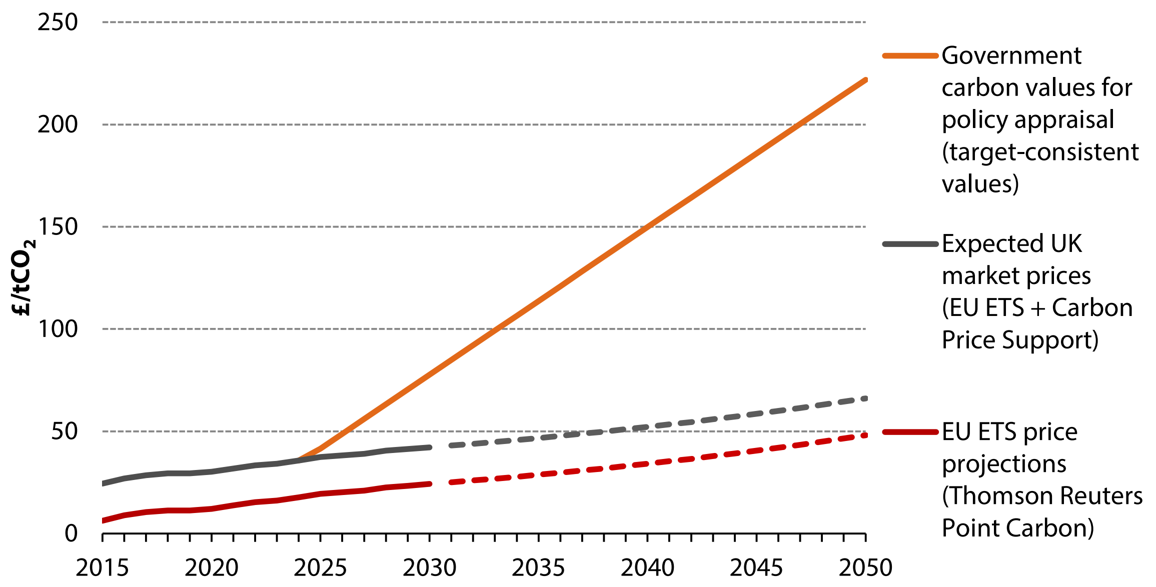
[10] For example, a carbon price at this level was needed to construct scenarios that could meet the 2050 target in CCC (2012) *The 2050 target*.

Box 1.2: Evaluating cost-effectiveness in our scenarios

If the world were to agree action to reduce emissions consistent with a 2°C target and deliver this through an efficient carbon market, market carbon prices would rise to the level required to meet the target, as expressed by the Government's carbon values.

Figure B1.2: Target-consistent carbon values and market prices (2015-2050)



Source: DECC (2009) *Carbon Valuation in UK Policy Appraisal*; DECC (2014) *Updated short-term traded carbon values used for UK policy appraisal*; PointCarbon Thomson Reuters (2015); projected beyond 2030 at 3.5% p.a.

Source: DECC (2009) *Carbon Valuation in UK Policy Appraisal: A Revised Approach*; DECC (2014) *Updated short term carbon values for UK policy appraisal*; CCC (2012) *The 2050 target*; Thomson Reuters Point Carbon (June 2015) and Aurora Energy Research (2015) each project a price of £24/tonne in 2030.

6. Assumptions underpinning our scenarios

Baseline demand for energy and energy services

We use a range of forecasts of GHG emissions and electricity demand, depending on the analytical tools appropriate to identifying abatement options across the various sectors:

- For some sectors (power, transport, residential buildings), our scenarios are based on detailed modelling of the sources of emissions, in both baseline (i.e. no climate policy) and decarbonisation scenarios. For the power sector, our scenario is based on DECC's baseline forecast of electricity demand, modified to take account of the change in electricity demand from abatement measures in end-use sectors (i.e. reductions in demand from energy efficiency and increases due to electrification), and our assessment of the appropriate generation mix. For the road transport sector, our scenarios are based on a projection of travel demand produced with the Department for Transport's National Transport Model (NTM). For residential buildings, our scenarios are based on a projection of heat demand produced with DECC's National Household Model (NHM).

- For others sectors (industry, non-residential buildings, agriculture and other non-CO_2), our scenarios are based on baseline forecasts of GHG emissions and our assessment of the cost-effective abatement measures to reduce GHG emissions below this level. We use interim projections provided to us by DECC in October 2015 (in advance of their latest official projections, published this month) for baseline GHG emissions for the industry, non-residential buildings, agriculture, and other non-CO_2 sectors.

We have satisfied ourselves that the interim projections are a reasonable basis for our scenarios. In part that reflects a set of alternative projections we commissioned and considered from Cambridge Econometrics. This work suggests the projections we use may be cautious (e.g. the Cambridge emissions projection is 4% lower overall than the DECC interim projection). However, the Cambridge work also identified significant uncertainties overall.[11] We concluded that a sensible range for overall uncertainty is up to 10% higher or lower than our central estimates.

Macro drivers of emissions

In projecting emissions, it is important to allow for general economic trends, which will tend to increase energy demand and hence emissions in the absence of action. We use Government forecasts of population, economic activity and fossil fuel prices:

- **Population**. DECC interim projections (October 2015), which underpin our scenarios for industry and non-residential buildings, are based on GDP forecasts that are consistent with the latest population projection from the Office of National Statistics (ONS). Under this projection, the UK's population is now expected to grow by 10% from 64.6 million in 2014 to reach 71.4 million in 2030 (Figure 1.4). Our scenarios for residential buildings and road transport are consistent with the ONS's previous (November 2013) population projection, which reaches a slightly lower figure of 71.0 million in 2030.
- **Economic activity**. The latest DECC interim projections assume a growth in UK GDP in real terms of 47% between 2014 and 2030 (Figure 1.5).
- **Fossil fuel prices**. Oil, gas and coal wholesale prices are forecast to increase 19%, 32% and 9%, respectively, between 2014 and 2030 (Gas prices, Figure 1.6). DECC's long-run variable costs of energy supply (LRVCs) are consistent with their wholesale price forecasts. Where possible, we use the latest DECC interim costs (November 2015); in all other cases, we use the costs published in October 2014.

There is of course considerable uncertainty over these future trends and how they will affect energy demand. We discuss this uncertainty in the next section and in our Advice Report.

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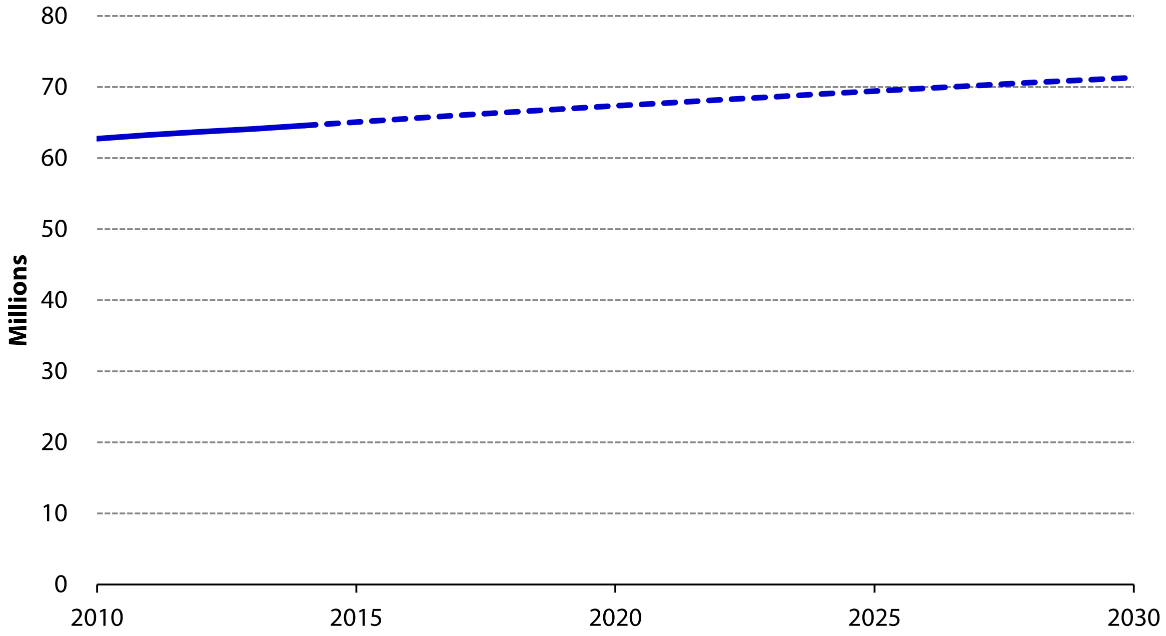
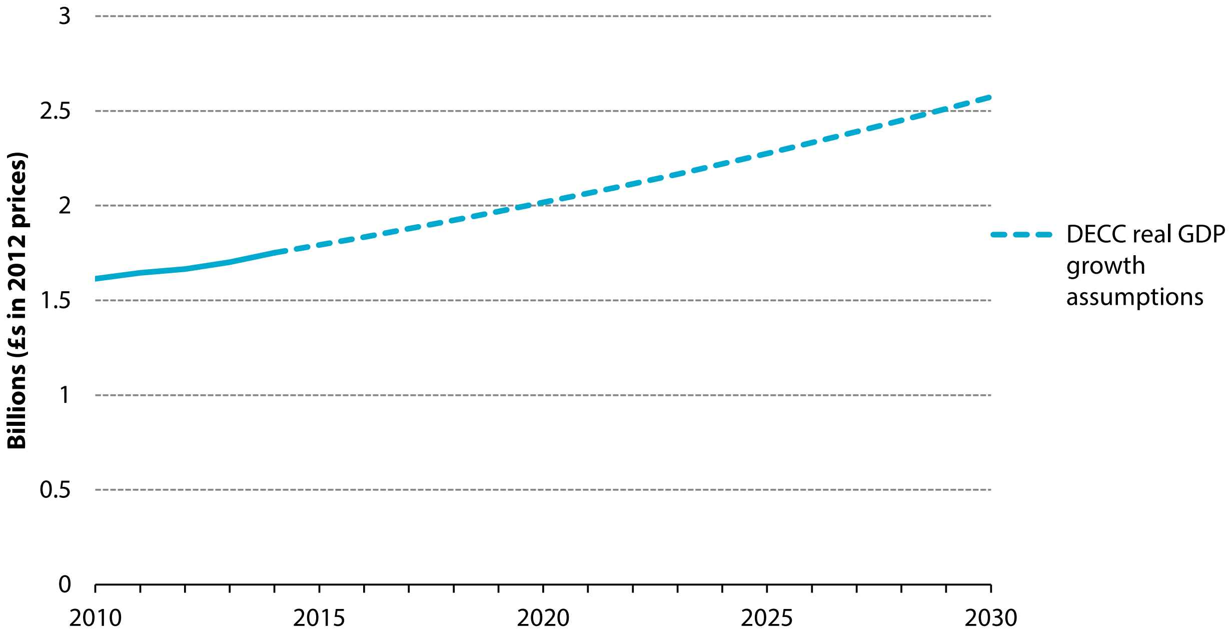
[11] This work is discussed further in our Advice Report, and is available on our website, www.theccc.org.uk

Figure 1.4: UK population projections (2010-2030)



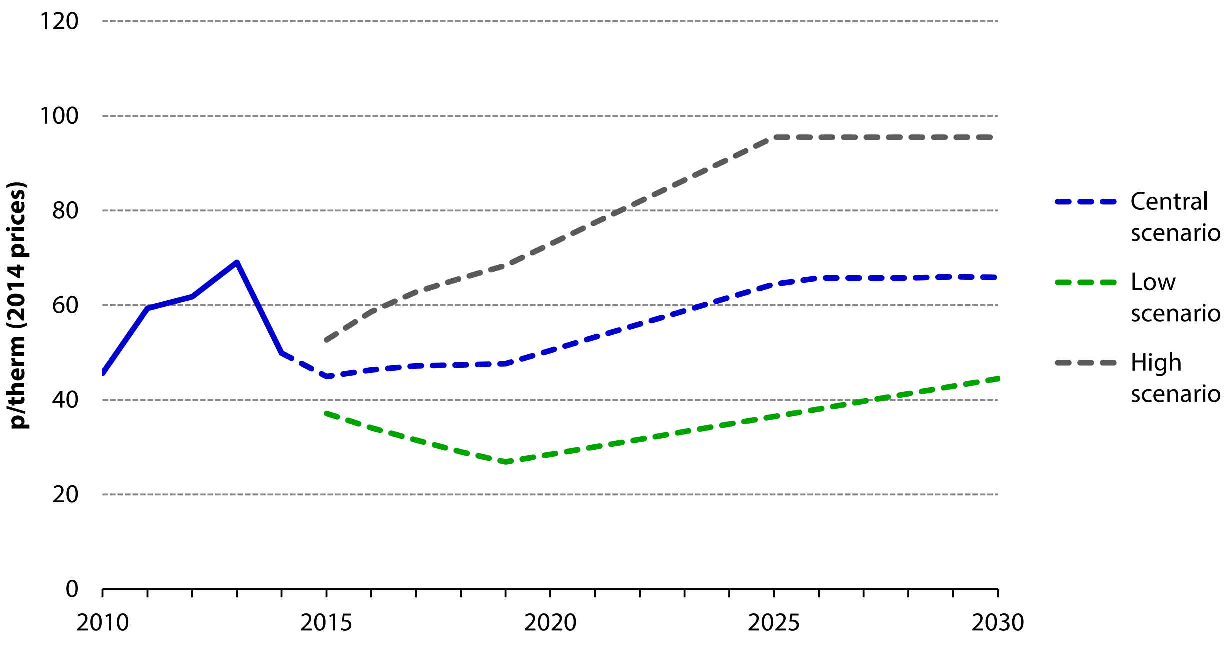
Source: ONS (2015) *Annual Mid-year Population Estimates, 2014;* ONS (2015) *Principal Projection - UK Summary, 2014-based*, available at http://www.ons.gov.uk/ons/taxonomy/index.html?nscl=Population+Projections#tab-data-tables

Figure 1.5: UK real GDP projections (2010-2030)



Source: ONS (2015) *Quarterly National Accounts*; DECC (2015) *Updated energy and emissions projections*

Figure 1.6: DECC gas price scenarios (2010-2030)



Source: DECC (2015) *Updated energy and emissions projections*

7. Economy-wide scenarios

The Central scenario requires continuing energy efficiency improvement across the economy, but also an extension of the shift to low-carbon sources of energy beyond the power sector. To stay on track to the 2050 target, markets for low-carbon heating systems and ultra-low emission vehicles must develop significantly in the 2020s. Similar emissions reductions could be achieved using a different low-carbon technology mix, as demonstrated by our Alternative scenarios. In summary:

- In **Power**, the carbon intensity of generation decreases from around 450 gCO_2/kWh in 2014 to 200- 250 g/kWh in 2020, and to below 100 g/kWh in 2030. This reduction could be delivered by a range of different mixes of low-carbon generation (i.e. renewables, nuclear and CCS), reaching a total share of around 75% of generation by 2030. It is important that the low-carbon portfolio includes roll-out in the 2020s of offshore wind and CCS given their long-term importance and the role of UK deployment in driving down costs (see our supporting report on Power Sector Scenarios). Improvements to energy efficiency (e.g. increased use of LED lighting and more efficient appliances) will support progress in the power sector. The demand side also has an important role in increasing the flexibility of the power system, alongside interconnection, storage and flexible back-up capacity.
- In **Industry**, there is improved energy management and process control, use of more energy efficient plant and equipment, waste heat recovery, use of bioenergy in space and process heat, and development of a carbon capture and storage (CCS) cluster allowing use of CCS in the iron and steel and chemicals sectors. The Alternative scenario involves the use of hydrogen instead of CCS.

- In **Buildings**, deployment of low-carbon heat increases so that heat pumps and heat networks from low-carbon sources provide heat for around 13% of homes and around half of demand in non-residential buildings; insulation increases (including a further around 1.5 million solid walls and 2 million cavity walls in the 2020s), and there is more use of heating controls and efficient lights and appliances. The Alternative scenarios involve either (i) conversion of a proportion of the gas grid to hydrogen use, with use of hydrogen boilers to generate heat in residential, commercial and public buildings; (ii) hybrid heat pumps[12] in place of a mix of conventional heat pumps or gas boilers in residential buildings; or (iii) greater deployment of heat networks, in place of a proportion of heat pumps in residential, public and commercial buildings.
- In **Transport**, efficiency of conventional vehicles continues to improve in the 2020s (e.g. conventional car emissions fall from 125 gCO_2/km in 2014 to 102g/km in 2020 then 86g/km in 2030), alongside deployment of electric vehicles across cars, vans and smaller HGVs (e.g. the combination of plug-in hybrids and battery electric vehicles reach 9% of new car and van sales in 2020 and around 60% in 2030). We include hydrogen buses (reaching 25% of sales in 2030), with the possibility of a bigger contribution from hydrogen for other vehicles types. On the demand side we assume some behavioural change results in modest reductions in total distance travelled and more fuel-efficient travel. The Alternative scenarios involve either (i) hydrogen transport technologies achieving widespread deployment across all vehicle types; (ii) use of LNG to fuel HGVs with only modest emissions savings, requiring an increase in the electrification of the car and van fleet; or (iii) a greater role for demand reduction compensating for barriers to electric vehicle deployment.
- In **Agriculture**, there is increased take-up of crops and soils measures that mainly target the reduction of N_2O through improved fertiliser use efficiency (e.g. use of cover crops and improved manure management practices); livestock measures targeting diets, health, and breeding that reduces methane; waste and manure management, including anaerobic digestion and improvements in the fuel efficiency of stationary machinery.
- In **Waste and F-gases**, five main biodegradable waste streams are fully diverted away from landfill across the UK by 2025, and F-gases are replaced by low-carbon alternatives in refrigeration, air conditioning and other uses by 2030.
- We also include 4 MtCO2e of abatement from biomethane in the gas grid. When presenting economy-wide abatement scenarios in this Chapter and in the Advice Report, we allocate this to the **Industry** non-traded sector for ease of presentation. In reality, this abatement would occur across a range of end-use sectors, including buildings.

The impact of the Central scenario on abatement by sector and residual emissions is set out in Figure 1.7, with the traded and non-traded sectors shown separately in Figures 1.8 and 1.9. Details of the Barriers and Max scenarios for each sector are set out in the chapters that follow. They indicate that:

- If there are barriers to the Central scenario that affect all sectors then the maximum deviation from the Central scenario involves about 46 $MtCO_2e$ of additional emissions in 2030.
- If all sectors proceed more quickly towards the maximum potential of their technologies then there is a further reduction of emissions beyond that in the Central scenario of 39 $MtCO_2e$.

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[12] Hybrid heat pumps are heating systems that use a combination of a heat pump and a boiler; the heat pump generally provides the heat required, supplemented by the boiler at peak times (i.e. on the coldest winter days).

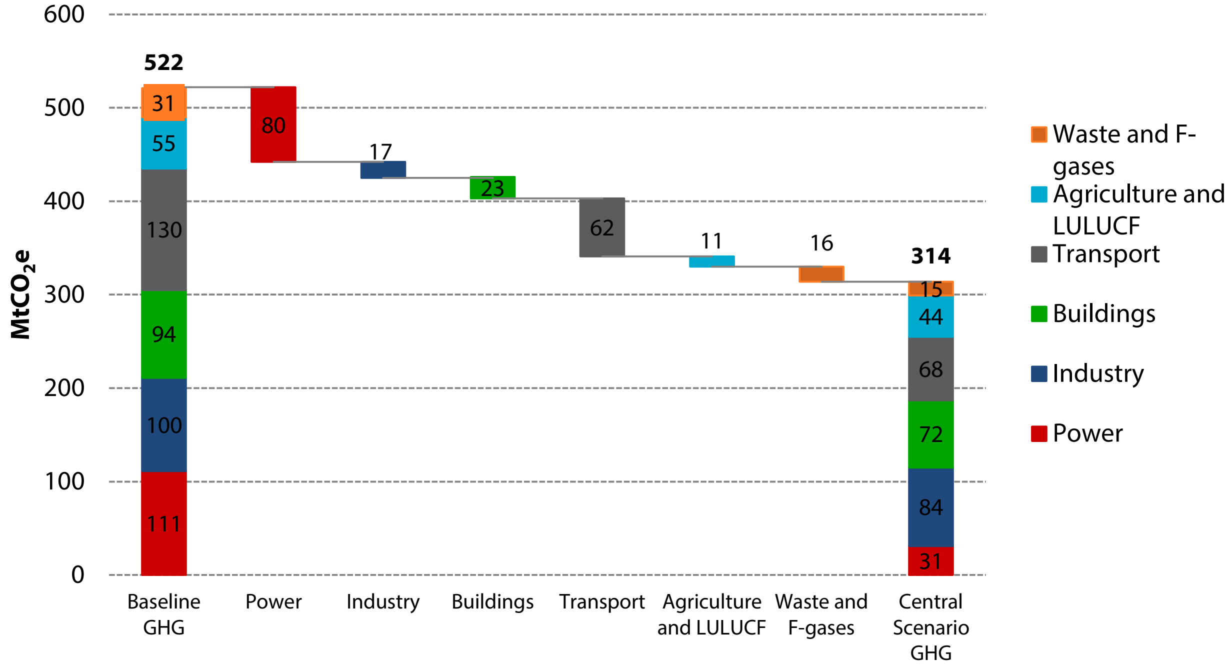
It is to be expected that some areas will prove more difficult than suggested in the Central scenario (e.g. costs may not fall as quickly as anticipated or barriers may prove harder to overcome) and other areas will prove easier (e.g. new innovation will make it easier to achieve the maximum potential). The types of additional barriers or new measures considered in these scenarios are summarised in Table 1.1.

Table 1.1: Composition of Barriers and Max sectoral scenario

Sector	Barriers Scenario	Max Scenario
Power	Further delays or failure to roll out nuclear or CCS	Greater deployment of low carbon generation as costs fall more quickly than anticipated
Industry	Lower uptake of energy efficiency and failure to deploy CCS	Greater deployment of electrification in industry and wider adoption of CCS
Buildings	Lower levels of deployment of low-carbon heat and fewer energy efficiency measures	Greater deployment of low carbon heat and energy efficiency options
Transport	Reduced uptake of low emissions vehicles	Greater change in travel behaviour, and better alignment of real-world emissions with test cycle
Agriculture	Slow introduction of measures to manage soils and crops, failure to reduce emissions from vehicles	Greater uptake of alternative diets for animals, new crops and more efficient vehicles
Waste and F-gases	More limited diversion of biodegradable waste streams from landfill with less of UK participating in such programmes	No further abatement beyond the Central scenario due to limited evidence

Source: CCC analysis.

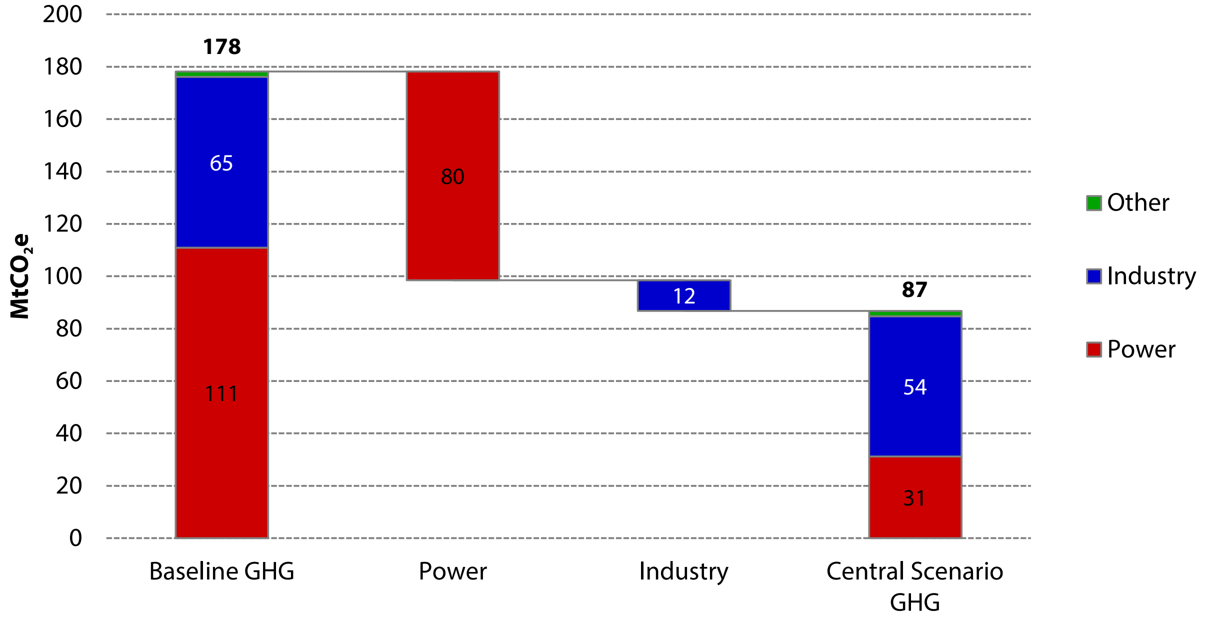
Figure 1.7: Abatement in the Central scenario (total emissions, 2030)



Source: CCC analysis

Notes: The Baseline is a projection of GHG emissions in the absence of further effort to reduce them. Baseline GHG emissions are drawn from Government models and our own modelling at the sector level. Biomethane in the gas grid is allocated to the industry sector.

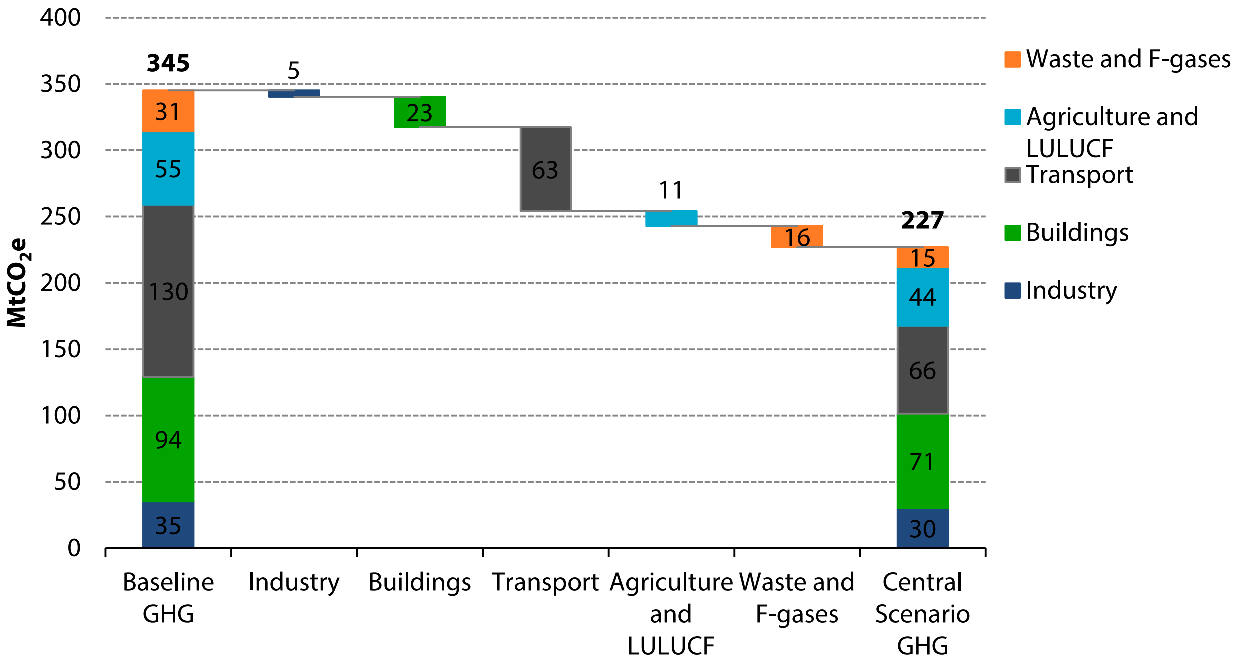
Figure 1.8: Abatement in Central scenario (traded sector, 2030)



Source: CCC analysis

Notes: The Baseline is a projection of GHG emissions in the absence of further effort to reduce them. Other includes traded emissions in buildings and transport sectors.

Figure 1.9: Abatement in the Central scenario (non-traded sector, 2030)



Source: CCC analysis
Notes: The Baseline is a projection of GHG emissions in the absence of further effort to reduce them. Baseline GHG emissions are drawn from Government models and our own modelling at the sector level. Biomethane in the gas grid is allocated to the industry sector.

Our central estimate of the emissions path under the Central scenario implies territorial UK emissions in 2030 that are 61% below 1990 levels (Figure 1.10).[13] A very similar level of emissions could be achieved through a combination of the alternative approaches illustrated in the Max and Barriers scenarios.

The estimated emissions path is subject to considerable uncertainty around macro drivers and their impact on GHG emissions. In addition, barriers to deployment of some measures might increase GHG emissions above the Central scenario emissions path.

Should macro drivers or barriers to deployment push emissions upwards, greater levels of emissions reductions consistent with the Max scenarios, and/or deployment of additional sustainable bioenergy resource, may be required to offset any increase (Figure 1.11).

A combination of all the Max or all the Barriers scenarios would imply total GHG emissions in 2030 either 56% or 66% below 1990 levels (Figure 1.12).

Under the Central scenario emissions decrease on average around 13 MtCO$_2$e per year between 2014 to 2030, and a further 9 Mt per year to meet the 2050 target (Figure 1.13).

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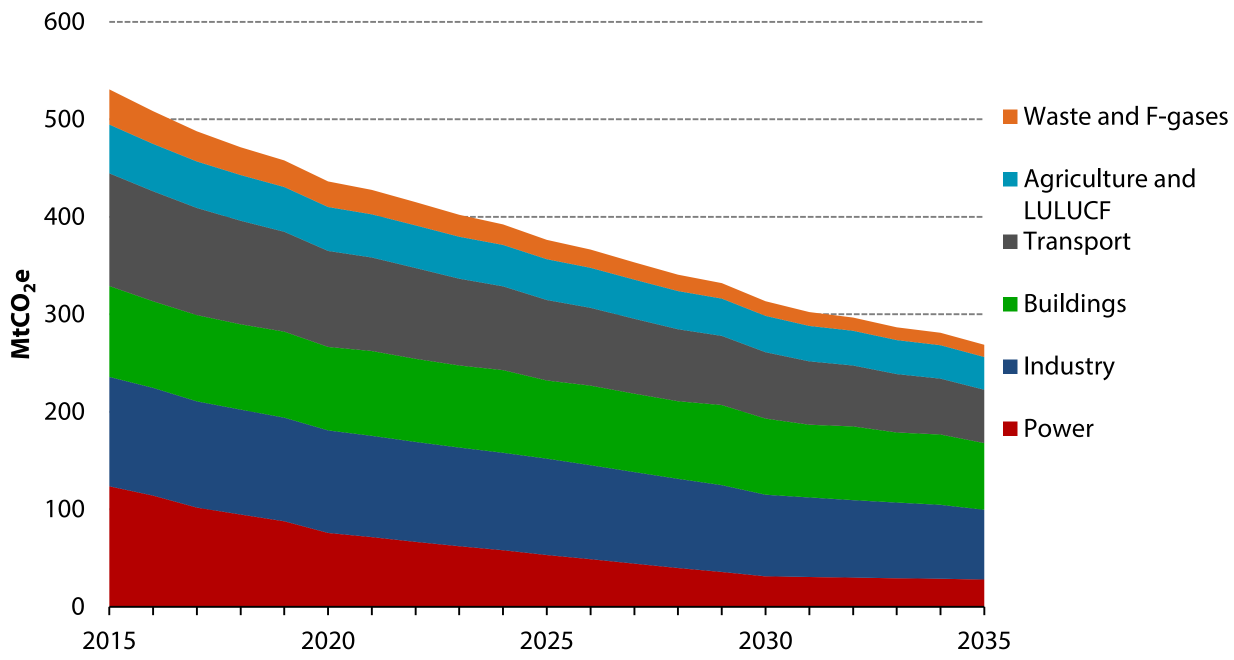
[13] Note that in our budget advice we distinguish between actual territorial, or 'gross', emissions and emissions as measured by the net carbon account. Whilst our scenarios involve a reduction in actual emissions of 61%, they would involve a slower reduction, of 57%, in the net carbon account. This reflects the impact of emissions trading in the EU Emissions Trading System and its treatment in the Climate Change Act. See our Advice Report for more details.

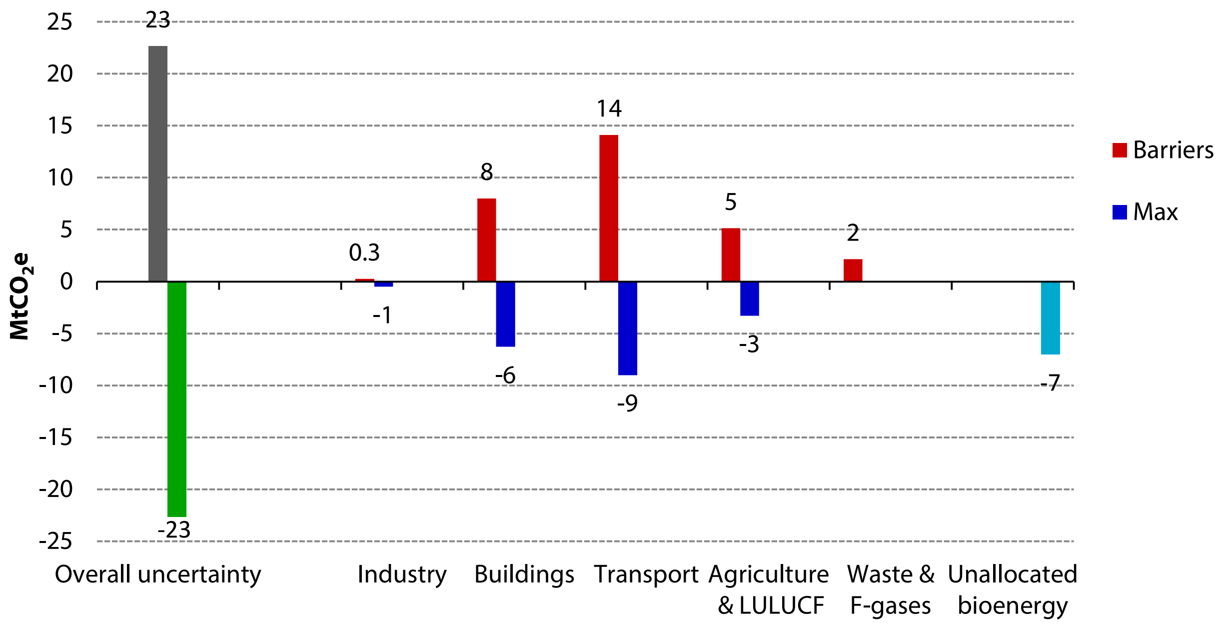
The shape of the emissions path under our scenarios is determined by the set of sector-specific paths, which reflect the different considerations in each case (Figure 1.14). Taken together they imply a cost-effective path across the economy that works out fairly close to a linear reduction in emissions to 2050.

Figure 1.10: Central scenario emissions (2014-2035)



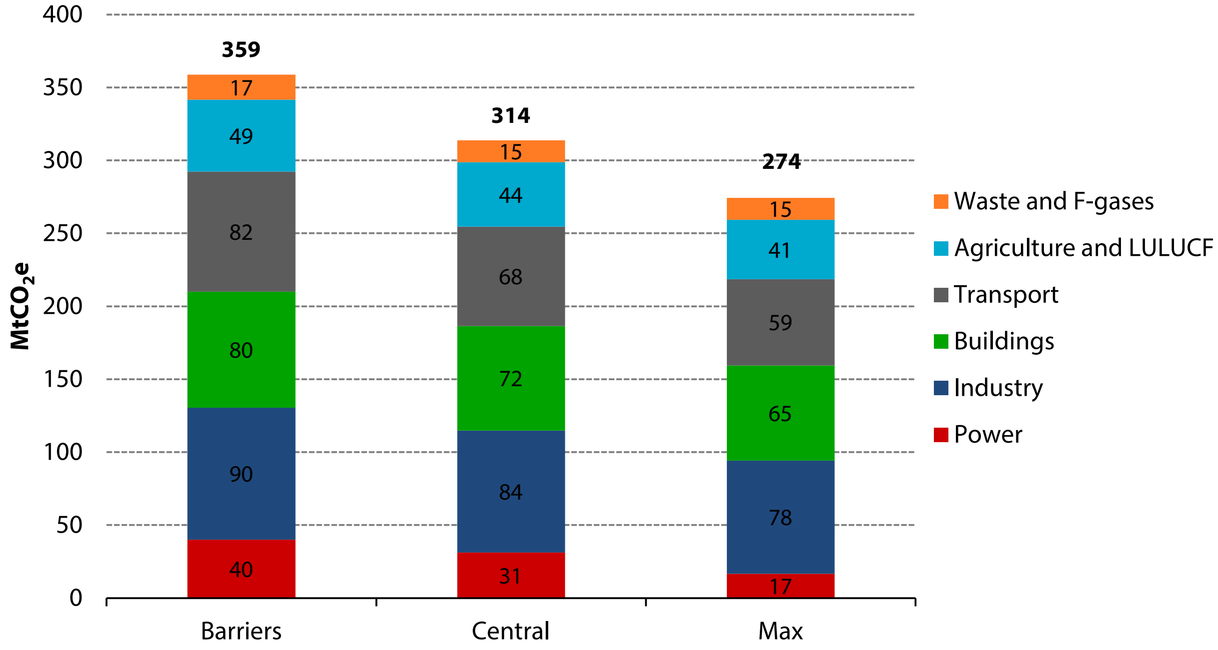
Source: CCC analysis

Figure 1.11: Impact of uncertainties on 2030 non-traded sector emissions



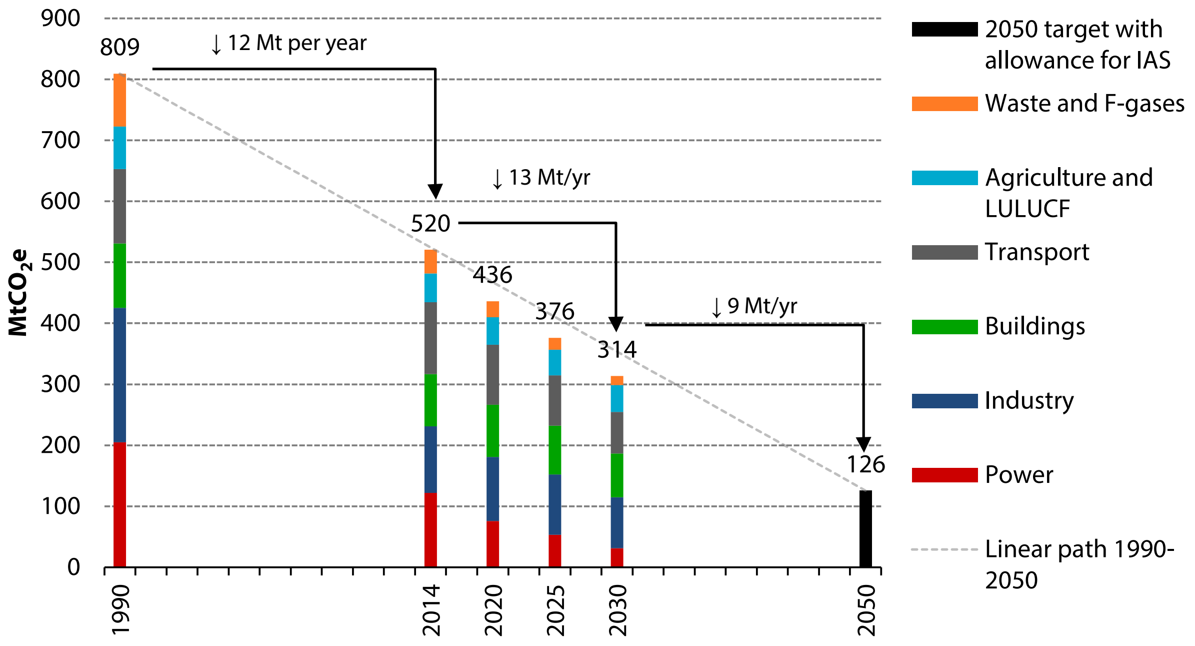
Source: CCC analysis
Notes: The range for industry emissions in the non-traded sector is very low as the majority of cost-effective abatement is in the traded sector.

Figure 1.12: Barriers, Central and Max scenarios in 2030



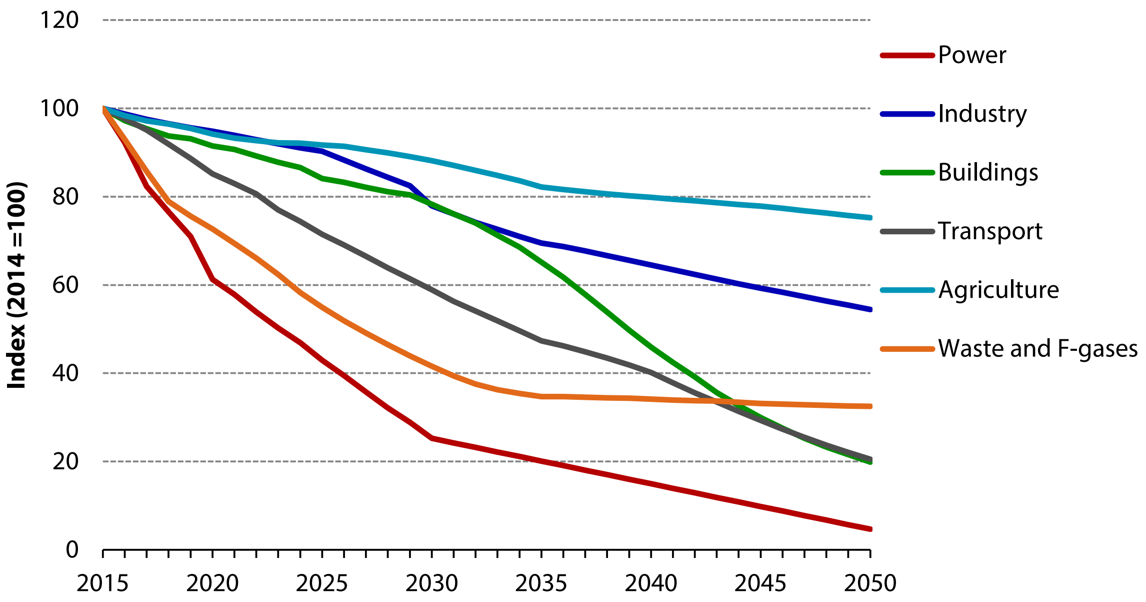
Source: CCC analysis
Note: Biomethane in the gas grid is allocated to the industry sector.

Figure 1.13: Emissions reductions in the Central scenario and to 2050



Source: CCC analysis

Figure 1.14: Central scenario emissions paths to 2050



Source: CCC analysis

8. Differences between the nations of the UK

The devolved administrations have an important role to play in achieving the UK's carbon budgets. Scotland, Wales and Northern Ireland accounted for 22% of UK emissions in 2013, whilst accounting for 16% of the UK's population and 13% of GDP.

The devolved administrations are covered in Chapter 5 of our Advice Report. The assessment in that chapter concludes that there is a similar pattern of abatement potential in the devolved administrations as in the UK, but with the following key differences:

- There is potential for Scotland to contribute a greater share of low-carbon power, given the size of its renewable resources.
- The high share of energy-intensive industry in Wales is reflected in a relatively lower amount of abatement and a lesser overall projected fall in emissions compared to the UK as a whole.
- Agriculture abatement is more pronounced, given the higher share of agriculture emissions in devolved nations. This is especially the case in Northern Ireland where the sector is relatively more important for emissions and the economy. This also contributes to a lower overall fall in emissions in Northern Ireland compared to the UK as a whole.

Succeeding in reducing emissions will require coordinated action across the UK. Many of the levers to enable change and drive emissions reduction are at the devolved level, and these must be used alongside UK policies if the carbon budgets and devolved climate targets are to be met.

9. Costs of meeting the fifth carbon budget

The proposed carbon budget is on our best assessment of the lowest cost path to the UK's 2050 target. Meeting it will ensure costs are kept as low as possible in the long term. However, there is a cost to climate action since low-carbon technologies currently have higher costs than high-carbon alternatives, which do not face the full cost of their emissions:

- The precise costs and benefits of meeting the budget depend on a range of uncertain factors. These include the pace of innovation and the path of technology costs and performance, fossil fuel prices, wider economic performance, the level of demand and behaviour of consumers and the mix of measures used to meet the budget.
- Under central assumptions, and based on meeting the Central economy-wide scenario, our best estimate for the cost of meeting the budget is 0.5% of GDP in 2030. Depending on assumptions about technology costs and fossil fuel prices, this could be between 0.1% and 0.9% of GDP (Table 1.2).
- Included within this estimate is an annual cost in 2030 of up to £3 billion (around 0.1% of expected GDP) more than the cost of meeting the fourth carbon budget that has already been legislated. Costs would be lower to the extent that reduced carbon emissions mean UK firms can purchase fewer emissions allowances in the EU ETS.
- Offsetting some of these costs, there are wider benefits to climate action through reduced air pollution and other health benefits. Using government valuation methods, we have previously estimated the monetary value of these to be around 0.1-0.6% of GDP in 2030.

Delaying action in the 2020s, and attempting to catch up after 2030, would increase overall costs and would make meeting the 2050 target very challenging:

- If nothing is done during the 2020s and it is not possible to catch up in later years, GHG emissions would only fall to around 235 $MtCO_2e$ by 2050 (i.e. there would be an abatement gap of 66 Mt from the 2050 target of 167 Mt).

- It may not be possible to catch up following a 10-year delay due to the rate of turnover of the capital stock and the impact of the delay on deployment of infrastructure, development of supply chains, and development of markets. Such a stop-start approach to abatement would also be likely to slow innovation, increase risks and ultimately increase costs of low-carbon technologies.
- In order to meet the 2050 target under these circumstances, it would be necessary to purchase significant quantities of credits (at potentially very high cost) or to undertake very costly domestic abatement (e.g. curtailment of demand for energy services, scrappage of capital equipment during its lifetime).

We have estimated the costs of delayed action in the 2020s for the non-traded sector. There would be an initial cost saving from avoiding costly measures in the 2020s, for which we estimate the net present value to be around £15 billion over the period to 2050. However, the additional costs of delay, incurred through credit purchase or more costly domestic abatement after 2030 would be much greater, at around £110 billion over the period to 2050. Overall, delayed action in the 2020s would impose a cost of around £95 billion in present value terms, under central assumptions about fossil fuel and carbon prices, over the period to 2050.

Table 1.2: Estimated costs of meeting the fifth carbon budget under a range of assumptions

Costs as % GDP	**Central estimate**	**High or low fossil fuel prices**	**Low or high technology costs**
Total costs	**0.5%**	**0.1% to 0.8%**	**0.2% to 0.9%**
Of which:			
Power	0.5%	0.3% to 0.7%	0.4% to 0.7%
Industry	0.0%	0.0%	0.0%
Buildings	0.0%	-0.1% to 0.0%	-0.1% to 0.0%
Transport	0.1%	-0.1% to 0.2%	-0.1% to 0.2%
Agriculture, waste and F-gases	0.0%	0.0%	0.0%

Source: CCC analysis.
Notes: The cost estimates presented are based on the resource costs of the measures in our scenarios to reduce emissions. They do not include quantified costs or benefits relating to changes in welfare (e.g. warmer homes or changes in demand for energy services), or impacts on health (e.g. due to improved air quality). We expect net abatement costs in agriculture to be negative; in these calculations we assume zero costs due to uncertainties around exact magnitudes. Numbers may not sum due to rounding.

Chapter 2: Decarbonising power

Introduction and key messages

Power sector emissions accounted for around a quarter of total UK emissions covered by carbon budgets in 2014.

It has been a common finding of our previous work that meeting the 2050 target will require that emissions from energy use – power, heat and transport – are almost eliminated. To achieve this it is important to have low-carbon sources of energy that are low cost, secure, acceptable to the public and attractive to investors. A decarbonised power sector can provide that low-carbon energy source.

In preparation for our advice on the fifth carbon budget we published a separate report on *Power sector scenarios for the fifth carbon budget*. That report set out a range of future options to reduce emissions from the UK's power sector in 2030, balancing issues of affordability, security of supply and decarbonisation[14]. The conclusions from that report were:

- **New investment will be needed in the 2020s.** Up to 200 TWh of new generation will be needed in the 2020s to replace generation from retiring coal and nuclear capacity and to meet possible increases in demand. The 2020s are therefore a crucial decade for the future of the power sector.
- **Low-carbon options are likely to be cost-competitive.**
  - Several low-carbon options should reach maturity by or during the 2020s. If unabated gas-fired generation faces the full cost of its carbon emissions (i.e. a 'target-consistent' carbon price, estimated at £78/tonne in 2030), these options could be delivered without further subsidy, even when intermittent generation faces the full system costs it imposes.
  - These options represent good value investments for a society committed to climate targets and are included in our scenarios: onshore wind and ground-mounted solar from the first half of the decade, and nuclear, offshore wind and potentially carbon capture and storage (CCS) in the second half of the decade.
- **A portfolio approach is appropriate and justifies continued support for less mature technologies, which should fall until subsidies can be removed.**
  - Our scenarios also include investments in less mature options – principally offshore wind and CCS – in the first half of the 2020s, when these will still need subsidies. These are required to drive down costs for competitive deployment from the second half of the decade.
  - CCS is very important for reducing emissions across the economy and could almost halve the cost of meeting the 2050 target in the Climate Change Act.
  - Offshore wind is demonstrating cost reduction and has the potential to meet a large share of total electricity demand. The majority of required development costs have already been committed as part of efforts to meet the UK's 2020 renewables target.
- **Flexibility is important.** To maximise the value of these investments and ensure security of supply

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[14] CCC (2015) *Power sector scenarios for the fifth carbon budget*. Available at: www.theccc.gsi.gov.uk

Introduction and key messages

it will be important to improve the flexibility of the power sector. That will require investment in flexible gas-fired generating capacity alongside expansion of international interconnection, flexible demand response and potentially electricity storage. The costs of these measures are included in our assessment of intermittency and system costs.

- **Scenarios for the fifth carbon budget.**
  - Low-carbon investments are already committed to 2020. Along with the closure of coal capacity, this will reduce the emissions intensity of the power sector from around 450 gCO_2/kWh to 200-250 gCO_2/kWh.
  - Our new scenarios for 2030 are towards the upper end of the 50-100 gCO_2/kWh range that we have previously identified as suitable for 2030. That reflects delays to new nuclear and CCS projects alongside good progress for renewable technologies. Emissions in 2030 are around 60 $MtCO_2$ lower than if investment in the 2020s was in gas-fired rather than low-carbon generation.
- **Impact on consumer bills.**
  - In 2020, a typical household will be paying around £105 through their annual electricity bill of around £500 to support investment in low-carbon generation, including the market carbon price. Those costs are already committed through investments that are underway and contracts that have been awarded.
  - In our scenarios, support will increase to £120 per household in 2030 and then fall as support for earlier investment expires.
  - Costs to households would be around £20 higher in 2025 and £40 higher in 2030 in our scenarios than if investment in the 2020s was focused on gas-fired generation facing a market carbon price (which we expect to rise to £42/tonne in 2030).

In this chapter we summarise the evidence from our October report and align our power sector scenarios to the updated assessment of electricity demand after abatement in other sectors (e.g. uptake of energy efficiency measures, heat pumps, and electric vehicles, see Chapters 3, 4 and 5).

- The latest scenario for demand is lower by 6% than the central estimate used in our October report (which reflected earlier economy-wide analysis set out in our 2013 *Fourth Carbon Budget Review*). This is within the range of scenarios we considered in October and would make reducing emissions in the power sector slightly easier than the central scenarios presented in that report.
- The revisions are mainly due to lower projections for baseline demand and greater uptake of energy efficiency measures, which imply lower required low-carbon deployment in the 2020s.

We set out our analysis in the following sections:

1. Overview of emissions from the power sector
2. Options for reducing emissions from electricity generation
3. Existing ambition and projected emissions without further policy
4. Abatement scenarios
5. Costs and impacts
6. Delivering the scenarios

1. Overview of emissions from the power sector

Power sector emissions were 121 $MtCO_2$ in 2014, 23% of total UK greenhouse gases (Figure 2.1). The majority of these emissions are from coal (71% of emissions, whilst providing 32% of generation) followed by gas (27% of emissions, 29% of generation). There are no direct emissions from the 19% of generation from nuclear or 20% of generation from renewables.

Emissions have decreased by 41% since 1990, mainly as a result of reduced burning of coal but also in recent years due to increased low-carbon generation and lower demand (Figure 2.2):

- Since 1990 the generation mix has shifted from coal towards gas and renewable generation:
  - The coal share of generation reduced from 80% in 1990 to 35% in 2007 and 30% in 2014. The recent reductions reflect the EU Large Combustion Plant Directive, which restricts the use of coal on air quality grounds, as well as changing economics (e.g. carbon pricing and lower gas prices).
  - The dash for gas led to an increase in gas penetration from 1990 to 1999 (from zero to 34% of generation). In recent years the penetration of gas has fluctuated and in 2014 was around 30%.
  - Low-carbon generation has increased from 21% of generation in 2007 to 38% in 2014, reflecting an expanded contribution from renewables (19%).
- From 1990 to 2005, electricity generation increased in line with demand, which rose at around 1.6% annually. More recently, generation has fallen by an average 1.9% annually from 2006-2014 due to energy efficiency, changing economic structure and slower growth. In 2014, generation was 298 TWh to meet 290 TWh of demand, with 21 TWh net imports and 28 TWh of transmission and distribution losses.

Emissions are the result of the type of capacity on the system and how it is used, which resulted in an emissions intensity of around 450 gCO_2/kWh in 2014. Emissions from the current plant mix could be reduced by 48 $MtCO_2$, to an average emissions intensity of around 250 gCO_2/kWh by dispatching gas generation before coal, alongside the low-carbon capacity. [15] Almost all of demand in 2014 could have been met without using coal generation. This 'achievable emissions intensity' has fallen 46% since 2007 (from over 450 gCO_2/kWh) as a result of falling demand and increased low-carbon capacity.

Total de-rated capacity[16] in 2014 was around 68 GW, the largest share of which was provided by gas (20 GW), followed by coal (18 GW) and nuclear (8 GW). Peak electricity demand was 51 GW in 2014.

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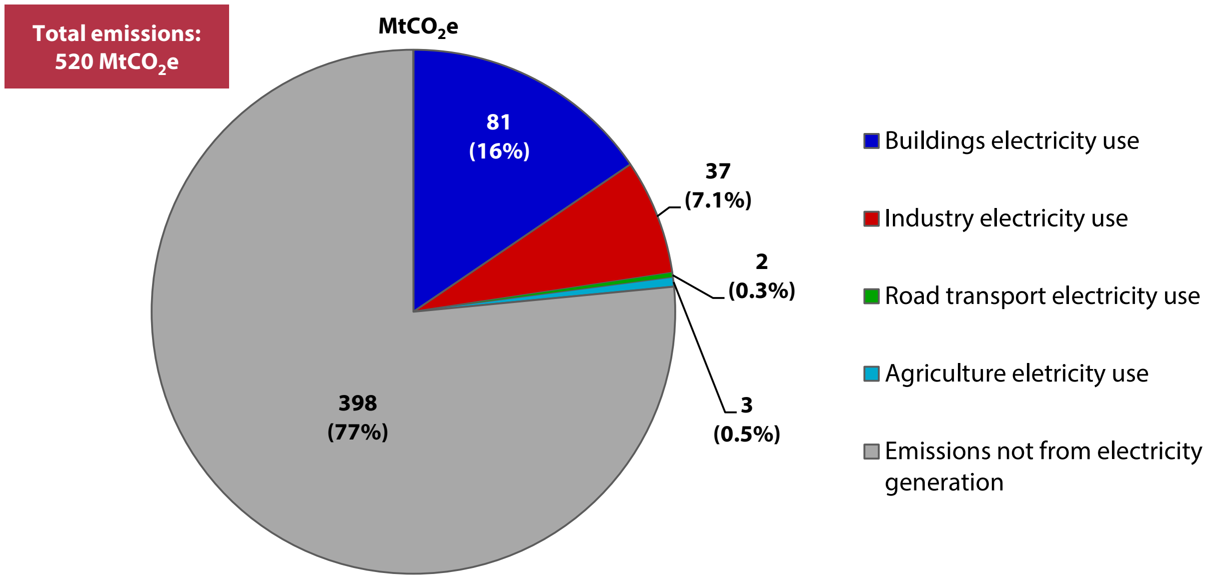
[15] We refer to this as 'achievable emissions intensity, the minimum average emissions intensity that could be achieved in a year, given the installed capacity of power sector technologies, electricity demand and the demand profile of that demand.

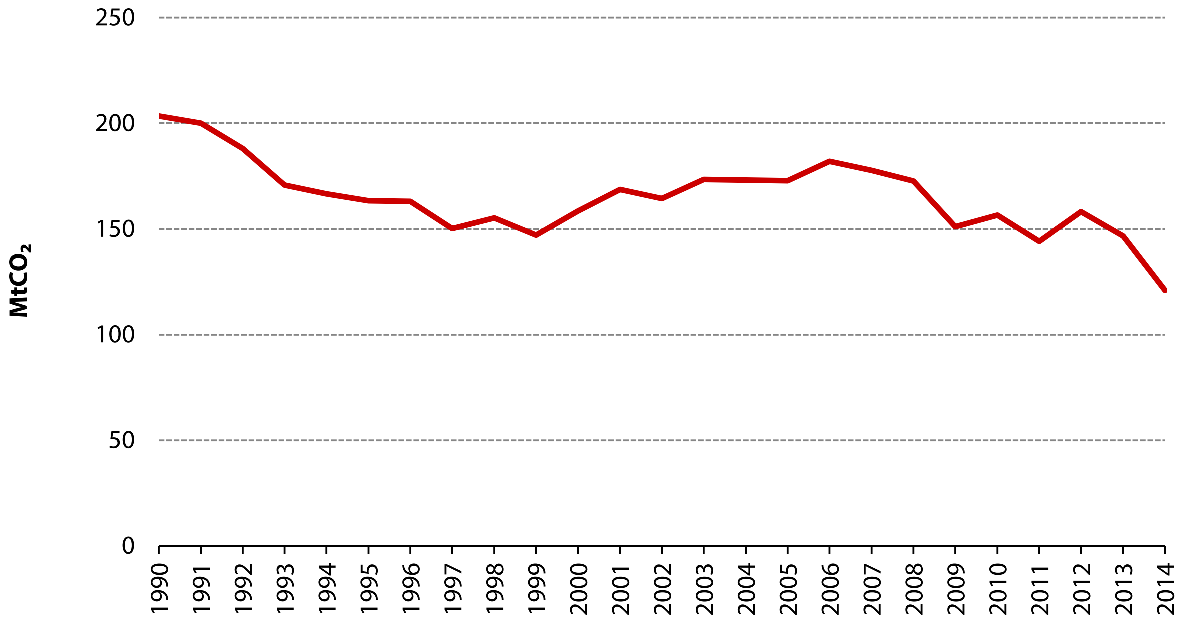
[16] 'De-rated' capacity standardises capacity across technologies with different availabilities. It reflects the probable proportion of a source of electricity which is likely to be technically available to generate. We adopt de-rating factors consistent with the Governments' Capacity Market and the Digest of UK Energy Statistics.

Figure 2.1: Power sector CO_2 emissions as a percentage of total GHG emissions (2014)



Source: NAEI (2015), CCC calculations.

Figure 2.2: Historical power sector emissions (1990-2014)



Source: NAEI (2015)

2. Options for reducing emissions from electricity generation

Low-carbon technologies are, and in the 2020s will continue to be, a more expensive way to generate electricity than burning gas and allowing the emissions to enter the atmosphere for free. However, in a carbon-constrained world this is not an option.

Plans are already in place to continue the increase in low-carbon generation to 2020 (section 3). In the 2020s, several low-carbon generation options should be cost competitive with unabated gas-fired generation provided it faces the full cost of its carbon emissions (Table 2.1 and Figure 2.3).

We distinguish in our analysis between the likely market carbon price (i.e. the cost of each carbon allowance in the EU Emissions Trading System and the UK's carbon price support) and a carbon price that is consistent with meeting the UK's 2050 target (Box 1.2 in Chapter 1).

- The actual carbon price in the market is expected to be lower. We estimate it will increase to around £42/tonne in 2030. However, if applied across the economy and extrapolated to 2050, these prices would not be enough to meet the 2050 requirement in the Climate Change Act to reduce emissions by at least 80% relative to 1990 levels.
- The Government's carbon values are designed to be consistent with action required under the Climate Change Act and reach £78/tonne in 2030. These values are the appropriate basis for decision-making for a country committed to long-term carbon targets and international efforts to tackle climate change.

If unabated gas-fired generation faces the full cost of its carbon emissions, several low-carbon options could be delivered without further subsidy even when intermittent generation (e.g. wind and solar) faces the full system costs it imposes. In section 5 we discuss how increased penetration of intermittent technologies can be effectively integrated to the electricity grid while maintaining security of supply without causing cost escalations.

Mature low-carbon options

Favourable sites for onshore wind and solar are likely to be as cheap as or cheaper than gas-fired generation by 2020, suggesting that these projects should proceed. New nuclear will not be available until 2024/25, with costs comparable to gas-fired generation facing its full carbon cost:

- **Unabated gas as an alternative to investment in low-carbon technologies.** In a central scenario for gas prices and with a value attached to carbon that is consistent with meeting the UK's 2050 target, the full cost of new gas generation would be £85/MWh for new plants coming on line in 2020 and £95/MWh for 2025. That assumes a gas price that increases from 46 p/therm in 2015 to 66 p/therm by 2025. If gas prices remain at 46 p/therm, the full costs for gas generation would be £70/MWh in 2020 and £85/MWh in 2025.
- **Onshore wind and solar – low-cost sites are already demonstrating competitiveness.**
  - Onshore wind and ground-mounted solar projects have signed contracts to deliver electricity at £83/MWh from 2016/17.[17]
  - These generators have a lower capacity value as their output is variable – that implies an intermittency cost, which we estimate at around £10/MWh for both wind and solar.
  - Offsetting this, contracts only cover around two-thirds of the plants' life expectancies, after

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[17] Original contracts at £80/MWh in £2011/12 prices, adjusted to £2014 prices.

  which they can continue to produce power at low cost. This value is worth around £5/MWh.
  - Taken together, these imply a full cost of onshore wind and ground-mounted solar projects similar to that of gas generation in 2020 (e.g. £85/MWh). In practice, some of the best sites could be considerably cheaper and costs should continue to fall.
  - We assume that securing only the lowest-cost sites for onshore wind implies a slowdown in deployment compared to the 2010s. On that basis onshore wind and solar could provide 10-15 TWh/year of the new generation required in both the first and second half of the decade.
- **New nuclear – competitive and available from the mid-2020s.** The appropriate role for nuclear will depend on whether new projects can deliver to cost and time, and the cost of alternatives.
  - At the strike price offered for the first plant at Hinkley Point C (£93-96/MWh, adjusted to 2014 prices) this would be comparable to unabated gas facing its full carbon cost.
  - This first project has been delayed until 2024/25, with the potential for at least one or two further projects in the latter half of the decade. This implies around 20-25 TWh/year of new generation in 2024/25, with the potential to go further (i.e. up to 75 TWh/year) by 2030 should additional projects deliver to time.
  - Further sites have been agreed for new nuclear projects (up to 25 GW total) and have active developer interest, but these are at an earlier stage and our scenarios assume they do not deliver until after 2030. In line with recent work by the Energy Technologies Institute we assume that small modular reactors are not available before 2030.[18]
- **Other mature options** (e.g. sustainable biomass, tidal lagoons) could also provide more generation during the 2020s. It is less clear at this stage that tidal lagoons will provide a cost-effective alternative to unabated gas or that there will be sustainable biomass supply available for use in the UK power sector, so we only include a small amount of these in most of our illustrative scenarios. However, projects remain a possibility especially if alternatives fail to deliver and we include some generation from tidal technologies in our scenarios with no CCS and with no nuclear.

Less mature options

In our 2015 *Progress Report to Parliament* we identified carbon capture and storage (CCS) and offshore wind as the key options that are less mature and require extra support beyond 2020:

- Both have the potential to provide power in the second half of the 2020s below the full cost of gas generation (i.e. £95/MWh in a central case). There is more uncertainty over CCS as the technology is at an earlier stage. Although the first 'at scale' CCS plant commenced generation in Canada in 2014, CCS is yet to be demonstrated in the UK. Offshore wind is well established and demonstrating cost reduction: latest contracts have been signed at around £120/MWh, compared to costs in 2011 estimated at around £150/MWh (adjusted to 2014 prices).

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[18] ETI (2015) *The role of nuclear within a low carbon energy system.* Available at: www.eti.co.uk.

- **Offshore wind** has a potential resource of over 400 TWh/year, greater than total UK electricity demand in 2014. Besides current high costs, it has fewer barriers and risks to its roll-out than other options. For example, onshore wind and new nuclear face site restrictions and potential public opposition. Development of offshore wind therefore hedges against the risk that other options are constrained. That is particularly important given ongoing delays to nuclear and CCS.
- **CCS** has the potential to fill several roles in a low-carbon economy where alternatives are limited. CCS could be used in heavy industry, in the power sector offering flexible low-carbon generation and to open up other routes to reduce emissions (e.g. based on hydrogen or using CCS in combination with bioenergy to offset emissions elsewhere). Our previous estimates as well as those by the Energy Technologies Institute suggest the cost of meeting the UK's 2050 emissions target would double in the absence of CCS deployment[19].

The near-term goal should be development of these options, rather than deployment per se. However, analysis published alongside our progress report demonstrated the importance of UK deployment in driving down the costs of offshore wind and, subject to demonstration success, the need for a subsequent scale-up to reduce costs of CCS:

- **Offshore wind.** A sufficient scale of market, signalled in advance, is required to drive private sector investment in innovation (e.g. to create bigger turbines), to support a competitive project pipeline and supply chain, and to encourage a falling cost of capital through mature financial sector involvement. The UK is a key part of the wider European market that will drive technology development. Assuming that offshore wind is successfully commercialised in the first half of the decade, costs could fall to below £90/MWh in 2025, below the full cost of gas generation. Deployment in the 2020s would build on development of offshore wind in the 2010s; we estimate that around 75% of the total cost of commercialising offshore wind has already been committed to 2020.
- **CCS.** The key opportunity for delivering cost reduction is through economies of scale delivered by shared infrastructure for transporting and storing CO_2. This implies a minimum level of roll-out will be required in the UK which, if signalled in advance, can also support a competitive pool of projects and increase interest from the financial community. Projects in the power sector are vital to provide 'anchor loads' for smaller industrial sites.

Based on those assessments we identified a minimum level for UK deployment of 1-2 GW per year of offshore wind in the 2020s and 4-7 GW of CCS by 2030. Whilst higher deployment could be plausible we do not include it in our scenarios as it could involve cost escalation as supply chains and the development pipeline are stretched.

There are other emerging options, which are currently high cost but could have a significant future role and would benefit from innovation support. In the power sector, these include rooftop and distributed solar, where there is potential for UK-based cost reduction in installation but where the panel technology is likely to develop globally (supported by UK research), and wave and tidal stream technologies, for which the UK has a strong resource and which currently requires early-stage innovation and demonstration support. Innovation will also be important in supporting areas such as energy storage and smart grids.

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[19] The CCC's *The 2050 Target* (2012) report found the cost of meeting the 2050 target would increase from 0.5% to 0.9% of GDP without CCS. ETI (2015) *Carbon capture and storage - Building the UK carbon capture and storage sector by 2030* found that a "complete failure to deploy CCS would imply close to a doubling of the annual cost of carbon abatement to the UK economy" in 2050.

Table 2.1: Key statistics for power sector generation technologies

Key technologies	***Cost 2020***	***Cost 2030***	***Cost 2030 (3.5% discount rate)***	***Capacity in 2014 (GW)***	***Generation in 2014 (% of total)***	***UK practical resource***	***Load Factors (%)***
Unabated gas	£55-89/MWh (market carbon price); £69-103/MWh (target consistent carbon price)	£64-97/MWh (market carbon price); £97-129/MWh (target consistent carbon price)	£57-89/MWh (market carbon price); £101-133/MWh (target consistent carbon price)	32 GW	87 TWh (30%)	Limited by emissions constraint.	Up to 100%
Onshore wind	£67-102/MWh	£65-98/MWh	£48-62/MWh	8.5 GW	18 TWh (6%)	Around 80 TWh per year, depending on planning constraints	26-30%
New nuclear power	-	£76-103/MWh	£38-40/MWh	New: - Existing: 9 GW	New: - Existing: 58 TWh (19%)	In theory could be very large. In practice may be limited by sites – 8 currently approved sites could provide over 20 GW (e.g. 175 TWh per year). Including small nuclear reactors this could reach up to 50 GW (e.g. over 400 TWh per year)	Up to 95%
Biomass	£107-117/MWh	-	-	3.4 GW	20 TWh	Limited by land use and sustainability concerns.	Up to 95%
Offshore wind	£106-137/MWh	£88-128/MWh	£51-67/MWh	4.5 GW	13 TWh	Very large – over 400 TWh per year.	38-45%
Carbon capture and storage	£150-170/MWh	£89-130/MWh	£55-94/MWh	-		Likely to be large - storage unlikely to be a limiting factor.	Up to 95%
Tidal range	£107-154/MWh	£83-138/MWh	-	-		Up to 40 TWh.	22%
Tidal stream	£100-200/MWh	£70-100/MWh	-	< 1 GW	<1 TWh	Potentially large – 18 to 200 TWh per year.	31%
Solar PV	£84-96/MWh (large-scale ground-mounted); £158-246/MWh (rooftop)	£64-72/MWh (large-scale ground-mounted); £128-198/MWh (rooftop)	£57-65/MWh (large-scale ground-mounted);	8.0 GW	4 TWh	Large – around 140 TWh per year (on the basis of current technology) with more possible with technology breakthroughs.	11%

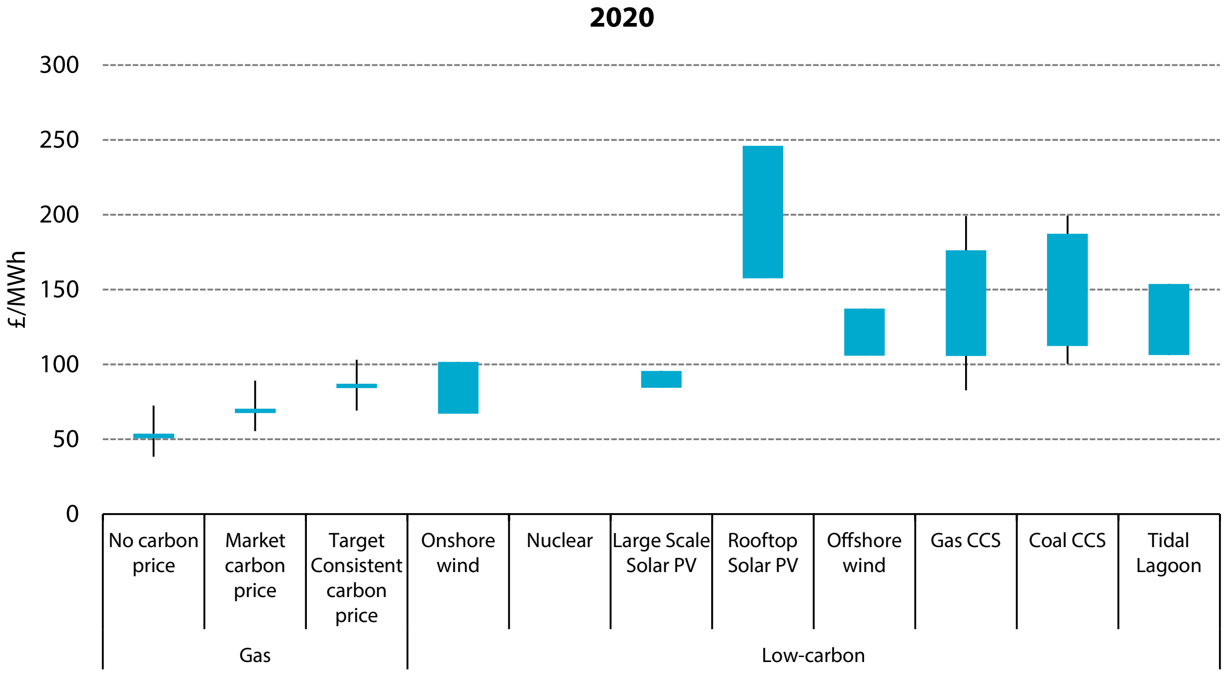
Source: CCC calculations, based on DECC (2013) *Electricity Generation Costs*. BVG Associates (2015) *Approaches to cost reduction in offshore wind*; Pöyry/Element Energy (2015) *Potential CCS Cost Reduction Mechanisms*. Mott MacDonald (2011) *Costs of low-carbon generation technologies*. Available at: www.theccc.org.uk; DECC (2015) *Energy Trends*; *Digest of UK Energy Statistics*; *Public Attitudes Tracker*. Available at: www.gov.uk

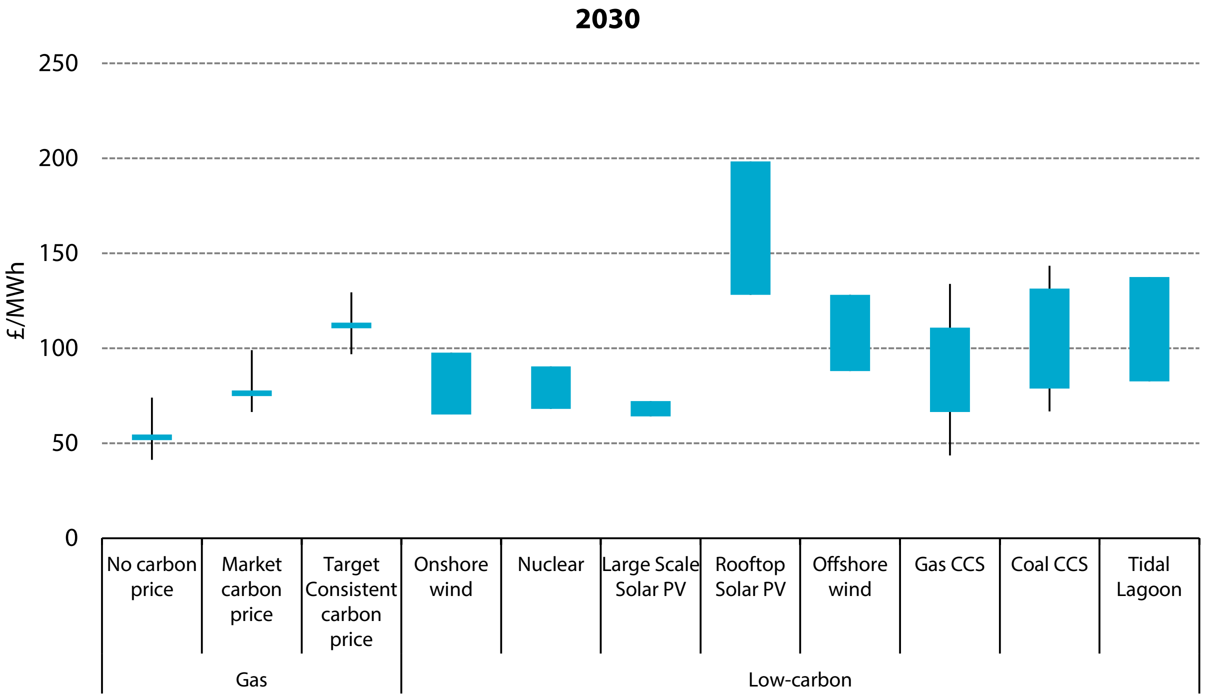
Table 2.1: Key statistics for power sector generation technologies

Estimated deployment rate in 2010s	***Potential deployment rate in 2020s***	***Assumed generation lifetime***	***Public Acceptability***	***Importance of UK deployment for reducing costs***	***Other considerations***
-	-	40 years	-	-	High levels of capacity could have low emissions through lower load factors.
0.8 GW per annum	*1 GW per annum*	25 years	66%	Technology is already well-established and is being deployed globally. UK impact on costs likely to be limited.	Variability of generation output. Possible local resistance.
-	*Up to 1.5 GW per annum from 2024/25*	60 years	38%	Equipment costs likely to be driven by global deployment, with some potential for local learning-by-doing and reduction in cost of capital.	Mature technology, globally deployed. Waste disposal and proliferation concerns. Public acceptability risk.
< 0.5 GW per annum	-	May be limited by feedstock availability or age of base plant (if converted).	49%	Limited cost reduction expected.	Sustainability concerns about use of wood pellets in biomass generation. Competition from other sectors for use of scarce bioenergy, where low-carbon alternatives may be limited.
1.0 GW per annum	*1-2 GW per annum*	25 years	74%	UK deployment likely to be important to reducing costs, given significant capabilities already established and a large share of the global market.	Variability of generation output. Lower visual impact (less local resistance).
-	*0.5-1 GW per annum*	40 years	55%	UK deployment important alongside global cost reduction efforts. UK has existing strengths (e.g. in CO_2 storage and transportation, subsurface evaluation & geotechnical engineering, and power plant efficiency & clean coal technologies), likely an early deployer internationally.	Dispatchable. Exposed to fossil fuel price risk. Higher lifecycle emissions, including direct residual emissions.
-	*Depends on individual projects*	120 years	-	Limited cost reduction expected, though arguments have been made for benefits of a programme of tidal lagoons.	Predictable output, though intermittent. Possibility for baseload equivalent generation if multiple projects paired together. Environmental concerns.
< 0.1 GW per annum	*Uncertain*	25 years	74%	UK has an important role. UK companies have significant marine design/engineering experience and already have a sizable share of device developers and patents. UK resource also a large share of the global market.	Predictable output, though intermittent.
1.0 GW per annum	*Multiple GW per annum*	25 years	82%	Limited learning from deployment though UK does have research strength. Technology development likely to be driven by international deployment or by research in the UK that is not dependent on UK deployment.	Variability and intermittency of generation output, which is highest in summer when demand for electricity is lower.

Notes: In 2014, peak demand was 51 GW, total capacity 95 GW producing 298 TWh of generation, wholesale electricity prices were around £45/MWh. Table shows latest published levelised costs but in calculating actual expenditure under the LCF, we used outturn strike prices for solar/onshore wind from the 2015 CfD auction round, until 2020 (after which we used DECC levelised cost projections).

Figure 2.3: Expected costs of generation by technology (2020 and 2030)





Source: Calculations based on: DECC (2013) *Electricity Generation Costs*. BVG Associates (2015) *Approaches to cost reduction in offshore wind*; Pöyry/Element Energy (2015) *Potential CCS Cost Reduction Mechanisms*. Available at: www.theccc.org.uk.
Notes: Gas prices range from: 30-76p/therm in 2020, 38-99p/therm in 2025 and 46-99p/therm in 2030. Target consistent carbon price: carbon price rises in line with Carbon Price Floor, to £23/tCO$_2$ in 2020 and £78/tCO$_2$ in 2030; Market carbon price: based on EU ETS projection from Thomson Reuters Point Carbon (June 2015), including carbon price support, rising to £37/tCO$_2$ in 2025 and £42/tCO$_2$ in 2030. Solid boxes represent range for technology costs; whiskers represent range for fuel costs (where appropriate). Costs are estimated for technology specific load factors: 95% for CCGT, nuclear and CCS, 28% for onshore wind, 46% for offshore wind, 11% for solar PV and 22% for tidal lagoons. Costs reflect technology specific pre-tax real rate of return (7.5% for gas, 7.1% onshore wind, 9.5% nuclear, 5.3% large-scale solar PV and 10% coal/gas CCS).

3. Existing ambition and projected emissions without further policy

Current ambition to 2020

Based on the Government's 2014 projections and our assessment of demand after abatement in buildings, industry, and transport, our scenarios include a small increase (2%) in demand to 2020 from 2014 levels (303 TWh). This is due to increasing demand for energy services as the economy grows, offset to some extent by energy efficiency. Our final assessment of demand in 2020 (309 TWh) is similar to our assumptions set out in our October power sector scenarios report and in our 2013 *Fourth Carbon Budget Review*. Allowing for losses in transmission and distribution, this implies a total power requirement of around 335 TWh.

In line with Government projections, we assume this demand will be met by a different generation mix, reflecting retirements and new investment. The majority of these changes are planned or contracted, leaving a relatively narrow band of uncertainty in the period to 2020:

- **Coal retirements.** There was 20 GW of coal plant operating by the end of 2014. There is potential for a further 10 GW of coal to close in the period to 2020 due to EU directives and unfavourable market conditions (i.e. due to the carbon price).
- **New renewables.** A significant amount of new renewable electricity is likely to 2020. Most of the new capacity is already under construction, has been contracted under the Electricity Market Reform or is expected to connect within the grace period for the Renewables Obligation. In terms of installed capacity, we assume a further 3.8 GW (9 TWh/year) of onshore wind, 5.7 GW (21 TWh/year) of offshore wind and 2.2 GW (2 TWh/year) of large-scale solar: a total of 11.7 GW of new capacity (32 TWh/year of new generation). Alongside existing capacity (28 GW), we assume renewable generation rises to around 100 TWh/year in 2020.
- **Carbon capture and storage (CCS).** We assume that two CCS projects go ahead as planned under the Government's commercialisation competition. This is around 0.6 GW of capacity and 5 TWh/year of generation in 2020.
- **The capacity market.** Some new capacity has been contracted through the capacity market. Although it appears unlikely that this will all proceed, the auction results imply up to 1.7 GW of new gas capacity and 2.5 GW of small diesel generators could come on by 2020, with the latter only expected to run at very low load factors given their high running cost.

The coal retirements and new capacity additions identified above imply that de-rated capacity remains broadly flat to 2020, at around 68 GW. That includes interconnection to other power markets of 6 GW (3 GW in de-rated terms) in 2020.

The share of low-carbon generation would increase to around 55-60% in 2020 (of which around 20% is nuclear, 34% renewables and 1% CCS).

Actual emissions will depend on the relative shares of coal and gas, which in turn depend on prevailing prices of input fuels and carbon in 2020. Assuming around 10 GW of coal remains in 2020 (in line with latest available Government projections), and generates around 50 TWh (16% of generation), this would result in emissions of around 45 $MtCO_2$ in 2020. Total power sector emissions would be 85 $MtCO_2$ and the average grid intensity would be around 250 gCO_2/kWh. To the extent that gas-fired generation displaces coal-fired generation, emissions intensity could be as low as 180 gCO_2/kWh.

The expansion of renewable generation to 2020 is supported through the Renewables Obligation, Contracts for Difference and small-scale Feed-in Tariff schemes. Along with the market carbon price these added around £45 within a typical dual-fuel household's annual electricity bill of £470 in 2014, and will add around £105 in 2020. As set out in our 2014 report *Energy Prices and Bills*, there is potential for most households to offset this cost through improved energy efficiency of their lights and appliances.

The need for more generation and capacity beyond 2020

Beyond 2020 the possible path for the power sector is more open: a large amount of capacity is expected to retire, demand could increase and the longer lead-time means that more generation technologies are available for its replacement. Retirements are likely to be spread over the decade, implying a steady market for new generation, albeit with a potentially large drop around mid-decade, which will need to be carefully considered to ensure security of supply is maintained (Figure 2.4).

Demand

We have updated our demand assumptions from our October report based on the latest evidence presented in the sector chapters, which imply electricity demand increasing by 8% from 2014 to 328 TWh in 2030. This is mainly attributable to demand from electrification in heat and transport as projected increases in demand in the absence of policy effort are offset by greater uptake of energy efficiency measures (Figure 2.5):

- As part of our scenarios for meeting carbon budgets, we include ongoing improvements in efficiency, such as roll-out of LED lighting, increasing penetration of efficient appliances, and energy efficiency in industry, reducing demand by around 90 TWh from projected baseline levels.
- We add extra demand to allow for electrification of transport (21 additional TWh) and heating (9 TWh), reflecting our scenarios for uptake of electric vehicles and heat pumps.
- Overall final demand under our central economy-wide scenarios is 328 TWh.

Electricity demand at this level would require generation of around 355 TWh, allowing for losses in transmission and distribution. This is lower than the generation (around 380 TWh) assumed in the central scenarios in our October report, but within the range of uncertainty we considered. The October assumptions reflected analysis developed in our 2013 *Fourth Carbon Budget Review*, which included less potential from energy efficiency – see Chapters 3 and 4 for more detail on the latest assumptions for energy efficiency.

Plant retirements

Alongside this potential demand increase, some plant will close during the 2020s:

- **Coal.** We and the Government assume that the remainder of the UK's current coal capacity (10 GW) will cease operation in the 2020s. These closures are due to age (the youngest plants were built in the 1970s and 1980s), tightening requirements under European air quality directives, assumed increasing costs as a result of rising carbon prices and potentially conversion to burn biomass instead of coal.
- **Nuclear.** The majority of the UK's nuclear power plants will be over 40 years old in the 2020s and are expected to close. Of the current 9 GW of nuclear power plants, we assume only Sizewell B (1.2 GW) remains on the system by 2030. There may be scope for some further life extensions, subject to regulatory approval, which could leave more existing nuclear capacity operating in 2030.

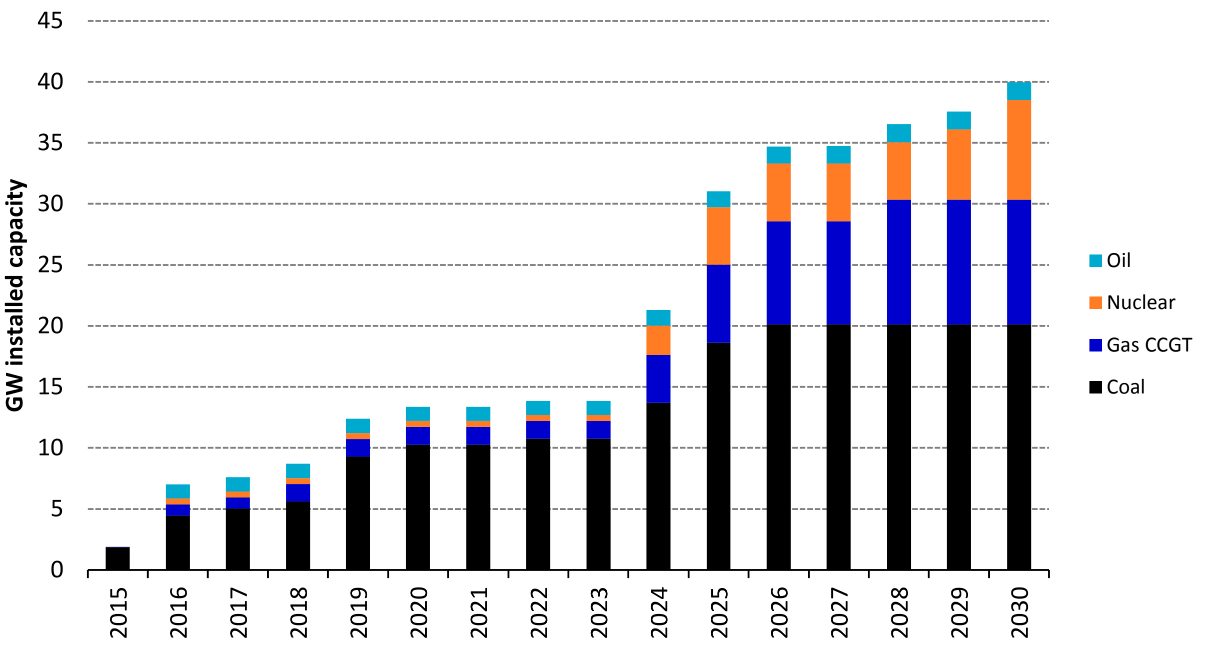
- **Gas.** Of around 33 GW of gas-fired capacity expected to be on the system in 2020, some may become uneconomic, depending on wholesale and capacity prices. We assume 9 GW retires through the 2020s.
- **Renewables.** Some older plant contracted under the Renewables Obligation will begin to reach the end of its life during this period (around 3.5 GW by 2030).

The closure of the UK coal plants is particularly important in the context of decarbonisation, since these plants account for over 70% of remaining emissions in 2020. All our scenarios assume that the remaining coal closes in the 2020s (or converts to biomass or installs CCS), mostly by 2025, with reducing running hours over the decade. The Government has recently announced a consultation on closing all coal plants by 2025 and restricting their use by 2023. As we advised in our October report, that would increase confidence for investors in replacement capacity.

Together, increasing demand and plant retirements imply the need for new investment in the 2020s. Based on the retirement and demand assumptions set out above, we estimate new capacity would need to supply up to around 150-200 TWh/year by 2030.

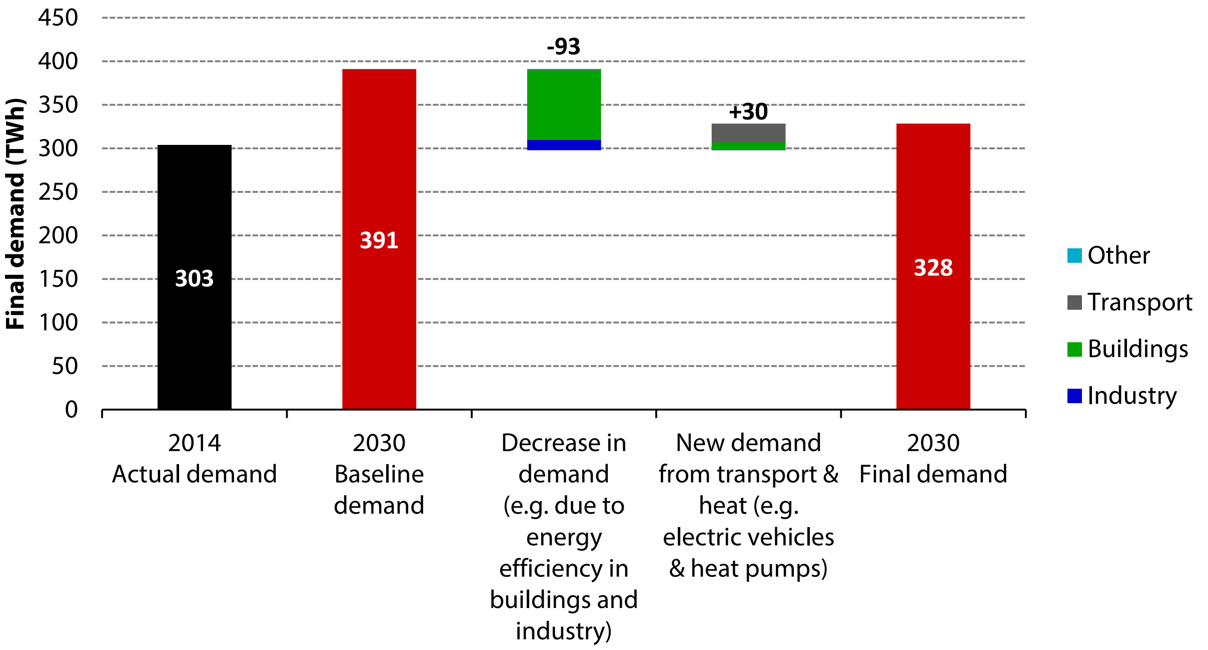
With no growth in demand during the 2020s, around 25 GW of new capacity would be needed to replace retiring firm capacity and maintain system security. More capacity will be needed to the extent that demand also grows. For example, if demand grows by 5% as in our central scenario, a total of 29 GW of de-rated capacity would be needed, possibly more if demand growth is concentrated in the winter peak periods.

Figure 2.4: Plant retirements by technology to 2030



Source: CCC modelling; DECC (2014) *Updated emissions and energy projections.*

Figure 2.5: Development of electricity demand from 2014 to 2030 reflecting existing and new demand sources



Source: CCC modelling; DECC (2014) *Updated emissions and energy projections.*

Reflecting uncertainty in the analysis

A key feature of our approach is a recognition of the inherent uncertainties in constructing scenarios for the future. Fossil fuel prices, technology costs, deployability of different options, the size and shape of demand are all impossible to predict with confidence. In our October report on the power sector, we reflected this uncertainty when we set out the latest evidence base, including ranges for estimates of future generating costs. Our scenarios reflect this uncertainty, by including several potential generation mixes.

Uncertainty does not imply that nothing can or should be done. The statutory 2050 target implies that the direction of travel must be towards sharply reduced carbon emissions. However, it is not possible to say in advance exactly what the mix of options should be, and there are likely to be limits to generation potential of some technologies. To keep down costs of delivery, clarity is needed about how policy will adjust as areas of uncertainty are resolved.

Given uncertainty about which technologies may be appropriate in a future power sector, we emphasise that technologies should be deployed that the market can deliver at lowest cost, while developing a wider portfolio of options to ensure both continuing cost competition between technologies and that other options are available should circumstances change. A narrow short-term focus solely on the current lowest cost options is not an appropriate strategy given the different risks and the importance of low-carbon power. Such an approach could increase costs in the longer term.

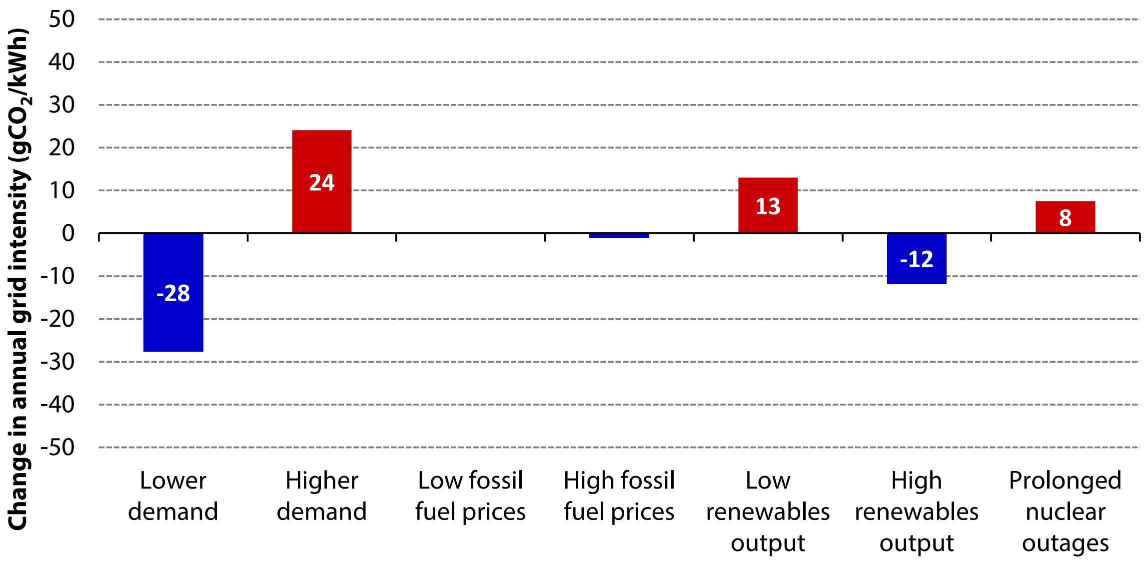
We have also assessed the impact of a range of specific sensitivities around a scenario reaching 100 gCO_2/kWh in 2030 (Figure 2.6). That includes different assumptions for demand, fossil fuel prices, renewables output and nuclear outages:

- **Demand.** Demand is 10% higher or lower than central projections.
- **Fossil fuel prices.** High/low fossil fuel prices based on DECC's fuel price projections (2014)
- **Expected output for renewables technologies.** Wind and solar generation is 10% higher or lower than central assumptions, reflecting the possibility of years with particularly favourable or unfavourable weather conditions.
- **Nuclear outages.** Unexpected and prolonged (6-month) outage of a nuclear plant.

The demand scenarios have the biggest impact; the expectation should be that if demand rises more/less quickly than projected then the rate at which new generation is procured from the low-carbon market should speed up or slow down accordingly. Fuel prices have a muted impact as by 2030 there is no coal capacity to switch to and low-carbon generation will dispatch before gas whether gas prices are high or low.

The sensitivities on renewables and nuclear demonstrate that there will be some sensitivity to conditions that can vary from year to year. It will continue to be important to track progress in terms of investment and capability as well as final emissions outcomes; we will reflect that in our monitoring approach.

Figure 2.6: Sensitivities around a 100 gCO_2/kWh scenario



Source: Imperial College London modelling for CCC (2015).

4. Abatement scenarios

In building the scenarios in our October 2015 report, we considered the range of options for the power sector, including both low-carbon and gas-fired generation, and options for integrating low-carbon technologies while ensuring security of supply at minimal cost. Our scenarios:

- **Include the full costs of providing generation and capacity.** In comparing the cost of low-carbon options with generation from unabated gas we assume a cost for the emitted carbon that is consistent with meeting the UK's 2050 target (see section 2 above).
- **Allow for flexibility for one technology to substitute for another.** We include scenarios with high penetration of renewables, nuclear or CCS, with other options providing less generation to offset those higher levels.
- **Involve a minimum roll-out of emerging options,** with around 1-2 GW of offshore wind each year and at least 4-7 GW of CCS by 2030.
- **Ensure that a portfolio of competitive options will be available from the late 2020s** to meet growing demand for low-carbon electricity from other sectors (e.g. heating, transport) as they move away from fossil fuels.
- **Maintain security of supply.** Throughout our analysis we require that the Government's standard for security of supply is met. We examined the different challenges posed by a low-carbon electricity system and assessed the full system costs of low-carbon options, including the need to back up intermittent renewables. We estimate this to be around £10/MWh of intermittent generation for levels of deployment assumed in our scenarios (based on a range in our estimates of £6-13/MWh) (see section 5(b) below).

Central/alternative scenarios

In our October report, we developed three scenarios that reach an average grid intensity of below 100 gCO_2/kWh and emissions of around 30 $MtCO_2$ in 2030. These are consistent with the lowest cost path to meeting the 2050 target in the Climate Change Act and meeting security of supply requirements.

Overall these scenarios involve a reduced deployment rate for low-carbon technologies compared to our previous scenarios (e.g. as set out in our 2013 *Fourth Carbon Budget Review* advice technical report). That largely reflects delays to new nuclear projects and slow progress on CCS.

These reduced deployment rates could also help to ensure that contracted projects are the lowest-cost projects available and that strong competition for contracts secures them at the lowest possible price. However, aiming for any slower rate of contracting low-carbon generation would risk parts of the project pool drying up, increase risks feeding through to higher costs, and/or increase reliance on gas, which would imply higher emissions and higher costs to consumers in the long run.

The scenarios involve the majority of new generation needs from 2020 being met by low-carbon sources, especially beyond 2025 (Figures 2.7 and 2.8):

- **High renewables** assumes that more acceptable sites are available for onshore wind and solar and that offshore wind can be deployed at low cost at 2 GW per year in the second half of the decade. In 2030 there is 93 GW of renewables capacity accounting for 61% of generation compared to around 45% in the other scenarios.

- **High nuclear** includes three new plants rather than the two included in the other scenarios. In 2030 there is 11 GW of nuclear capacity, accounting for 24 % of generation compared to less than 20% in the other two scenarios.
- **High CCS** assumes that CCS progresses well and expands to 7 GW by 2030, providing economies of scale across two clusters and potentially commercialising different CCS technologies or application to different fuels (i.e. coal and gas). That compares to 4 GW in the other scenarios, which would be consistent with narrower commercialisation, focused on a single cluster and/or technology. Higher deployment may be appropriate if costs fall below those of other low-carbon technologies.

The precise mix should reflect how costs develop, as revealed through mostly competitive procurement in the low-carbon auctions.

In October, we also assessed a scenario with lower demand. This scenario constrains the deployment of cost-effective technologies (onshore and solar) but maintains the minimum rates of investment in offshore wind and CCS. This scenario achieves a lower emissions intensity of around 75 gCO_2/kWh in 2030, and overall emissions of 26 $MtCO_2$. The updated demand scenarios implied by Chapters 3-5 of this report are between these levels of demand.

Risks - Barriers scenario

We also assessed scenarios which entail bigger deviations from our central assumptions, for example no new nuclear capacity or no CCS, to reflect current uncertainties about those programmes.

In these scenarios, we assume limited deployment of CCS or nuclear projects in the 2020s, resulting in a higher average grid intensity of 120gCO_2/kWh in 2030 (Figures 2.9 and 2.10):

- **No CCS** assumes no deployment of CCS beyond two initial projects (totalling 0.6 GW) selected in the Government's competition and a failure to demonstrate the technology effectively. It will be crucial that the other technologies deliver in this case, so the scenario builds in additional tidal lagoons and tidal stream as well as further offshore wind (leading to around 5 GW and 15 GW new build respectively in the 2020s). No CCS implies slower abatement in the industrial sector, which would need to consider higher cost options in place of CCS, and from the use of bioenergy. This is likely to lead to higher costs and greater risks for meeting the 2050 target.
- **No nuclear** assumes no new nuclear, consistent with technical and/or financial difficulties with the new nuclear projects, pushing the programme into the 2030s and raising questions over its long-term viability. Other technologies would need to compensate, at least in part, to stay on track to 2050. We include higher offshore wind (15 GW new build in the 2020s) and tidal lagoons (given their potential to effectively provide baseload generation).

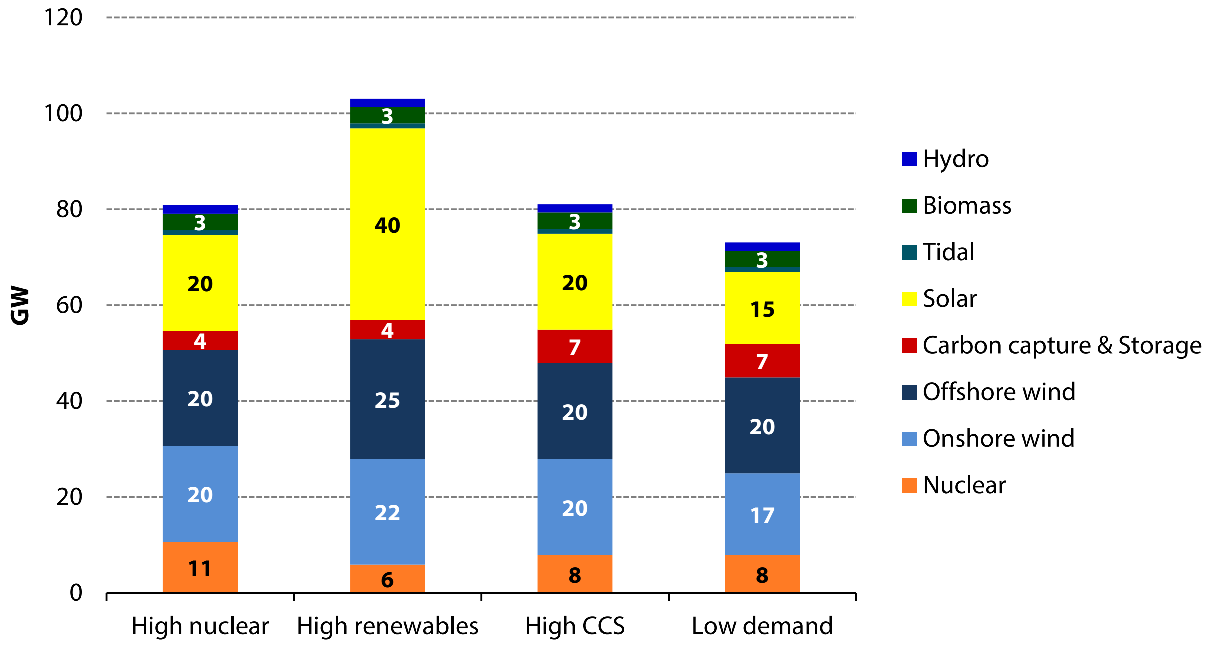
Since our updated scenario for demand reduces the need for UK generation, this would reduce the need for additional gas-fired generation. As a result these scenarios would have emissions closer to 100 gCO_2/kWh in 2030 even if progress is slow with nuclear or CCS.

Further opportunities - Max scenarios

We also include a 'Max' scenario **('High low-carbon')**, where progress is strong across low-carbon technologies in the 2020s. Delivering this scenario would depend on effective integration of the different options in the grid, with improved system flexibility and the role of CCS likely to be particularly important. This scenario reaches a CO_2 intensity of generation of 50gCO_2/kWh in 2030 (Figures 2.9 and 2.10).

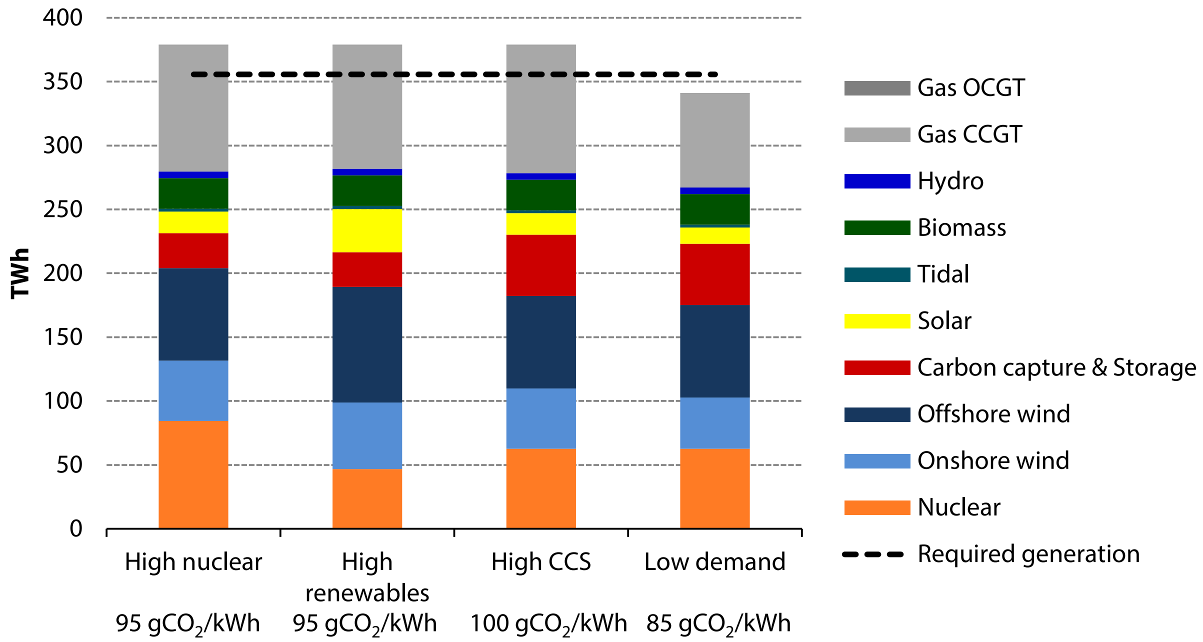
As we set out in our October report, it is neither necessary nor appropriate to commit now to any one of these specific scenarios, given the various uncertainties. However, investors need to make decisions now about investments due to come on line in the 2020s. It is therefore important that the Government sets out its approach now and commits funding consistent with that (see section 5).

Figure 2.7: Low-carbon capacity for Central/Alternative power sector scenarios in 2030 (GW)



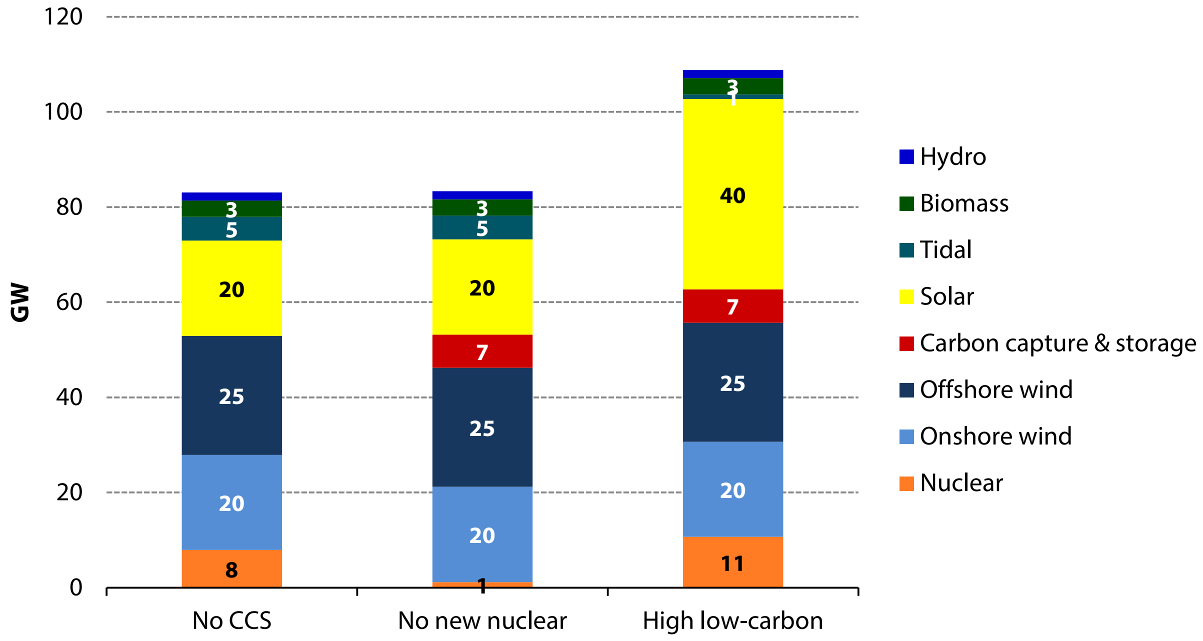
Source: CCC modelling.
Notes: Capacity figures for gas plant, storage and interconnection not shown.

Figure 2.8: Generation for Central/Alternative power sector scenarios in 2030 (TWh)



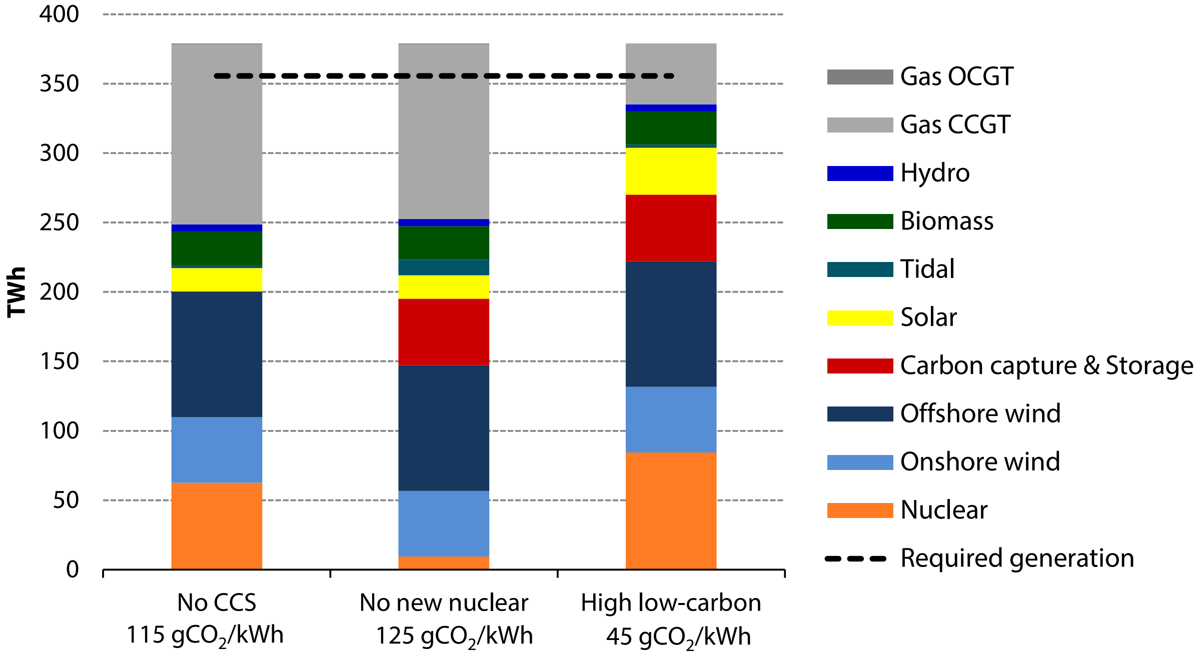
Source: CCC modelling.
Notes: 'Required generation' reflects the new level of generation we estimate to be required, based on a revised level of demand since our October report. We assume net zero flows across interconnectors.

Figure 2.9: Low-carbon capacity in Barriers and Max power sector scenarios in 2030 (GW)



Source: CCC modelling.
Notes: Capacity figures for gas plant, storage and interconnection not shown.

Figure 2.10: Generation for Barriers and Max power sector scenarios in 2030 (TWh)



Source: CCC modelling.
Notes: See Figure 2.8

Scenarios to 2050

The Committee has previously identified decarbonisation of the power sector reaching a carbon intensity of generation of around 50-100 gCO$_2$/kWh in 2030 as being on the cost-effective path to meeting the 2050 target*. Our new scenarios for 2030 are in line with this range, towards the upper end, reflecting delays in nuclear and CCS projects as well as an improved understanding of the system costs of reaching 50 g/kWh by 2030.

A very large degree of power sector decarbonisation by 2030 is a consistent result of energy system modelling in the UK:

- MARKAL and its successor TIMES are least-cost optimisation models of energy use, representing the entire energy system, from primary energy resources through to demands for energy services (e.g. passenger-kms driven).
- In runs of MARKAL conducted for the Committee in 2010 by UCL and in updated runs of TIMES in 2015 by DECC, carbon intensity falls to very low levels by 2030 (Figure 2.11). Electricity generation increases to 2050 due to increased electrification (e.g. roll-out of heat pumps and electric vehicles), although the extent of this depends on the balance between electrification and other abatement options in end-use sectors.

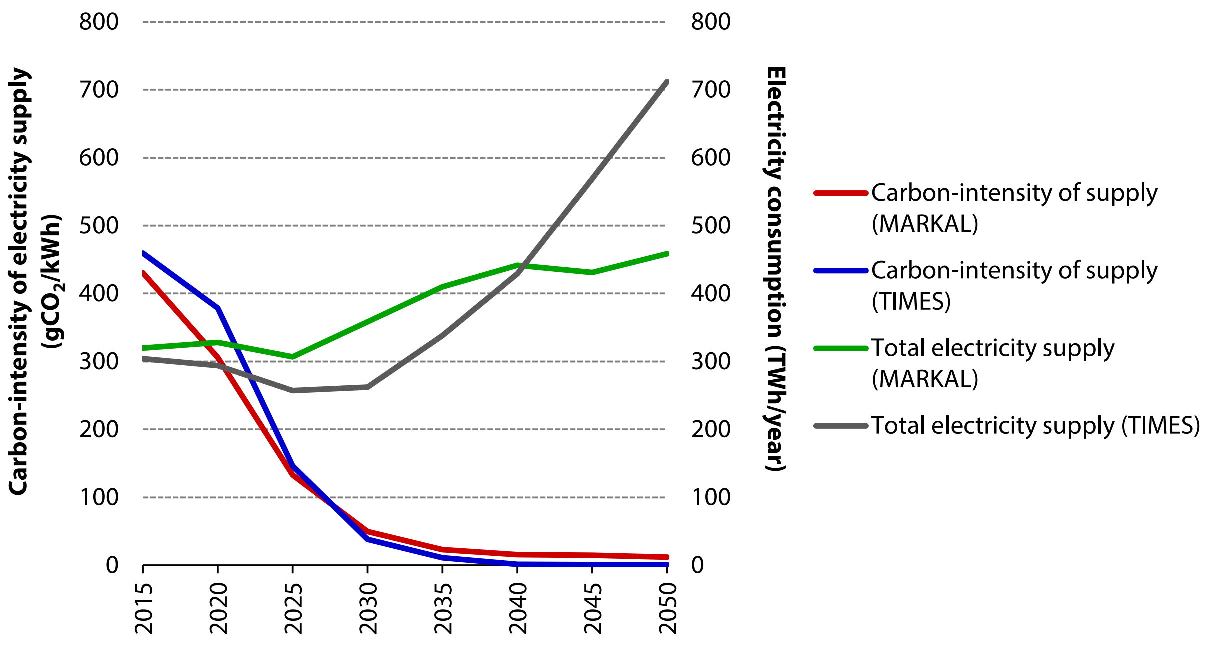
- While these models are rich in detail regarding technology options and costs, the power sector is characterised in less detail than in recent modelling conducted by Imperial College London and Nera[20]. In particular, given the lower temporal resolution, the requirements for gas back-up (and therefore emissions intensity) are likely to be underestimated.

Between 2030 and 2050 the momentum achieved in decarbonising the power sector will need to be maintained in order to continue reducing emissions intensity (e.g. to around 10 gCO_2/kWh in 2050).

A portfolio approach to decarbonisation in the 2020s will allow several technologies to be deployed cost-competitively during this period, whereas gas generation facing a rising carbon price, will continue to become more expensive.

Assuming a successful programme of CCS deployment during the 2020s, there may be an opportunity to combine biomass power generation with CCS, allowing for so-called 'negative emissions', which can provide flexibility to other sectors where decarbonisation may be harder to achieve.

Figure 2.11: Energy system model trajectories for the power sector (2015-2050)



Source: MARKAL modelling by University College London for the CCC (2010); UK TIMES modelling for the CCC by DECC (2015)
Notes: Carbon-intensity calculations exclude 'negative emissions' benefits of using biomass in conjunction with CCS.

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[20] Imperial (2015) *Value of flexibility in a decarbonised grid and system externalities of low-carbon generation technologies*. Available at www.theccc.org.uk.

5. Costs and impacts

The Climate Change Act sets out various factors that the Committee must consider in its advice on carbon budgets. Our scenarios for the power sector inform assessment of: energy policy generally; fuel poverty and competitiveness, through the impact on energy prices and bills; and energy security, through the impact on fuel imports and increased intermittency in power supplies. This section sets out the policy costs of our scenarios and the impact of these on energy bills, followed by our assessment of impacts for energy security.

a) Costs of supporting low-carbon generation and implications for energy bills

In assessing the costs of our scenarios we distinguish between the total social costs and the private costs to bill-payers. The former includes the full social cost of carbon (i.e. the target-consistent carbon price), whilst the latter includes only costs that would appear on a typical electricity bill (e.g. the market carbon price). To determine the additional cost or benefit in the "social" or "private" case, we compare our scenarios to an alternative where investment in the 2020s is solely in gas-fired generation: all new demand is met by gas-fired generation and all retiring plant is replaced by gas-fired generation where required.

Costs and bills to 2020

Support for low-carbon (primarily renewable) generation deployed in the period up to 2020 is expected to total around £8 billion per year by 2020 over and above the market carbon price (projected to be £23/tonne in 2020). Support is capped at this level under the Levy Control Framework (LCF) and is spread across all electricity consumers through the Renewables Obligation, Small-scale Feed-in Tariff and Contract for Difference schemes.

Annual electricity bills for the average household in 2020 will be around £105 higher as a result of the market carbon price and support under the Levy Control Framework. This compares to a total electricity bill projected to be around £500 in 2020. Businesses will similarly see higher electricity costs as a result of this support for low-carbon investment. These costs are already committed and they will largely continue into the 2020s.

Additional cost of low-carbon investment in the 2020s

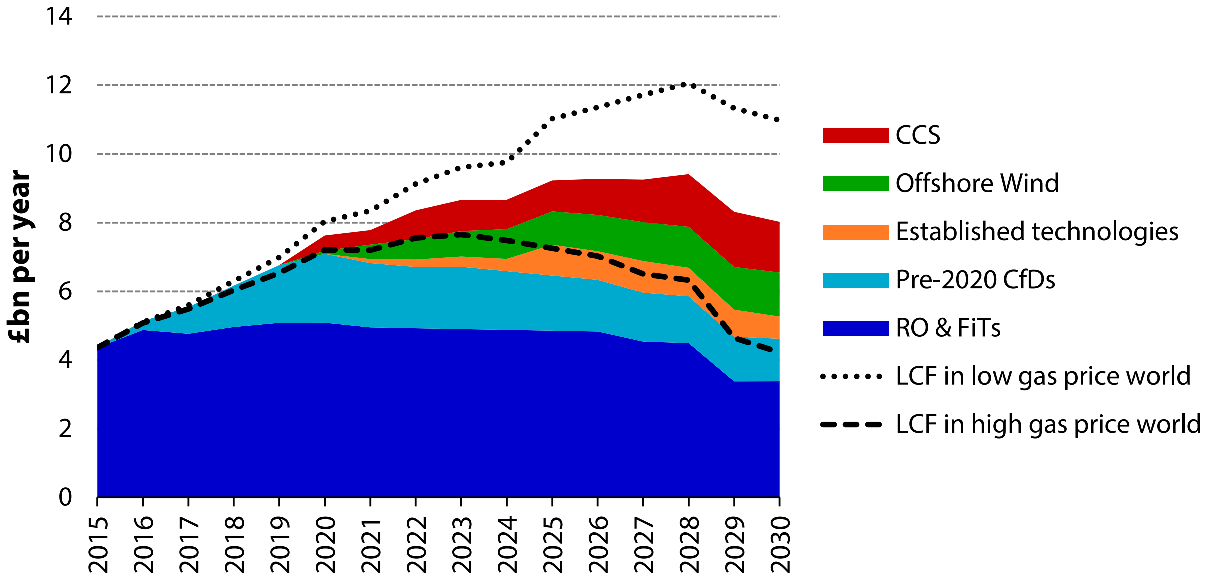
If more low-carbon capacity is to be deployed in the 2020s, as in our scenarios, the total support will initially need to increase beyond £8 billion per year.

- Offshore wind and CCS projects will be more expensive than the alternative of gas generation across their lifetimes, even if the full carbon value is reflected in the market. These create the main need for additional funding to 2025.
- Onshore wind, solar and nuclear are expected to be cheaper than gas generation across their lifetimes. However, they are likely to be more expensive in early years because contracts do not cover full project lifetimes, gas generation costs will rise over time with carbon prices and the market carbon price is likely to be below the full carbon value.

Taken together, and in a central scenario for gas prices, our scenarios require a support level of £9.2 billion per year in 2025 if carbon prices rise to the Government's target carbon value of £42/tonne (Figure 2.12). Support will need to be higher, at £9.4 billion if market carbon prices rise as currently projected to £37/tonne in 2025. A similar level of support would be needed in 2030, falling thereafter.

This increased support will feed through to consumer bills, along with increases in the market carbon price and costs associated with intermittent renewables.

Figure 2.12: Funding required under the Levy Control Framework for our scenarios (2015-2030)



Source: CCC modelling.
Notes: All years are calendar years. All money is in £2014. The Levy Control Framework cap for 2020/21 is £7.9bn in the calendar year 2020. We assume the following ranges for gas prices: 30-76ptherm in 2020, 38-99p/therm in 2025 and 46-99p/therm in 2030. Target consistent carbon price: rises in line with Carbon Price Floor, to £23/tCO_2 in 2020 and £78/tCO_2 in 2030.

Electricity bills in the 2020s

Offsetting this, investment in new low-carbon generation avoids some of the increase in bills that could result if all new generation is provided by unabated gas (the so-called 'merit order effect'):

- If new generation is provided by gas-fired plant, then it will set the price in the wholesale market, which will rise with the market carbon price. This would increase returns to operators of the existing nuclear fleet and renewables supported through the Renewables Obligation.
- If new generation is provided by low-carbon generation then wholesale prices will rise less quickly. That reflects that, once constructed, the cost of producing electricity for low-carbon capacity tends to be low, and this will be reflected in lower market prices as the low-carbon share increases.
- Compared to a scenario with investment in gas-fired generation that implies a saving to consumers, who would otherwise have to pay higher returns to existing low-carbon generators.

- We estimate that this “merit order effect” would reduce annual costs to the typical household by up to £10 in 2025 and 2030 in our scenarios.

We report bill impacts in Table 2.2 under central assumptions for gas prices (66 p/therm in 2025).

- Support for low-carbon generation, including the carbon price, would add £120 to the average annual electricity bill in 2030 (i.e. an impact that is £15 higher than we expect for 2020). Beyond 2030 this impact would fall as older support measures (e.g. the Renewables Obligation) reach the end of their lives.
- Compared to a scenario focused on gas-fired generation, bills would be £20 higher in 2025 and £35 higher in 2030 and 2035 (£25 and £45 higher ignoring the merit order effect).

From a “social” point of view there would be an additional value to the carbon saved, worth £25 per household in 2030 and £50 per household by 2035. The more positive outcome from a “social” point of view reflects that the market price for carbon, beyond 2020, is not projected to incorporate fully the costs that greenhouse gas emissions impose on the UK or the world.

If gas prices remain at current low levels (i.e. 46 p/therm) then the costs of investing in low-carbon generation would be higher by up to £20 per household per year. However, lower gas prices mean that total electricity bills would be lower for customers (by about £40 per household per year if gas is at 46 p/therm). Low-carbon investment also reduces the risk of very high increases in bills, which could otherwise occur if European gas or carbon prices were to rise sharply over the next decade.

Where there are increased costs imposed in the short term, and if these are not replicated in other countries, it will be important for the Government to continue schemes providing exemptions or compensation to affected industries that would otherwise be at risk of losing competitiveness.

The wider value of low-carbon investment in the 2020s

While low-carbon deployment could imply higher costs and bills in the early years of their contracts, especially if gas and carbon prices remain low, steady deployment in the 2020s is likely to reduce costs overall and in the long run:

- **Learning and stability.** Deployment in the 2020s can reduce costs of future projects. That is clearest for less mature technologies, but may also be the case for others, such as nuclear, where the first plant in a new build programme could require a premium in cost of capital and in proving the regulatory regime. More generally, a stable market for low-carbon generation will keep supply chains and investors engaged and risks low.
- **Life beyond contracts.** Low-carbon capacity can continue to provide power, at low cost, after the initial contract period. For example, offshore wind farms are expected to generate power for around 10 years beyond their 15-year contracts.
- **Repowering.** At the end of their lifetimes, renewable projects can be replaced at lower cost. That reflects that some costs, such as development and transmission, do not need to be incurred again, as well as the scope for technological improvement.

There are other benefits to low-carbon investment in the 2020s not quantified in our analysis. These include improved air quality and spillovers to other sectors (e.g. from development of CCS and increased availability of low-carbon electricity as a route to reducing emissions in heat and transport).

Table 2.2: Impact of low-carbon investment relative to investment in gas generation for the annual electricity bill of a typical dual-fuel household

£/household annual bill (central gas price = 66 p/therm in 2025)	**2014**	**2020**	**2025**	**2030**	**2035**
(A) BASELINE BILL *– if new generation in the 2020s is provided by unabated gas generation with no carbon price and no support for low-carbon generation*	425	380	415	415	415
TOTAL BILL IN OUR SCENARIOS	470	485	530	535	520
Of which:					
(A) Market carbon price	10	30	40	45	50
(B) Support for low-carbon investment already committed (pre-2020), including intermittency cost	35	70	55	40	20
(C) Additional support for low-carbon investment in the 2020s	-	5	25	40	40
(D) Intermittency cost of low-carbon investments in 2020s	-	-	0 to 5	5	5
(E) Merit order effect	-	-	-(5 to 10)	-10	-10
TOTAL IMPACT of low-carbon investment in the 2020s (relative to investment in gas-fired generation) = C+D+E	-	-	20	35	35
TOTAL IMPACT of carbon price and support for all low-carbon investment = A+B+C+D+E	45	105	115	120	105

Source: 2014 'Total Bill' outturn based on DECC (June 2015) *Quarterly Energy Prices*. Projections from CCC modelling.
Notes: Base bill includes wholesale costs of energy, network costs, supplier margins and VAT. Numbers may not sum due to rounding. Market carbon price: based on EU ETS projection from Thomson Reuters Point Carbon (June 2015), including carbon price support, rising to £30/tCO_2 in 2020 and £42/tCO_2 in 2030.

Resource costs of the power scenarios

In Chapter 1 and our Advice Report we include estimates of the resource costs of our scenarios relative to a hypothetical alternative with no climate action and no carbon cost. For the power sector, we estimate the total resource cost of our low-carbon scenarios relative to an alternative where new generation in the 2020s is from gas generation with no carbon cost to be £15 billion:

- Our scenarios include around 200 TWh of new low-carbon generation added in the 2020s, at an average cost of £94/MWh, compared to £57/MWh for unabated gas with no carbon price. That adds £7.5 billion to the total system cost in 2030 compared to gas.

- There is also 80 TWh of renewable generation currently on the system or due to be added by 2020 which will still be operating in 2030. It has a higher average cost of £132/MWh, adding £6 billion to the 2030 cost compared to gas.
- Additional costs from intermittency and other system costs add £1.4 billion in 2030.

If carbon is assigned its full target-consistent value (see Chapter 1, e.g. £78/tonne in 2030) then the low-carbon scenario is lower cost in the long run. By 2035, the rising value of carbon would bring the costs of gas generation in line with the average cost of low-carbon investments in the 2020s. Costs for gas generation would then continue to rise, whilst costs of low-carbon generation would be flat for the remainder of contracts and fall thereafter.

Moreover, under the low-carbon scenarios the UK would have a portfolio of active low-carbon options available for further deployment at low cost in the 2030s, whereas the scenarios with investment solely in gas generation in the 2020s would not. Our scenarios therefore represent good-value investments for a society committed to climate targets.

b) Implications of our scenarios for security of energy supplies

Our scenarios involve a significant reduction in the amount of fossil fuels burned compared to scenarios without climate action. This would reduce the UK's exposure to volatile international fuel prices. We set out the size of this effect across the economy in Chapter 4 of our Advice Report.

The transition to a low-carbon electricity system also brings new challenges in grid management, due to higher levels of intermittent and variable renewable generation (e.g. wind and solar), less flexible generation technologies such as nuclear, and higher demand from other sectors via electricity of heat and transport. These system challenges include the need for back-up firm capacity for wind and solar generation, the risk of excess generation at times of low demand, and the need for additional infrastructure to transmit power generated in more remote locations.

We published a detailed assessment of this challenge in our October report on *Power sector scenarios for the fifth carbon budget*. We concluded that it is possible to manage a deeply decarbonised UK power system in 2030 with high levels of intermittent renewables (e.g. 40% of total generation) while maintaining security of supply.

Managing this transition at lowest cost while ensuring security of supply will require investment in flexible gas-fired generation capacity alongside expansion of international interconnection, flexible demand response and electricity storage:

- **Flexible unabated gas plant.** More efficient and flexible generation technologies are available that can operate stably at lower levels of output, provide faster frequency response than at current levels, and consume less fuel when part-loaded to provide system reserve. Greater use of these would require less overall thermal plant to be built to stabilise the system, be less likely to curtail renewables output, and reduce overall emissions.
- **Interconnection.** Interconnection already provides a valuable source of flexibility to the UK with 4 GW of capacity linked to Ireland, France and the Netherlands. Increased interconnection to these or other electricity markets (e.g. Norway) can improve security of supply and operating efficiency through sharing of back-up capacity as well as ancillary services, and better accommodate intermittent generation by taking advantage of geographical diversity of renewable output and demand profiles. Studies have shown that greater levels of interconnection are generally associated with better security of supply.

- **Demand-side response.** Shifting electricity demand away from 'peak' time periods, such as on a winter evening and towards periods when demand is lower, is known as Demand-Side Response (DSR). DSR can help to manage large volumes of intermittent renewable generation and can significantly reduce the overall cost of a decarbonised system by shifting demand to off-peak periods with higher renewable output or by reducing the requirements for capacity during peak periods. New electricity demand from electric vehicles can provide further potential for DSR as could heat pumps where they are rolled out in thermally efficient buildings or with storage. Widespread deployment and use of smart technologies (such as smart meters) will facilitate increases in demand-side response given sufficient consumer engagement.
- **Energy storage technologies.** There is currently around 3 GW of pumped hydro storage in the UK. Further deployment of bulk and distributed energy storage (e.g. battery technologies) can reduce the need for additional back-up capacity and infrastructure, by storing electricity when demand is low and discharging when demand is high.

There is a cost to deploying these measures and managing intermittency, which for our scenarios we estimate at around £10 per MWh of intermittent renewable output (which may be compared to current costs of onshore wind of around £80/MWh, for example).

Costs would be likely to increase at much higher penetrations of intermittent renewables, but we exclude these from our scenarios. For example, intermittency costs could reach around £25/MWh for solar if capacity exceeds 40 GW or around £15/MWh for wind if capacity exceeds 50 GW, each within a power system reaching 50 gCO_2/kWh.

Our power sector scenarios all meet the Government's current reliability standard for security of supply in the electricity system[21], and take into account the new evidence on potential system impacts of individual low-carbon technologies in order to balance affordability and security of supply. For example, we constrain deployment of wind and solar to no more than 50 GW and 40 GW respectively in our 2030 power sector scenarios, and most of the scenarios reach an emissions intensity of around 100 gCO_2/kWh rather than 50 gCO_2/kWh.

Our power sector scenarios therefore maintain security of supply requirements and involve a significant deployment of flexibility options (e.g. demand-side response and interconnection) which bring down overall costs of managing intermittency. Deployment of electric vehicles and heat pumps can provide additional sources of system flexibility, traditionally provided by conventional fossil fuel plant.

6. Delivering the scenarios

Our investment scenarios set out above imply that the low-cost strategy for meeting the needs of the power sector in the 2020s involves low-carbon generation as the primary source of new generation and a move away from coal by the middle of the decade.

The Government has recently announced a consultation on closing all plants by 2025 and restricting its use by 2023. That is broadly in line with our scenarios, and, as set out in our October report, would increase confidence for investors in replacement capacity.

The key tools are in place to deliver low-carbon investment in the 2020s – long-term contracts

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[21] The UK's electricity system must be managed to meet the Government's reliability standard, which targets a loss-of-load expectation of no more than three hours per year. This represents the number of hours per year in which, over the long term, it is statistically expected that supply will not meet demand.

with price discovery through competitive auctions. However, to deliver at lowest cost, the Government must urgently clarify the direction for future policy.

- Investments in the power sector have long lead-times, with planning cycles stretching well beyond the current 2020 policy window. Large offshore wind farms, CCS plants and nuclear plants have a project lead-time of up to 10 years or more, with supporting investments in the supply chain stretching even further.
- If investors are exposed to policy risk in this timescale then they will apply risk premia to projects and costs will be unnecessarily increased. Potential projects in the pipeline could also be discarded, which would reduce the number of competitors in the auctions.

To increase certainty for investors and secure lowest costs for consumers the policy implications set out in our October report (Box 2.1) are still applicable.

Box 2.1: Policy implications of our power sector scenarios

- Extend funding for low-carbon generation under the Levy Control Framework to at least 2025. This is required to provide a clear long-term signal to investors that there will be a future market for low-carbon contracts, which are auctioned at the Government's discretion.
  - Total available funding should increase from £8 billion in 2020 to around £9 billion in 2025 under central assumptions, including that the Government keeps to its target trajectory for carbon prices (i.e. £42/tonne in 2025, on the path to £78/t in 2030).
  - For this to be an effective signal of funding available for new projects the Government must set out how the total will be adjusted if circumstances do not turn out as assumed. For example, funding should increase to £9.8 billion if the market carbon price reaches only half the level the Government has targeted for the carbon price floor (e.g. £21/tonne instead of £42/t in 2025).
- Set out the timetable and funding pots for the next auction round for low-carbon contracts. A separate funding pot should be reserved for emerging technologies, including offshore wind and CCS until the mid-2020s. These important technologies would be unlikely to secure contracts if they were to compete openly with other low-carbon technologies before 2025.
- Set auction reserve prices for low-carbon options that have reached maturity based on expected lifetime costs of new gas capacity facing its full carbon cost, allowing for intermittency costs and consistent with potential cost reduction (e.g. that would imply a maximum price for onshore wind and ground-mounted solar of £80/MWh from 2020, and for offshore wind of £90/MWh from around 2025, with the expectation that competitive auctions could deliver lower prices).
- Set out an approach to commercialise CCS through the planned clusters: including a strategic approach to transport and storage infrastructure, completing the two proposed projects and contracting for at least two further 'capture' projects this Parliament.
- Work with Ofgem and National Grid to ensure that flexibility options (e.g. flexible demand response, interconnection with other parts of Europe, storage) are able to capture their full value and low-carbon investments face their full system integration costs.
- Develop approaches to securing low-cost generation at the end of contract life and from repowering (i.e. re-using existing sites by installing new equipment but taking advantage of the existing grid connections and other existing infrastructure to reduce costs).
- Consider further routes to reduce the cost of capital alongside the increased policy certainty that would accompany carrying out the above actions (e.g. infrastructure guarantees, risk-sharing ahead of auctions).

Chapter 3: Buildings

Introduction and key messages

In this chapter, we examine scenarios for the abatement of emissions from homes, commercial and public buildings, which account for 17% of the UK's direct greenhouse gas (GHG) emissions. These emissions are primarily due to fossil fuel use in space heating. Indirectly, buildings also account for two-thirds of power sector emissions, mainly due to electricity demand for lighting and appliances.

There is considerable potential to reduce these emissions through a switch to low-carbon heat sources and energy efficiency improvements. In recent years, there have been substantial reductions in emissions through easy, low-cost measures such as efficient boilers, loft and cavity wall insulation. There is scope for continuing with the deployment of these measures for the next five years. However, from the early 2020s, the solutions will become more challenging.

Our key messages are:

- Meeting the 2050 target will be much more expensive, and may be impossible, without a near complete decarbonisation of heat.[22]
- The least-cost mix of technologies to remove emissions from heating is not yet known. There is value in exploring several options to 2030 for meeting the 2050 target, and in aiming for a balanced mix of technologies.
- Heat pumps remain a promising option, though there are a number of challenges around performance and cost – particularly in retrofit – which need to be addressed. Keeping in play the option of a high level of heat pump deployment requires installing around 2.5 million heat pumps in homes by 2030. The main cost-effective opportunity to install heat pumps in the 2020s is in buildings that are not connected to the gas grid. New-build properties are also well-suited to heat pumps.
- Heat networks with low-carbon sources can deliver a significant level of abatement in 2030, broadly on a par with the potential from building-scale heating technologies.
- Heat decarbonisation will have to go hand in hand with improvements in energy efficiency. To 2030, the main new potential lies in insulating homes with solid walls.
- Further policy would be required to deliver the measures included in our scenarios, including addressing the immediate policy gap on home energy efficiency. Other priority areas relate to support for building-scale technologies in the 2020s in properties not connected to the gas-grid and in new-build. Our scenarios also imply the need for a new policy framework for achieving a step change in the rollout of heat networks.

Our central scenario suggests that direct buildings emissions could reduce from 84 $MtCO_2$ in 2014 to 72 $MtCO_2$ by 2030, notwithstanding the predicted growth in the number of households from 27 million

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[22] This is supported by our cross-sector analysis, discussed in Chapter 1.

Introduction and key messages

in 2014 to over 31 million in 2030.

This central projection is within a wider scenario range of 66 to 80 $MtCO_2$ in 2030, and leaves open a wide range for potential emissions in 2050 (4 - 66 $MtCO_2$). The large range in 2050 reflects the relative difficulty in decarbonising heating, with significant barriers to overcome.

Implementing the abatement measures in our scenarios also provides other benefits, most notably reducing fuel poverty.

We will carry out more in-depth work and analysis of heating in 2016 to help us monitor progress and assess how best to overcome barriers.

Notes: The carbon emission figures given above are on a CO_2 basis. Also including methane and nitrous oxide implies a further 0.5 $MtCO_2e$ for current and projected residual emissions. F-gas emissions arising from refrigerants in buildings are covered separately in Chapter 7.

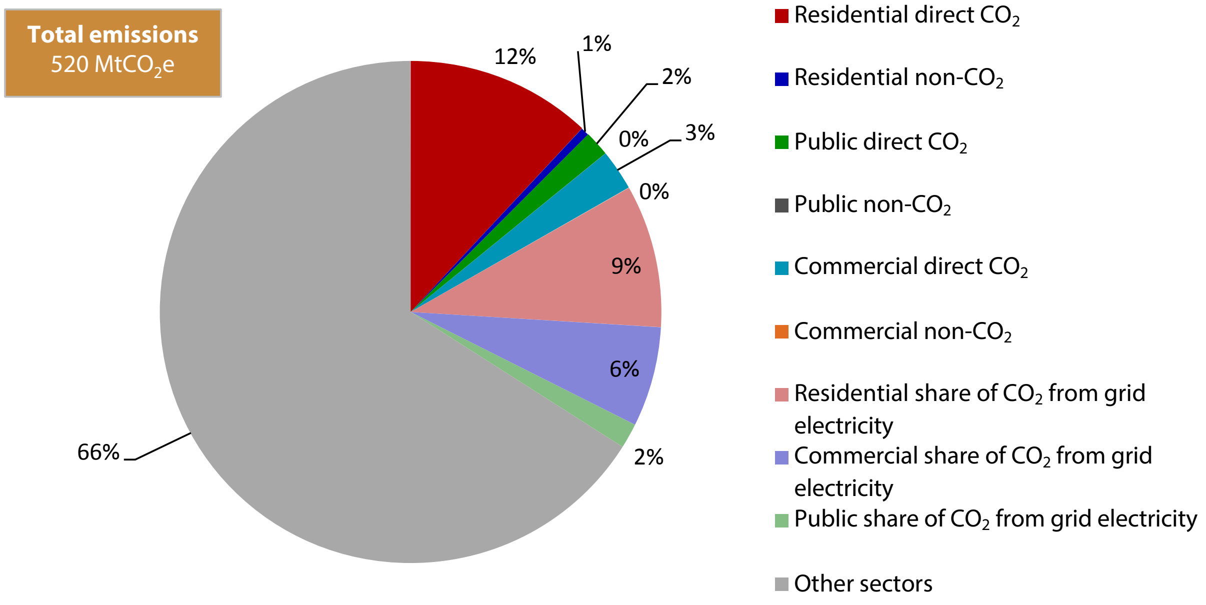
We set out the analysis that underpins these conclusions in the following sections:

1. Overview of emissions from the buildings sector
2. Options for reducing emissions
3. Existing ambition and projected emissions without further policy
4. Abatement scenarios
5. Costs and impacts
6. Delivering the scenarios

1. Overview of emissions from the buildings sector

Direct buildings emissions accounted for 17% of all UK GHG emissions in 2014. Direct building emissions are split between homes (74%), commercial buildings (16%) and the public sector (10%) (Figure 3.1). Electricity demand from buildings was 201 TWh in 2014 and is associated with 67% of total power sector emissions (81 $MtCO_2$).

Figure 3.1: GHG emissions from buildings in the context of total UK emissions in 2014



Source: NAEI (2015), DECC (2015) *Energy Trends, March 2015*, DECC (2014) *DUKES*; CCC calculations.
Notes: 2014 emission estimates are provisional. Commercial sector and non-CO_2 are based on CCC estimates. The emissions from grid electricity are mainly power sector emissions, with a small contribution of 8 Mt from other sectors (mainly industry).

Direct emissions result primarily from the use of fossil fuels for heating. Around 75% of the UK's heating demand in buildings is met by natural gas, 8% by oil, with most of the remainder heated by electricity (11%). Fewer than 2% of buildings are heated with low-carbon heat, mostly through biomass heating and heat pumps.[23]

Electricity consumption mainly stems from the use of appliances and lighting in the home and in commercial premises. In homes, appliances account for around 56% of residential electricity demand, lighting for another 13%. In addition, for those homes that are not connected to the gas grid, electricity use is also a significant component for space heating, accounting for around a fifth of total residential electricity consumption.

Total emissions from buildings have fallen by 27% since 1990, mainly reflecting energy efficiency improvements and reductions in the carbon intensity of electricity consumption (Figure 3.2). Since 2010, total emissions have fallen by 21%. Emissions from buildings, especially homes, vary from year to year in response to variations in temperature during the winter months.

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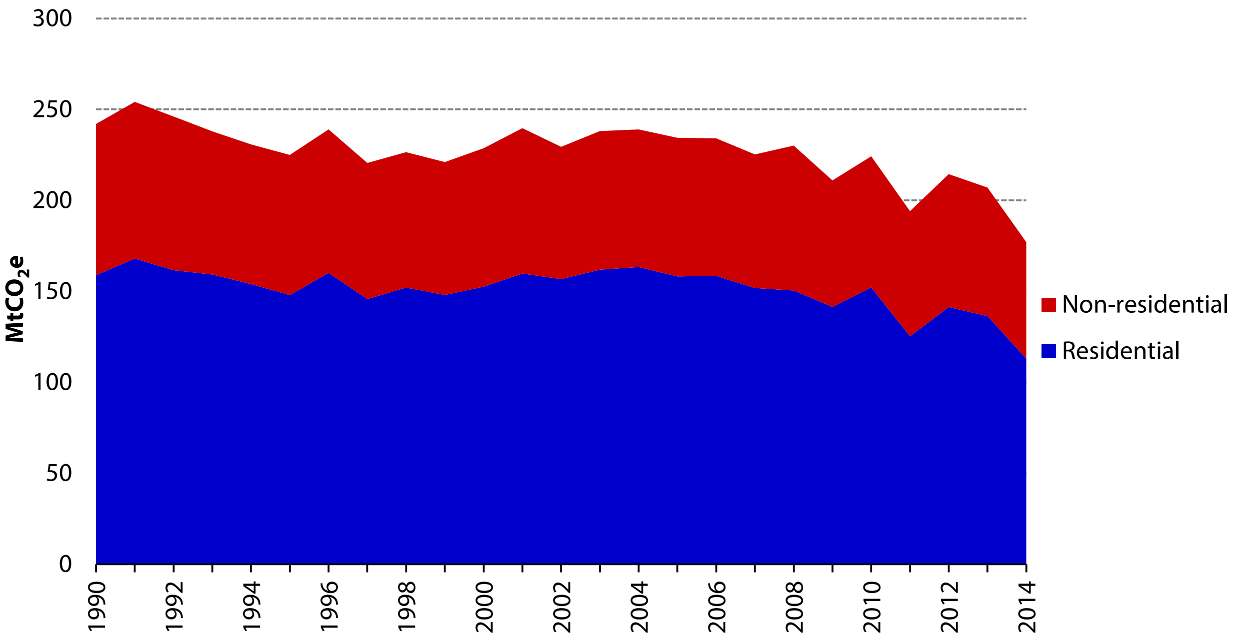
[23] This also includes small contributions from low-carbon heat networks served by waste heat and gas Combined Heat and Power (CHP).

Figure 3.2: Historical buildings emissions (direct and indirect) since 1990



Source: NAEI (2015), DECC (2015) *Energy Trends, March 2015*, DECC (2014) *DUKES*; CCC calculations
Notes: 2014 emission estimates are provisional.

The decrease in emissions has been particularly marked from homes and public buildings, while commercial buildings have seen less of a reduction:

- **Residential buildings:** falling emissions reflect declining energy demand for space heating, hot water use, lighting and appliances due in part to energy efficiency improvements:
  - **Boiler efficiency:** The Building Regulations of 2005 introduced stricter energy efficiency standards for boilers. As a result, the share of efficient gas and oil condensing boilers has increased to around 44% of the stock by 2012 compared to 17% in 2008.
  - **Hot water efficiency:** More efficient heating systems (e.g. condensing boilers), and improved insulation of tanks and pipes have reduced heat loss from stored hot water.
  - **Fabric insulation:** The installation of loft, cavity and solid wall insulation has improved the thermal performance of the residential building stock. The combination of efficiency improvements in boilers and insulation has led to an increase in the average SAP[24] rating of the existing housing stock from 53 in 2008 to 60 by 2013. Meanwhile, tighter energy efficiency standards in the Building Regulations now deliver a typical SAP rating of 80 for new-build homes.
  - **Lighting and appliances:** Despite the increase in appliance ownership and use, emissions from this source have been more than offset by the increased energy efficiency of lighting and electrical appliances.

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[24] The Standard Assessment Procedure (SAP) is the Government's method for assessing the energy performance of homes (space heating, hot water and lighting). SAP ratings are expressed on a scale of 1 to 100 - the higher the number, the more efficient the home.

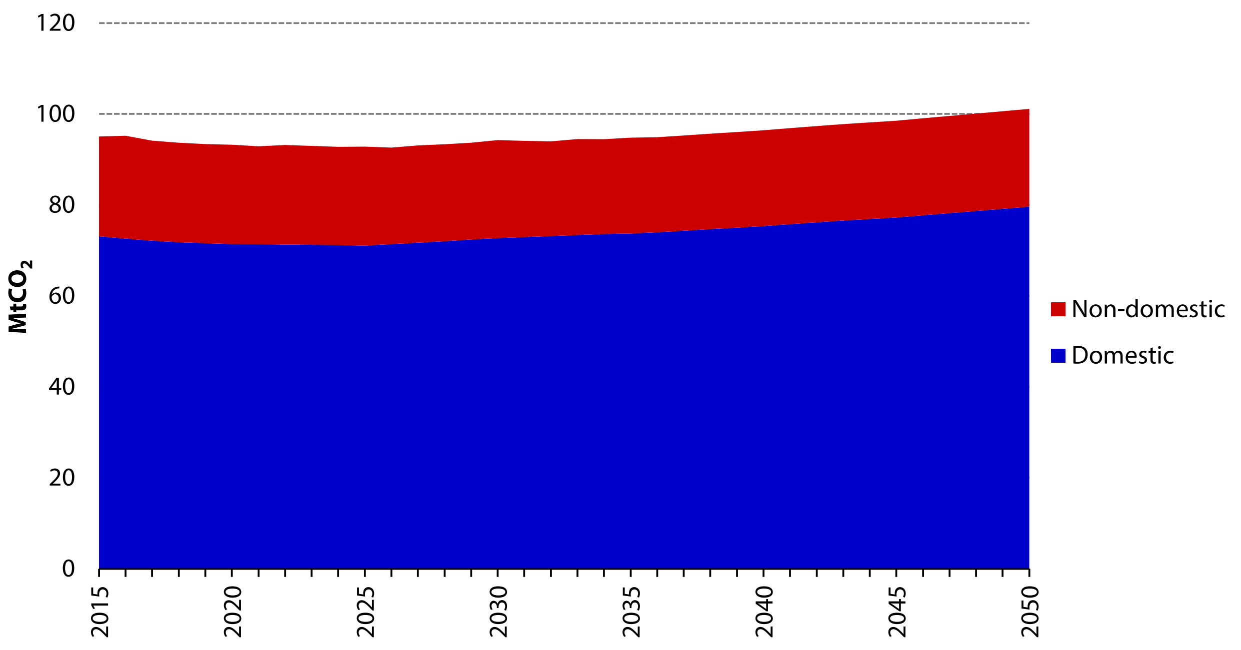
- **Public sector** direct emissions have fallen 37% from 1990 to 8 $MtCO_2$ in 2014.
- **Commercial buildings** are the only portion of the building stock for which direct emissions have not reduced since 2007. Commercial energy intensity fell steadily between 1990 and 2007, but has not fallen further since.[25]

In the absence of new policy, residential buildings emissions are expected to remain fairly flat to 2035 (Figure 3.3), with emissions from new homes largely offset by efficiencies from the turnover of the boiler stock.[26] By 2035, we expect an additional five million homes on top of the current stock of 27 million homes. The additional impact from this increase is small as new homes are either new-build properties with low energy consumption or created through the subdivision of existing properties.

Emissions in public and commercial buildings are also forecast to remain flat to 2035.

There is significant uncertainty in these projections, related to assumptions on build-rates, levels of efficiency and macro-economic drivers, which we consider in Section 3.

Figure 3.3: Projections of baseline emissions in the buildings sector to 2050



Source: DECC interim projections (October 2015) and CCC analysis.

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[25] A similar picture is given when comparing energy intensity per unit output with energy consumption per employee and on a floor area basis over the past five years. All indicators fell in 2014, offsetting an increase in 2008 and bringing intensities in line with 2007 levels.

[26] This differs to the DECC Interim Baseline Policies projections (October 2015), which forecast an increase of around 8 $MtCO_2$ in homes to 2035, roughly equivalent to the forecast increase from new homes in our analysis. This is considered in Section 3.

2. Options for reducing emissions

In the buildings sector, opportunities for further emission reductions are in three areas: switching away from fossil-fuel based heating; increasing the energy efficiency of the building stock; and improving the energy efficiency of electrical appliances. In this section, we first discuss opportunities in low-carbon heat and then cover the potential for energy efficiency improvements in the residential and non-residential sectors. We focus on areas where there have been developments in the evidence base since our fourth carbon budget advice in 2010.

a) Low-carbon heat

Meeting the 2050 target will require a near complete decarbonisation of space and hot water heating. There are currently three main options to reduce emissions from heating.

1. Electrification, particularly through high efficiency heat pumps, in conjunction with the decarbonisation of the power sector.
2. Connection of properties to pipe networks which supply low-carbon heat directly to the buildings.
3. Switch from gas- and oil-based heating to low-carbon sources such as hydrogen, or to a limited extent, bioenergy.

There are also technologies that could play niche roles, such as solar thermal heating used to top up hot water supply, particularly during months of the year with higher solar radiation.

Together, these supply-side measures are complemented by actions to curb demand such as heating controls and behaviour change, which are covered in Section 2b.

No single solution can service all of heating demand. The cost-effective solution is a function of the technology and also the location and characteristics of the buildings in question:

- Whether the building is currently connected to the gas grid.
- The level of efficiency of the property, and size of the heat demand.
- Whether it is new build or an existing property.
- Whether the property is in a densely or sparsely populated area.
- Whether the building would be well placed to use the new heating technology for multiple purposes (such as using heat pumps for heating and cooling).

Given the range of technologies, the differences across buildings and the relatively low levels of penetration of these technologies to date, there is considerable uncertainty about what combination of technologies will emerge as most cost-effective in which locations.

This suggests that any approach to low-carbon heat should aim to keep a number of options in play to 2030. It should aim for a balanced mix of technologies rather than relying on any one technology.

Heat pumps

Heat pumps (Box 3.1) remain an important part of our heat decarbonisation scenarios. In part this reflects the limitations of other options:

- Heat networks are generally viable only in high heat density areas (Box 3.5).

- Biomethane stocks are limited, which means it is not a viable option for displacing gas and oil use across the building stock.
- Whilst biomass boilers could be deployed at scale in buildings now, as we approach 2050 there is likely to be a need to prioritise resources in other areas such as bio-CCS (to obtain negative emissions) or in areas where other options are limited (such as industry).
- The technical viability and costs of hydrogen are highly uncertain.

These limitations reinforce the need to support heat pumps to 2030, and of work to address barriers to uptake.

Hybrid heat pumps (typically combining an air-source heat pump with a gas boiler) deliver lower carbon savings but have a number of advantages.[27] These include the practicality of top-up gas, fewer barriers to installation, higher acceptability to consumers, and lower peak load electricity demand. This is balanced against the risk that they will be run predominantly in gas mode, and the possible difficulty in making a subsequent switch to electric heat pumps or other low-carbon heat by 2050.[28]

This suggests they could play a transitional role, and potentially also a more limited role to 2050 in the case of hard to treat homes. We assume that they operate in heat pump mode for 75% of demand, which implies uptake would need to be a third higher than if just including electric heat pumps to achieve the same level of abatement.

Box 3.1: Heat pump technology

Heat pumps are a high efficiency form of electric heating which operate like a fridge in reverse, by using electricity to extract heat from the environment. One unit of electricity can generate between around 2 and 5 units of heat. We consider a range of different heat pumps:

- **Air-source (ASHP)** draw heat from the outside air (lower capex, lower efficiency).
- **Ground-source (GSHP)** make use of trenches or vertical boreholes to draw heat from the ground (high capex, higher efficiency).
- **Hybrid heat pumps** typically combine an ASHP with a gas boiler, with the boiler used to top up heating on the coldest days of the year.
- **Gas heat pumps** use gas rather than electricity and are around 150% efficient (compared to around 90% for a condensing gas boiler).
- **Water-source and sewage-source heat pump** tend to be larger installations with multiple units. We have considered these as a supply-side option for heat networks, but they could equally replace other heat pump uptake, particularly in larger domestic and non-residential properties.

We also look at combining heat pumps with a hot water storage tank. This gives some flexibility as to when the heat pump is run, enabling consumers to make use of off-peak electricity tariffs, and improving the performance of the heat pump through reduced cycling (i.e. switching on and off, which lowers efficiency).

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[27] Factoring in power sector decarbonisation.

[28] Gas heat pumps could also play a transitional role. These offer a high efficiency form of gas heating (around 150% efficient, compared to around 85-95% for a new condensing gas boiler). They provide similar benefits to hybrid heat pumps in terms of reduced peak electricity demand, but would imply the same challenge of having to switch over properties with gas heat pumps to electric heat pumps or other low-carbon heating by 2050.

Heat pump costs

Heat pumps have high initial capital costs. They are currently only financially attractive to replace very expensive resistive electric heating, particularly in non-residential buildings where it is possible to achieve economies of scale. Heat pumps are expected to become cost-effective in a growing number of electric and oil-heated buildings over the next decade, but require both higher carbon values and cost and performance improvements before they become cost-effective relative to gas boilers.

Whilst it is technically possible to install heat pumps in most buildings, the costs of running heat pumps are prohibitive in the least energy efficient homes:

- Heat pumps operate best at lower flow temperatures (e.g. around 30-40°C). This means they operate effectively in homes with low heat loss and either large radiators or underfloor heating. They are particularly suited to new properties, or else usually require additional insulation and central heating upgrades in order to work optimally.
- In homes with high heat loss and/or undersized heat emitters, heat pumps need to be run at higher temperatures in order to achieve comfort levels, leading to a lower performance and higher heating bills. This could be addressed by improving the efficiency of the building (for example, through solid wall insulation), but the costs are also high. In certain properties such as very inefficient solid wall homes, the abatement costs are over £300/tCO_2.

Our assessment reflects new evidence about the cost-effectiveness of heat pumps in homes (Box 3.2). It also draws on more detailed analysis of the range of cost-effectiveness across the housing stock in the National Household Model (Box 3.3).

Box 3.2: Latest evidence on cost-effectiveness of heat pumps in homes

Evidence review

We conducted a review of the evidence on cost-effectiveness, working with DECC and a range of industry stakeholders. In general, this points to lower cost-effectiveness of heat pumps compared to our previous assessment.

Costs

We assume costs of around £1000/kW for an air-source heat pump (ASHP), and £2000/kW for a ground-source heat pump (GSHP), implying total costs of £6,000-8,000 for an ASHP and around £12,000-16,000 for a GSHP installed in a three-bed semi-detached home.

We include new evidence of boiler capital costs, at an installed cost of £2,500 for a typical 24kW boiler.

We have updated our assessment of the potential for capital cost reductions over time in line with recent evidence from the International Energy Agency and Delta-ee, which suggests around 20% reduction potential (up from 10% in our fourth carbon budget review analysis).

We use an updated set of uniform carbon values. These put a higher value on traded sector emissions (e.g. from heat pump electricity use), and less value on non-traded sector savings (Figure B3.2).

Efficiency

Heat pump design efficiency is denoted by a Coefficient of Performance (COP), which is the ratio of heat generated to electricity used. The in-situ efficiency is given by the Seasonal Performance Factor (SPF) which reflects lower efficiency in summer months (due to the increased share of direct hot water demand) and lower efficiency in the coldest days of the year in the case of air-source heat pumps.

Our assessments of achievable SPFs factors in the low results from two sets of field trials conducted by the Energy Savings Trust and DECC, along with results from monitoring of heat pumps installed under the Renewable Heat Premium Payment (RHPP) scheme and stakeholder views of the scope for improvement over time. We assume improvements in SPFs of 0.5 between 2020 and 2030, in line with our fourth carbon budget review analysis.

Lifetime

We have modelled a range of 16-20 years lifetime for domestic air to water heat pumps, reflecting lower durability compared to GSHPs (assumed to last 20 years). We also consider a low sensitivity where ASHPs last 15 years.

Suitability

Space requirements are a limiting factor for all heat pumps. We assume ASHPs cannot be installed in 10% of flats. GSHPs require additional space, as do heat pumps with hot water storage tanks.

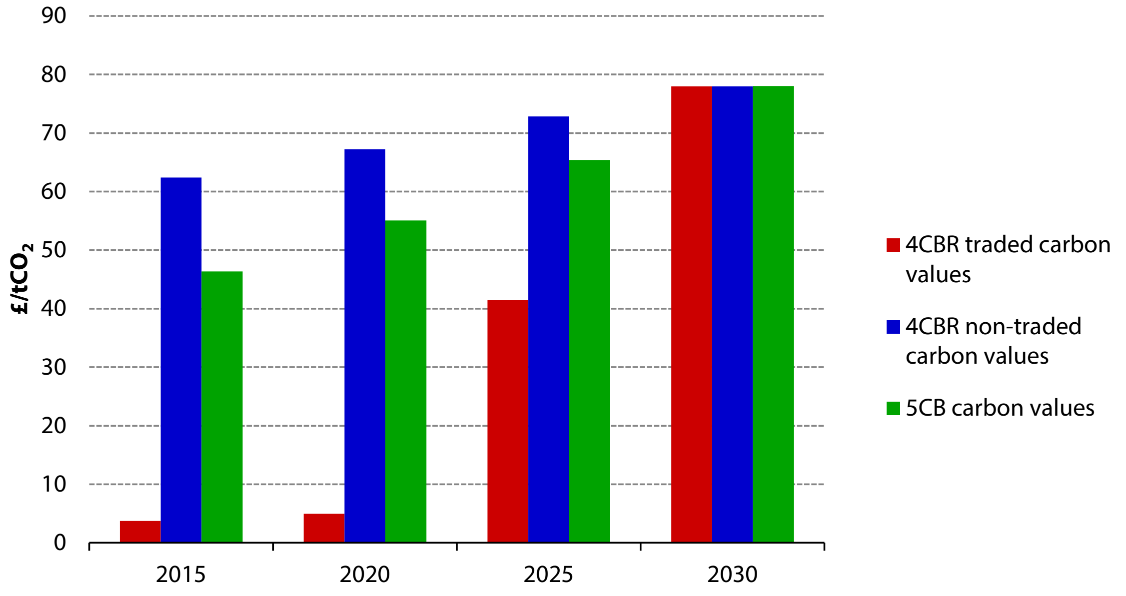
Balance of uptake

Current assumptions impact on the uptake of GSHPs, as the higher capital costs are not offset by the improved efficiency relative to ASHPs. However, this does not reflect the lower costs of renewing GSHPs by making use of existing boreholes, or the scope for communal ground arrays serving a number of individual heat pumps. For this reason, we present figures for a total uptake of heat pumps rather than giving relative shares of different heat pump technologies.

There is scope for hybrid heat pumps to displace electric heat pumps, which we consider in Section 4.

Box 3.2: Latest evidence on cost-effectiveness of heat pumps in homes

Figure B3.2: Fifth carbon budget central carbon values, compared to fourth carbon budget review traded and non-traded sector carbon values



Source: DECC (2013, 2014) Interdepartmental Analysts Group guidance and CCC calculations
Notes: 2014 prices.

Current deployment and barriers to uptake

Levels of take up of heat pumps in the UK remain very low, with only around 100,000 currently installed across the housing stock, compared to between five to ten times this level in France, Sweden and Germany.[29] Apart from the high cost, low consumer awareness and trust in the technology are barriers to uptake, despite the availability of generous subsidies under the Renewable Heat Incentive. In part this may reflect a general lack of appetite for change: some comparison can be drawn for example with concerns around condensing boilers (including cost, reliability and the need to operate at lower temperatures) when regulations were introduced in 2005.

Overcoming these barriers will require actions from installers to reduce cost and continue to improve on performance, along with support from Government to help overcome perception barriers and address the lack of carbon price signal.

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[29] Eur'Observer, 2014. *'The State of Renewable Energies in Europe.14th Eur'ObservER report'*

Box 3.3: National Household Model scenarios

The National Household Model is a micro-simulation model developed for DECC, which draws on detailed English, Scottish and Welsh housing surveys. This enables a more accurate and detailed analysis across the stock. Input assumptions can be reviewed and amended within the model code (including the Standard Assessment Procedure buildings physics assumptions, technology costs and performance, and energy costs).

We developed detailed scenarios to 2050 for decarbonising heating in the existing housing stock, with support from the Centre for Sustainable Energy, assessing cost-effective rollout of building-scale technologies.

Approach

We assess cost-effectiveness on a social basis, using the HM Treasury Green Book social discount rate of 3.5% real, and factoring in a set of projections of carbon values to 2050, along with energy cost projections. Our approach to scenario development is set out in more detail in Chapter 1.

The scenarios on the National Household Model contain the following steps:

1. We include a range of scenarios for the rollout of heat networks and energy efficiency measures to 2050, along with projections for heat pumps and biomass boilers uptake under the Renewable Heat Incentive to 2021;
2. In each year, existing technology fails based on a probability distribution, with the probability of failure increasing with age. New heat pumps and biomass boilers are replaced after 15-20 years.
3. Consumers choose between a like-for-like replacement and low-carbon technology, based on the discounted lifetime costs including carbon. Technology is sized based on the peak heating load, with an oversizing factor for gas boilers, based on market intelligence.
4. Levels of low-carbon technology are constrained by an assumed supply-chain constraint of 30% annual growth in sales, along with a constraint on the total bioenergy available (see Box 3.7). Allocation is optimised so that consumers with the greatest cost savings are prioritised over the more marginal cases.

The modelling assumes decreases in capital costs between 2020 and 2030 of 20%, along with improvements in heat pump performance.

Notes: DECC are aiming in time to make the National Household Model open access.

Non-residential heat pumps

Heat pumps in public and commercial buildings are relatively cost-effective – due to economies of scale and higher quality installations – and have lower barriers to uptake than in homes.

Air-to-air heat pumps are more suitable due to typically lower hot water demands in non-domestic properties, and have the additional advantage of delivering both heating and air conditioning, making them well adapted to offices and retail. Based on our latest energy costs projections, these currently cost around £65-70/MWh over a fifteen year lifetime (including £5/MWh carbon costs), significantly less than conventional electric heating (around £120/MWh) and comparable to the cost of oil heating when including a cost of carbon. According to our central assumptions, they are cost-effective on a social basis relative to gas from the late 2020s in the case of public buildings, and 2030 for commercial buildings (Box 3.4).

Air source heat pumps with storage are a viable option for buildings with sufficient space. The additional capital costs of the hot water storage are offset by the ability to shift electricity demand and make use of lower off-peak tariffs.

Our previous assessment for the 2013 *Fourth Carbon Budget Review* suggested a near complete decarbonisation of non-domestic buildings to 2030:

- This factored in uptake of 11 TWh of ASHPs and 3 TWh of GSHPs under the Renewable Heat Incentive (RHI) to 2020, which have since been revised significantly downwards.
- It included 1 $MtCO_2$ of abatement from biogas, which is now accounted for at an economy-wide level.

Our revised estimates reflect lower cost-effectiveness and the impact of lower ambition under the RHI to 2020:

- Our updated assumptions assume that ASHPs and biomass boilers last 15 years, compared to 20 years previously. This, together with new carbon values, suggests lower cost-effectiveness than previously assumed.
- We also factor in the impact of the lower estimates from DECC of projected uptake to 2020 under the RHI. Take up under the scheme has to date been made up of close to 100% bioenergy schemes.

The impact on our scenarios is set out in Section 4.

Box 3.4: Cost-effectiveness of heat pumps in public and commercial buildings

Our assessment of the cost-effectiveness of heat pumps is based on a review of costs and performance assumptions with DECC and other stakeholders, and includes RHI scheme delivery data.

There is a high degree of variation across the non-domestic building stock in terms of heating demand and patterns, types of systems and sizes. We explored this range through sensitivities on technology costs and performance.[30]

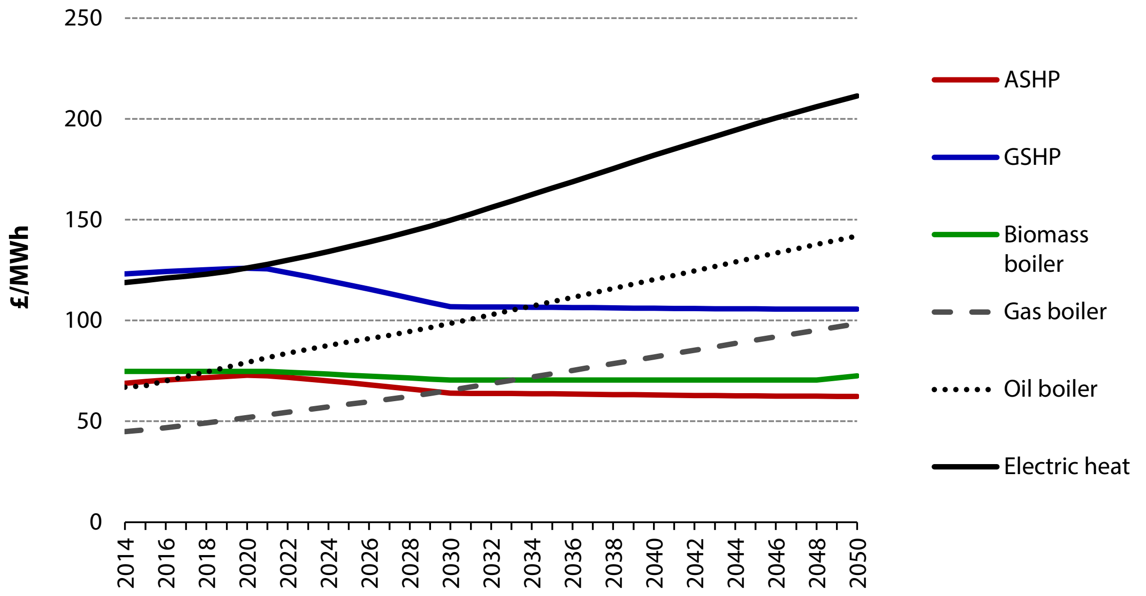
Costs

Capital costs ranges are set out in Box 3.8. Our central case costs of low-carbon technologies in commercial buildings compared to gas, oil and electric heating are set out in Figure B3.4. These include capital costs, maintenance costs, fuel costs and carbon costs, on a MWh basis.

We calculate costs to businesses including a cost of capital of 7.5%. The equivalent public sector costs are around £5/MWh lower because of lower borrowing costs, assuming a 3.5% cost of capital.

Adding hot water storage to heat pump installations implies additional costs of around £5/MWh.

Figure B3.4: Levelised costs of heating technologies in commercial buildings including a cost of carbon, 2014 to 2050



Source: CCC analysis.
Notes: 2014 prices. Levelised costs include the cost of carbon. Lower cost of capital assumptions have a more significant impact on the more capital-intense technologies (e.g. GSHPs).

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[30] Further work is planned using the outputs from the Building Energy Efficiency Services (BEES) project, currently underway in DECC.

Heat networks

Heat networks (also referred to as district heating) supply heat in the form of hot water directly to buildings. In the UK, heat networks supply around 2% of heat, compared to around 60% in Denmark and Sweden. Currently, they are primarily based on natural gas boilers, but this could change to low-carbon sources over time:

- They are particularly suited to areas of high heat density such as cities, where there are space restrictions for other technologies such as heat pumps and biomass boilers (and in the case of biomass, also air quality concerns).
- They have potential to be a low-regrets and flexible option insofar as they can later be combined with other key options – heat supplied from both hydrogen and heat pumps – and make use of other sources (waste heat from power, industry, and Energy from Waste).[31]
- Heat networks are also a key technology for public and commercial buildings, which are more concentrated in urban locations and which can provide important 'anchor' heat loads to make schemes economic to run.

We commissioned a new study into the cost-effective potential for low-carbon heat networks, which has undertaken new detailed spatial analysis to assess potential for a range of low-carbon technologies to 2050 (Box 3.5).

The spatial analysis of the UK matched up zones with high heat density to sources of low-carbon supply (waste heat, water and sewage source heat pump potential):

- Around 17% of heat demand is in 1 sq.km zones above a heat density of 50 GWh/sq.km, which would typically be considered as suitable for heat networks.[32]
- The detailed modelling demonstrates how this threshold varies depending on a number of other factors, including the mix of building types, technology and energy costs and the location and availability of low-carbon heat sources.

This analysis suggests that cost-effective heat networks could account for nearly 10% of heating demand in 2030. In the following section we consider how this varies as a function of the assumptions on technology costs and other economic factors such as fuel prices.

Heat network costs

Heat networks are capital-intensive infrastructure. These vary according to the type of heat source, the extent and type of pipe used and the cost of capital:

- **The source of heat supply**. High-temperature waste heat and Energy from Waste are the most cost-effective supply options, both with negative abatement costs in 2030. The top end of the range is given by water-source and sewage-source heat pumps, with abatement costs over £200/tonne CO_2 in 2030.

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[31] This flexibility is balanced against the risk of stranded assets if consumers install competing building-scale technologies, which needs to be managed through a clear policy framework if deploying heat networks at scale. The policy implications are considered in Box 3.6 and in Section 6.

[32] Practical examples which are exceptions to this rule of thumb include smaller community schemes and areas with a high proportion of non-domestic heat demand and lower connection costs.

- **The length and type of pipe**. A greater share of non-domestic buildings makes schemes more cost-effective as they require fewer connections and distribution pipe. Schemes connecting urban sources of demand with waste heat from large power or industrial plant will typically face additional costs for transmission networks.
- **Levels of perceived risk from investors**, which affects the cost of capital.

The overall viability of schemes is very sensitive to the level of demand, which has a significant impact on the unit cost of heat (in terms of £/MWh). This is determined by heat density and the portion of buildings which connect in a given area:

- **Heat density.** Heat networks are suitable for areas of high heat demand density, where capital costs can be justified by a high utilisation factor.
- **The proportion of properties connecting to the network**. We explore a range from 50-100% in our scenarios. The lower end represents voluntary action, and is based on the proportion of homes voluntarily connecting to new gas grid infrastructure in Northern Ireland. The upper bound is seen in countries which mandate connection, such as Denmark.

Finally, the unit costs also reflect wider economic factors, such as fuel prices.

Costs are projected to fall for less developed technologies such as water-source heat pumps as a function of learning, but to remain flat for more mature technology such as gas Combined Heat and Power (CHP). Other opportunities for cost reduction lie in reduced oversizing, lower network flow and return temperatures and reduced network thermal losses.

Barriers to heat networks

The key barriers to uptake include the lack of carbon pricing, misaligned policy incentives, and a lack of consumer interest and trust, all of which contribute to uncertainty of demand. Further barriers include high capital costs as well as issues around coordination, ownership and skills.

Achieving a step change in the rollout of heat networks will require a set of interventions to address these barriers. This could include measures such as zoning where district heating is identified as cost-effective, financial incentives and additional oversight of competition (Box 3.6).

Box 3.5: Element Energy project on cost-effective potential for low-carbon heat networks

We commissioned Element Energy to undertake new detailed analysis of the cost-effective potential of low-carbon heat networks in the UK to 2050. The work included a review of district heating, thermal storage and district cooling, along with consideration around the transition over time to both low-carbon and low-temperature heat networks.

The scenarios are based on detailed spatial analysis of supply options, combined with spatial analysis of demand.

- On the demand-side, the analysis derived 144 zone archetypes from national heat map data, allowing for variation in heat density different mixes of residential and non-residential buildings, and building types (solid wall/cavity wall, house/flats).
- It considered a range of supply-side technologies, including high temperature waste heat from power and industrial plant, low temperature waste heat boosted by heat pumps, gas Combined Heat and Power (CHP), Energy from Waste, and large-scale heat pumps (water-source and sewage-source).

The study highlights a key role for thermal storage, but a more limited role for gas CHP plant.

- Thermal storage can reduce the size of peak load plant, help match supply to demand and manage the network return temperature (improving overall efficiency). The most common form of storage is large hot water tanks; interseasonal storage is expensive unless there is a natural source (such as an aquifer), and it is not expected to play a significant role. Just over 7% of operational schemes in the UK are known to use a thermal store currently – this is expected to increase.
- As the electricity grid decarbonises, the carbon savings from gas CHP diminish, with no additional abatement in new schemes from the end of the 2020s. Gas CHP plant is modelled as a supply-side option combined with other low-carbon sources.

District cooling involves transporting water at around 5 °C, generally produced using compressor chillers, absorption chillers or heat pumps. It is not currently widespread in the UK, and the study does not predict a growing role over time.

- The economics are less favourable than district heating due to the larger pipes required, which lead to higher losses and lower efficiency.
- Current UK schemes mostly integrate district cooling with CHP (trigeneration). As the carbon savings from gas CHP decrease over time, absorption chillers would be less favourable compared to electric chillers. Larger centralised chillers do not offer any increased efficiency compared to smaller units, therefore it is harder to make the case for district cooling over time.

Water-source heat pumps contribute around a quarter of the heat in the central scenario in 2030, with further growth potential to 2050. The analysis is based on new water source heat map data developed by DECC together with the Environment Agency.

Source: Element Energy, Frontier Economics and Imperial College (2015) *Research on district heating and local approaches to heat decarbonisation.*
Notes: Source published on CCC website as supporting evidence to this report.

Box 3.6: Frontier Economics study on barriers to uptake

We commissioned Frontier Economics to look at barriers to uptake for the roll-out of heat networks, and to consider a set of policies to overcome these barriers. They undertook a combination of stakeholder interviews and a review of existing research, drawing on lessons from other countries with more developed markets for heat to conduct a gap analysis of the UK market.

Their assessment is that policy intervention will be required to overcome a number of barriers, including the lack of carbon pricing, natural monopoly issues and uncertainty of demand.

- **Externalities**. The lack of carbon price means that the cost of heat networks does not currently reflect the benefits of lower carbon emissions.
- **Natural monopoly**. Heat networks are natural monopolies, as the high fixed costs make it more efficient for one operator to supply heat. The reduced competition can lead to poor outcomes for consumers, such as higher prices or poorer service.
- **Demand uncertainty**. The high capital costs of heat network infrastructure mean that the viability of the investment is very sensitive to the level of demand secured.
- **Misaligned or conflicting policy incentives.** Supporting competing solutions (for example, heat networks and small building-scale heat pumps) within the same location undermines the viability of heat networks, and drives up the overall costs of decarbonisation. Barriers are encountered where there are restrictive planning policies. Shifts in heat policy also create uncertainty for investors, which can increase financing costs.
- **Consumer non-financial barriers.** These include low consumer awareness and perceptions of poor quality or perceived hassle in connecting.
- **Institutional issues.** There are shortages in terms of local resources, skills and knowledge, along with issues around a lack of coordination.
- **Barriers to the supply of waste heat**. There is currently no systematic means for investors to gain information of local availability of waste heat source from power and industrial sites. Even with adequate information, planning and coordination may be complex.

These barriers interact and are largely self-reinforcing – for example, low consumer awareness and trust may be partly fuelled by concerns around natural monopoly issues; in turn, it impacts on demand uncertainty together with policy uncertainty and the lack of carbon pricing.

Frontier Economics set out a number of recommendations:

- **A financial incentive** to investors, which could be replaced by carbon taxation in the longer term.
- **Competition policy**, to address natural monopoly issues.
- **Supportive planning policy**, in the form of dedicated zones for heat networks, where other conflicting incentives are not available (e.g. for small domestic heat pumps). Frontier Economics suggest this could be combined with a policy of public bodies connecting to heat networks where this is cost-effective.
- **A set of 'low-regret' policies** including information provision on waste heat and localised approaches to developing consumer trust and awareness.

We will return to these policy recommendations in 2016 in our work on low-carbon heat policy.

Source: Element Energy, Frontier Economics and Imperial College (2015) *Research on district heating and local approaches to heat decarbonisation.*
Notes: Source published on CCC website as supporting evidence to this report.

Other low-carbon heat options

Bioenergy

Our assessment of the total bioenergy supply potential and best use across the economy is based on our 2011 *Bioenergy Review*. We have reviewed these assumptions taking into account more recent evidence and have concluded that they remain appropriate.

When determining resource potential, we look at UK domestic resource and add in potential international supply, based on the UK share of total energy consumption.

Whilst biomass boilers are a viable route for decarbonising some heating, by 2050 scarce biomass resources will mainly need to be diverted to use in conjunction with Carbon Capture and Storage in order to remove emissions from the carbon cycle (Chapter 1), or be used in higher priority areas such as high temperature process heat in industry. We therefore include a limited role for biomass space heating over the fifth carbon budget period (Box 3.7). However, there is a small role for biomass heating based on locally-sourced sustainable supplies (e.g. woodchip from forestry thinnings) which are not cost-effective for use in other sectors.

Our previous fourth carbon budget analysis included abatement of 5.9 $MtCO_2$ in buildings in 2030 from 31 TWh of biomethane injected into the gas grid. This is now covered at an economy-wide level (Chapter 1).

Box 3.7: Best use of biomass – potential for buildings

The two main routes for using biomass in buildings are building-scale biomass boilers and larger biomass boilers or Combined Heat and Power units connected to heat networks.

Burning biomass leads to air quality issues arising from emissions of fine particulate matter and nitrogen oxides. These emissions can be mitigated through tail-pipe measures such as filters, scrubbers and catalysts, although the costs are more easily absorbed in the case of larger-scale boilers than with smaller units.

This suggests that the two key roles for biomass in buildings are either in connection with heat networks (where other cost-effective options such as waste heat are not readily available, or in a secondary role for smoothing demand peaks) and in more rural areas (particularly properties which are expensive to insulate where heat pumps are less suited).

We have developed a set of scenarios for biomass use in buildings, based on our updated assessment of the *Bioenergy Review* and previous sector scenario analysis:

- We include 5-15 TWh of biomass used in building-scale boilers in 2030, and 11-27 TWh including biomass used in heat networks. This is in line with our previous assessment in the 2013 *Fourth Carbon Budget Review*.
- To 2050, we include 13 TWh of local bioenergy sources for use in heat networks in our central scenario, with a high end estimate of 59 TWh, comparable with our analysis for the 2012 report on the 2050 target.

A higher level of deployment is possible in the 2020s and 2030s – provided this does not displace other low-carbon technology and jeopardise the ability to meet the 2050 target. Consideration would then need to be given as to how to transition to other low-carbon heat options in buildings, should this bioenergy be diverted to other uses such as bio-CCS to 2050.

Hydrogen

We have developed new analysis on the potential role of hydrogen for heat, based on conversion of the gas grid to hydrogen.[33] This is feasible in principle, with further work underway to understand the full practicalities and costs.[34]

Using 100% hydrogen requires conversion of boilers, appliances and meters in buildings over the period to 2050. Converting the low pressure gas network at a rate of a million properties a year would imply starting in the 2020s.

The costs might be broadly comparable to those of converting from town gas to natural gas, estimated at around £3,500 in some recent costings from the Isle of Man, with additional hidden costs from the need to reinforce the gas grid to accommodate higher pressures.[35]

A large-scale switch to hydrogen would require a major training programme for skilled technicians such as gas fitters. Given the high level of financial risk (including regulatory risk), central and local government would need to play a significant role, with support from local gas Distribution Network Operators. One approach could see local authorities drawing up heat plans and establishing whether hydrogen is a viable option in their area.

Solar thermal

Solar thermal uses the energy of the sun to heat hot water through panels, typically installed on rooftops. It is not a standalone heating technology, but can be integrated into a system to supply hot water during months with high solar radiation. If used with a large thermal store, it can also supplement space heating. This approach is well-suited for combining with heat pumps, as the thermal store simultaneously improves the efficiency of the heat pump by reducing cycling, and allows consumers to make use of off-peak electricity tariffs.

Currently, hot water demand accounts for 21% of domestic heating demand, and 16% of commercial and public sector demand. This proportion is forecast to grow in line with reductions in building heat losses from improved insulation and the introduction of heating controls, which curb space heating demand.

This suggests a growing role for solar thermal alongside other demand-side measures (efficient taps and shower heads, shorter showers) as well as supply-side measures such as hot water recovery. Water reduction measures are equally important for adapting to climate change and managing water scarcity.[36]

We have not developed scenarios for solar thermal as part of the fifth carbon budget analysis:

- Our previous analysis suggested this is a high cost option in most applications.[37]

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[33] E4tech et al (2015) *Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target.*

[34] One example is the H21 project in Leeds, a feasibility study commissioned by Northern Gas Networks.

[35] In order to achieve a similar energy density, hydrogen would need to be piped at higher velocity to make up for the fact that it is three times less dense than natural gas.

[36] For further discussion, see CCC (2015) '*Meeting Carbon Budgets – Progress in reducing the UK's emissions*', and CCC (2012) '*Climate change – is the UK preparing for flooding and water scarcity?' Adaptation Sub-Committee Progress Report 2012*.

[37] CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*, available online at https://www.theccc.org.uk/publication/international-aviation-shipping-review/

- Developing a full picture of cost-effectiveness across the building stock requires detailed consideration of a range of issues such as variation between summer and winter efficiencies of the back-up heater, and interactions with the rest of the heating system (e.g. electric showers).

A variant on the scenarios presented could see solar thermal complement some of the other hot water efficiency measures discussed in Section 2b. Equally, a portion of buildings with low-carbon heating systems could see heat pump systems including solar thermal. We will return to this in future work.

Gas boiler replacement

There will be a need for replacement over time of gas boilers, with older back boilers and standard non-condensing boilers replaced with more efficient condensing and condensing combi boilers, as required under the 2005 gas boiler regulations. We assume that by around 2035, the boiler stock has seen a complete turnover.[38] The implications of this are discussed in Section 3 (projected emissions) and Section 6 (policy implications).

We use efficient condensing boilers as the comparator for assessing cost-effectiveness of low-carbon technologies.

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[38] In general, we assume an average lifetime of 15 years for gas boilers. Analysis of English, Scottish and Welsh housing survey data shows that a small portion of boilers last for upwards of 40 years. We model failure rates on a probabilistic basis (as a function of age), which implies that the stock has fully turned over by around 2035.

Box 3.8: Costs and performance of low-carbon heat technologies

The following quantities were estimated during the evidence review of building-scale technologies.

- Capital costs, including equipment costs, installation costs, auxiliary costs
- Fixed operational costs (mainly maintenance costs)
- Lifetime
- Thermal efficiency and seasonally adjusted performance factors
- Representative sizes and economies of scale

The capital costs fall within the following ranges (Table B3.8).

Detailed assumptions used in the heat network modelling are set out in the Annex of the Element Energy report (published as part of the supporting evidence).

Table B3.8: Ranges of capital costs and initial central estimate of in-situ efficiency of building-scale low-carbon heating technologies

Technology	**Domestic (£/kW)**	**Non-domestic (£/kW)**	**Domestic efficiency (%)**	**Non-domestic efficiency (%)**
ASHP	750 - 1250	210 - 690	251%	320%
GSHP	1500 - 2500	1040 - 2080	284%	360%
Biomass boilers	710 - 1190	300 - 800	74%	75%

Sources: Based on a review of a range of sources including Sweett for DECC (2013), Frontier Economics and Element Energy (2013) *Pathways to a high penetration of heat pumps*, Ofgem Scheme data, and stakeholder consultation.
Notes: Non-domestic biomass data is based on 'medium-sized biomass of average size of 550kW.

b) Residential energy efficiency

Building fabric energy efficiency

Energy efficiency plays an important role in delivering carbon budgets. There is a large potential for carbon savings from improving the thermal performance of homes, as well as the efficiency of lighting and appliances.

Improvements in residential energy efficiency can also deliver a range of benefits beyond the reduction in carbon emissions. This includes greater energy affordability, particularly for the fuel poor, and the associated health benefits from living in better insulated homes. These wider benefits should be factored in when considering the deployment of measures that are not cost-effective solely from a carbon perspective (e.g. solid wall insulation).

Over recent years, there has been good progress in installing insulation measures such as loft and cavity wall insulation. In our scenarios, we assume that the cost-effective potential for these measures will have largely been realised by the early 2020s, though there may be some additional potential (Box 3.9).

Box 3.9: New research on cavity wall insulation potential

DECC has commissioned a project to assess whether there could be additional cost-effective abatement from cavity wall and loft insulation.[39] This follows indications that some cavity wall homes may not have been built to the required Buildings Regulations with regards to thermal efficiency. Furthermore, there have been suggestions that the number of standard lofts and cavity walls left to fill may actually be higher than current estimates:

- **Cavity walls built between 1985 and 2001:** There is evidence that some cavity wall homes built during this period may not have achieved the required u-value as set out in the relevant Building Regulations of the time (i.e. no more than 0.6 W/m^2K in 1984, and 0.45 W/m^2K by 1990). Retrofitting the cavities that are empty or partially filled may offer good potential for energy savings. The work will involve measuring the thermal performance of a sample of homes representative of the stock built between 1985 and 2001. The consultants will then consider the work needed to reduce the heat loss through the walls, taking account of the costs and benefits.
- **Non-standard lofts and cavity walls:** Some properties previously labelled as non-standard, may in fact be easier to treat with insulation. This issue covers both lofts and cavity walls. The project will review the number of non-standard cavity walls and lofts, and the energy savings and costs of filling them.

As the project requires winter weather for measurements to be undertaken, it is not expected to complete until March 2016. We will consider the conclusions as part of the 2016 progress report.

For the fifth carbon budget period, the main technical potential is estimated to come from solid wall insulation:

- Out of the UK's housing stock of 27 million, over seven million are of solid wall construction, of which the vast majority have no wall insulation.
- There is a technical potential of 4.8 $MtCO_2$ from insulating these walls, although the range of cost-effectiveness estimates (from -£141/tCO_2 to £1,050/tCO_2) varies considerably depending on size of home, heating fuel type and whether the insulation is installed externally or internally. In general, large- and medium-sized electrically heated homes are the most cost-effective to insulate, while gas-fuelled homes of any size only become cost-effective beyond the fifth carbon budget period.

We have previously identified major barriers to solid wall insulation uptake. Since our advice for the fourth carbon budget in 2010, the emergence of new evidence on energy use in homes and the energy performance of solid wall homes have combined to reduce our assessment of the savings potential of this measure (Box 3.10). These updated estimates on energy savings used by DECC and others, together with new estimates on installation costs, have important implications for cost-effectiveness:

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[39] *'Research into performance of, and measures to improve the performance of, UK dwellings with Cavity Walls'* – on-going project for DECC.

- The cost of insulation is high, especially for one-off installation (e.g. £8,000 to £9,600 to externally insulate a three-bedroom house).
- Lower costs can be achieved however, if the measure is taken forward in conjunction with general home renovation works or as part of an area-based scheme. For example, scaffolding already in place for other works (e.g. a loft conversion) will reduce the fixed costs for external solid wall insulation, while average costs can decline to around £7,000 per house when neighbouring homes are being treated at the same time.
- Innovative solutions to reduce labour costs could also improve the cost-effectiveness of solid wall insulation. This could include the pre-fabrication and assembly of the materials off-site, which would reduce the time taken to install the insulation.
- Additional barriers to increased uptake of solid wall insulation such as long-term inconsistency of Government policy and general lack of awareness among householders were identified by the Chief Construction Adviser as part of his recent report[40] on how to unlock demand in England (Box 3.11).

Beyond 2030, refurbishment opportunities and the possible development of cheaper methods to insulate could allow for a substantive proportion of the solid wall housing stock to be insulated.

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[40] Sir Peter Hansford, Chief Construction Advisor (2015) *'Solid wall insulation – a report to the Green Construction Board and Government'.*

Box 3.10: New evidence on solid wall insulation

Energy use and performance

The National Energy Efficiency Data framework (NEED) was established by DECC to improve the understanding of energy use and energy efficiency in the residential sector. It found that energy use in homes based on actual meter point data and the level of savings from installing energy efficiency measures differed to that predicted by the theoretical BRE Domestic Energy Model (BREDEM) using SAP. Evidence from NEED reduced estimated energy savings by 49%. Some of this difference is attributed to the fact that uninsulated solid walls are more thermally efficient than previously thought.

An ongoing project launched by DECC and BRE in 2013 is looking to improve our understanding of heat losses from solid wall properties. The latest evidence suggest uninsulated solid wall homes have a lower mean U-value of 1.3 W/m^{2}K, compared to the modelled U-value of 2 W/m^{2}K. However, there is a wide distribution of U-values across the stock, both within properties built with the same material (e.g. bricks) and across properties built using different materials. For example, the mean U-value for brick walls is lower at 1.29 W/m^{2}K compared to 1.34 W/m^{2}K for stone wall properties. This compares to current building regulations, which requires a U-value of 0.3 W/m^{2}K post-insulation.

New cost data

Our previous cost-effectiveness assessment in the *Fourth Carbon Budget Review* (2013) used cost data from Purple Research (2009).[41] This gave an average one-off cost of over £13,000 based on installing external insulation to a three-bedroom semi-detached house. We have subsequently revised these estimates, following consultation with industry and local authorities. Delivery through area-based schemes, with economies of scale in scaffolding and marketing, can deliver cost reductions. To cover a range of one-off and area-based installation costs, we have therefore assumed a cost range of £8,000-9,600. Due to the absence of evidence on cost data for internal solid wall insulation given low uptake to date, we use DECC's estimate of £4,900 for the central cost.[42] DECC estimates hidden costs for such installation could be as high as £16,000 per property.

It is important to consider other benefits of solid wall insulation beyond carbon reductions (e.g. potential for fuel poverty alleviation and comfort).

Box 3.11: Summary of the Solid Wall Insulation review by the Chief Construction Advisor

The Government's Chief Construction Adviser, Peter Hansford was commissioned by the Green Construction Board to undertake an independent review of solid wall insulation (SWI) in order to consider *'what more might be done to unlock demand for SWI, improve its affordability and increase its attractiveness as a solution.'* The main recommendations of the review, which was published in November 2015, included:

- Government to consider the appropriateness and effectiveness of its policies in relation to SWI. The review found a strong requirement for consistent and long-term Government policy. To date, the stop-start nature of policy was found to have resulted in confusion and misunderstanding, with industry reluctant to invest in manufacturing capacity and developing skills.
- The need to have longer-term availability of funding or policy drivers to incentivise take-up across all tenure types. Examples given included stamp duty and VAT benefits for owner occupiers, and allowing rent adjustment based on energy performance for social landlords.

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[41] Energy Saving Trust, Energy Efficiency Partnership for Homes (2009) *'Purple Market Research (2009) Solid Wall Insulation Supply Chain Review',*

[42] DECC (2012) '*Impact Assessment for the Green Deal and Energy Company Obligation'* (2012) - uplifted to 2014 prices

Box 3.11: Summary of the Solid Wall Insulation review by the Chief Construction Advisor

- To overcome issues relating to poor installation/workmanship, a range of options were put forward, which included establishing a clear minimum quality standard for SWI assessment, improving the standards and incentives for assessment, with possible sanctions for inadequate work, and having a registrar of competent assessors.
- The need to raise general awareness of the benefits of SWI among householders and landlords, which could be delivered through a campaign with clear messaging around the link between using less energy and spending less.
- Government and industry to work together in order to develop, by the end of 2016, an Implementation Plan for SWI. The Plan should look to address the barriers to uptake in the areas identified by the review: technical; knowledge and skills; quality; policy; and consumer demand.

We will consider any response by Government to the recommendations of this review as part of our annual Progress Report next year.

Appliance efficiency

Penetration of the most efficient wet and cold appliances remains low. Cold appliances (e.g. fridges) with an energy rating of A++ or higher account for only 1% of the total stock, while wet appliances (e.g. dishwashers) with a rating of A+ or better make up 14% of the stock. As such, there remains a large technical potential for further improvements post-2020 as the existing stock of less efficient appliances reach the end of their life.

While LED lamps are the most efficient lights, they only comprise around 1% of the current stock. We expect uptake to accelerate in-line with end of lifetime replacements of halogen lamps and tightening EU energy efficiency standards.

c) New-build homes

Generally it is much cheaper to integrate high efficiency and low-carbon heating sources to new homes than to retrofit them to existing homes. However, existing regulations in the UK do not require this for the large number of new homes expected to be built between now and 2035.

The energy efficiency requirements for new homes have tightened considerably over recent years. For example, average annual gas demand in a three-bedroom new home in England built to current building regulations (Part L 2013) is around 5,500 KWh, compared to 19,000 KWh in a Victorian solid wall house. Currently, homes built to high energy efficiency standards make up a relatively small part of the building stock but this will increase. It is also possible that energy efficiency requirements will be tightened further over time:

- By 2035, we estimate that around five million new homes will be built, based on Government household projections and ONS population projections.
- From 2021, these homes will meet 'Nearly Zero Energy' requirements under the EU Energy Performance in Buildings Directive. This may require further changes to the building regulations.

We assume that by 2030, around a quarter of new-build homes will have a low-carbon heat source (mainly heat pumps).

d) Non-residential buildings energy efficiency

We have updated our previous Fourth Carbon Budget review analysis based on the latest energy demand projections and new estimates of energy savings from Products Policy.

Our evidence on energy efficiency potential in public and commercial buildings builds on the non-domestic MAC curve presented in our 2008 report, *Building a Low-Carbon Economy*:

- Savings in our 2008 report are mainly from energy management measures (e.g. heating controls) with some boiler efficiency, insulation and glazing measures.
- Products Policy electricity savings include more efficient lighting, pumps and motors.
- Projected impacts from DECC also factor in savings from Mechanical Ventilation Heat Recovery (MVHR). MVHR systems extract air from inside the building and replace it with fresh air from outside. The warm, extracted air is passed through a heat exchanger to recover the heat. The fresh air is also passed through a different section of the heat exchanger, where it is pre-warmed without coming into contact with the outgoing air.

As noted in our previous reports, the evidence base for abatement potential in the non-residential sector needs to be strengthened. Some work on this is underway (BEES project).[43]

e) Opportunities for the devolved administrations (DAs)

There are significant opportunities for the DAs to deliver building sector abatement, both in terms of heat and energy efficiency. The opportunities will reflect amongst other things, the different characteristics of the respective building stock, heating fuel type and the higher incidence of households living in fuel poverty compared to the UK average. With energy efficiency a partly devolved matter, the DAs will need to ensure that policies are in place to deliver savings. A more detailed account is given in chapter 5 of the Advice Report.

3. Existing ambition and projected emissions without further policy

a) Existing ambition

Current Government ambition is set out in the annual DECC Updated Energy and Emissions Projections. DECC assume that direct emissions in the buildings sector could reach 73 MtCO2 by 2035 if current policies deliver, compared to 103 $MtCO_2$ in the absence of low-carbon policies.[44]

We previously identified that some of these policy savings are at risk due to:

- **Design and delivery problems:** this includes ECO, EU Products Policy and the CRC Energy Efficiency Scheme. Government is also currently considering revisions to the non-domestic energy efficiency policy framework, including the CRC.
- **Lack of funding:** the RHI post-April 2016 is currently unfunded, while there is no clarity about funding the replacement for ECO once it ends in 2017.

The latest ambition reflects the fact that the Green Deal and Zero Carbon Homes have been abandoned and as yet, no replacements have been put in place.

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[43] CCC (2013) *Fourth Carbon Budget Review*. Available online at: https://www.theccc.org.uk/publication/fourth-carbon-budget-review/

[44] DECC interim projections (October 2015)

b) Projected emissions

Our starting point for our scenarios for non-domestic buildings is DECC's 'Baseline Policies' scenario in the interim emissions projections (October 2015).

For homes, we use emissions and energy projections based on detailed modelling of the building stock (Box 3.12). This highlights the potential from boiler efficiency in the existing stock, if the new boilers are correctly run in condensing mode.

To 2020, our abatement scenarios are based on a bottom-up assessment of the uptake of cost-effective measures, rather than the impact of specific policy. However, we do factor in some policy savings:

- We include some savings from EU Products Policy regulations in non-domestic buildings, where this is additional to the efficiency measures included in our scenario (Section 2c).
- We align to projected uptake under the domestic RHI to 2020, based on recent Government figures. In the case of the non-domestic RHI, we factor in lower uptake of biomass to 2020 based on considerations around best use of bioenergy (Section 2a).
- We include savings from measures delivered since 2008 under the various domestic energy efficiency schemes (e.g. CERT and ECO).

In general, our scenarios align with the Government's assessment of what can be realistically delivered through policy. The main exceptions to this relate to domestic energy efficiency and heat networks:

- There is significant potential for low-cost energy efficiency improvements in homes, which is no longer covered by policy to 2020 following the ending of the Green Deal.
- We factor in 10 TWh of uptake of heat networks to 2020. Policy support exists at a national level (2013 DECC Heat Strategy measures, including the work of the Heat Networks Delivery Unit) and at a regional and local level (Scottish Government 2020 district heating target and London Plan target for 25% of energy from Decentralised Energy by 2025). There are no DECC estimates on the impact of this policy support, but we include abatement potential on the strength of the initiatives underway.

Projected emissions to 2035 are also influenced by key uncertainties such as house-building rates, boiler efficiency and internal temperatures.

Box 3.12: Domestic sector baseline emission projections

Our scenarios make use of new estimates of residential emissions to 2050 using the National Household Model:

- We model future emissions in the existing stock based on the National Household Model. In the baseline scenario, we assume that consumers replace their heating technology on a like-for-like basis, so for example, an old gas boiler is replaced with a new model. This means we model the turnover of the boiler stock and the replacement of inefficient gas boilers with new condensing boilers (required by the 2005 boiler regulations).
- We incorporate estimates of energy and emissions from new-build using household projections based on latest DCLG household projections to 2035 and ONS population projections to 2050.
- We assume that demand for water heating and cooking grows in line with population (at a more rapid rate than space heating, which is a function of the building stock).

The DECC baseline projects future energy demand and emissions based on a set of statistical relationships and macro-economic projections such as GDP, population and households. As a result, it can be difficult to compare these 'top-down' projections with the 'bottom-up' assessment based on modelling the building stock.

Projected emissions are uncertain and subject to revision over time. Variation in projections stems from differences in estimated gas demand from new homes, along with estimates of comfort-taking / income effects and boiler efficiency improvements in existing properties.

- **Boiler efficiency.** Efficient condensing boilers currently made up around 44% of the stock in 2012, with a fleet wide efficiency of 79%, compared to design efficiencies of around 95% for new condensing boilers. Closing this gap requires high installation standards and for boilers to run in condensing mode. It is likely that this is not currently being achieved across the stock, based on conversations with installers.
- **Comfort-taking and income effects**. We do not factor in any increase in demand for heating from rising incomes. Whilst internal temperatures increased between 1992 and 2005, they have remained stable since. We include a level of comfort-taking of 15% for homes which install insulation, in line with our previous fourth carbon budget review advice.

It is likely that further government intervention will be needed to realise savings from boiler efficiency.

Notes: Energy demand from new build properties is derived by assuming a mix of 70% houses and 30% flats, based on a 20 year average trend. We assume an average heating demand of 7.5 MWh/yr for new houses, and 5.5 MWh/yr for flats, based on our previous fourth carbon budget review analysis.

4. Abatement scenarios

Our broad approach to building scenarios is out in Chapter 1.

We set out the scenarios first for homes, then for public and commercial buildings, before bringing the two together.

a) Residential buildings

We start by setting out a central scenario along with a number of variants which achieve the same level of abatement over the budget period. We then examine the range for 2030 given by our Barriers and Max scenarios, before finally considering the implied rate of change across homes to 2030 and 2050.

Central scenario

Just under half of the abatement potential to 2030 is from the rollout of low-cost energy-efficiency measures and solid wall insulation (Table 3.1). The rest is from replacing high-carbon heating technologies with low-carbon technology such as heat pumps.

Table 3.1: Residential sector Central scenario to 2030

Measure	**Cumulative uptake from 2008**	**Direct abatement ($MtCO_2$)**	**Electricity savings (TWh)**
Retrofit heat pumps	1.2 m homes *	2	1
Heat pumps, new-build	1.1 m homes	1.5	-2.5
Heat networks	14 TWh / 1.5 m homes*	2	-1
Biomass boilers	0.3 m homes	1	3.5
Solid wall insulation	2 m homes	1	1.5
Cavity wall and loft insulation top-up	6 + 9 m homes	3	1
Other fabric measures	-	0.5	0.0
Lighting and appliances	-	-3	25.5
Heating controls	-	0.5	0
Hot water efficiency measures	-	1.5	0.5
Behavioural measures	-	1.5	0.5
Glazing	-	0.5	0.5
Total abatement		**13**	
Residual emissions by 2030		**60**	

Notes: Heat pump and network figures are given as additional from 2014. The abatement also includes 0.1 $MtCO_2$ from the electrification of cooking in homes which convert to heat pumps and heat networks. Abatement and electricity savings are rounded. There are 0.4 $MtCO_2e$ additional emissions from methane and N_2O in 2030.

Heat pumps in the central scenario

In our assessment for the *Fourth Carbon Budget Review* in 2013, we assumed take up of four million heat pumps in homes by 2030. That aimed to maintain the option of a very high rollout of heat pumps across the housing stock in 2050 (of around 31 million).

Our updated assessment revises this down to 2.3 million heat pumps in homes by 2030, which is the minimum that could keep deep decarbonisation of heat in buildings in play for 2050.

We have identified cost-effective potential for 1.1 million heat pumps retrofitted in homes to 2030. We supplement this with an additional 1.2 million heat pumps to 2030 from new-build properties, out of a projected 4 million new properties built to 2030.[45]

We developed scenarios for uptake of heat pumps through the 2020s in homes not connected to heat networks, reaching 100% of new-build properties by 2030 (Box 3.13). Whilst this is a relatively expensive way to reduce emissions through the 2020s (£130/tCO_2 in 2030), it would prepare for 2050 by developing the supply-chain and raising awareness and consumer confidence in the technology:[46]

- It means that heat pumps can be designed in the property, rather than retrofitted, improving overall system efficiency and reducing costs.
- Additional standards for the construction industry are likely to be easier to implement than a performance standard on consumers.

Whilst we have focused on new-build, an alternative approach could aim for higher uptake in the four million domestic properties which are off the gas grid. The advantages of this would be greater opportunities for installer learning on retrofit and higher cost-effectiveness (due to displacing higher cost fuels, as the alternative for new-build is considered to be a gas boiler). The disadvantages would be to miss the opportunity to optimise installations in new-build properties, and a comparative difficulty in regulating boiler replacements.

In total, this implies 2.3 million heat pumps in homes by 2030, factoring in a current stock of around 100,000.

Our previous analysis considered a critical path for heat pumps,[47] defined as the minimum level of uptake in each given year to 2050 to keep in play a high heat pumps rollout. It is based on the natural replacement rate for boilers of 15 years and assumes an annual growth constraint on the supply-chain of skilled heat pump installers in early years (set at 30% through the 2020s). It suggested a need to install around 2.5 million heat pumps in homes by 2030 to keep in play the high heat pumps scenario.[48]

Our approach to 2050 for heat pumps is set out in Box 3.14.

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[45] Projections developed by Element Energy based on DCLG household statistics Table 401.

[46] See discussion of the impact of consumer risk premium in CCC (2014) *Progress Report*.

[47] CCC (2010) *Fourth Carbon Budget Review* and supporting evidence in Frontier Economics and Element Energy (2013)*Pathways to a high penetration of heating*, available online at: https://www.theccc.org.uk/publication/fourth-carbon-budget-review/

[48] Another way to approach it is work back from 100% sales in 2035, which implies between 1.7 and 3.7 million cumulative installations to 2030, assuming supply-chain growth of 20-30%.

Box 3.13: Costs and approach for new-build homes

Cost

On our central assumptions, heat pumps would become cost-effective from 2028 in the case of flats, and around 2031 in the case of new houses. This is of course uncertain, given uncertainties not least around the future for gas and electricity prices.

We assume the same capital costs as in retrofit. These are a high end estimate as we do not include the avoided cost of connecting to the gas grid. Similarly, there is some evidence that heat pumps can be installed at lower cost by large home builders when delivering at scale. Hassle costs and barriers to installation are much lower for a new build installation compared to a retrofit.

We assume a slightly higher performance of 0.25 compared to retrofit homes, based on the benefits of designing the heat pumps alongside the heating system (including larger radiators or underfloor heating).

Approach

In developing the scenarios, our starting point is projections of housebuilding, based on DCLG household projections, ONS population projections and historic build-rates.

In the central scenario, we assume heat pumps are 50% of sales in 2025, rising to 100% of remaining sales in 2030.

This approach implies around 100,000 heat pumps installed in 2025, with 1.2 million cumulative installs by 2030. Whilst delivering at this volume in 2025 would be challenging, there would be relatively fewer barriers to individual installations in retrofit, which is the main bottleneck in the market currently.

The Max scenario includes 50% sales from 2020, rising to 100% of sales by 2030.

In the Barriers scenario, we assume 100% sales from 2030, with no uptake in the 2020s. New-build properties with gas boilers do not switch to heat pumps when renewing their heating system after 2030, in contrast to the Central and Max scenarios.

Box 3.14: Keeping open the option of reducing heat emissions to very low levels in 2050

Beyond 2030, further fuel switching away from gas boilers and towards low-carbon options will be required. Meeting the overall 2050 target will be expensive, if not impossible, without a near complete decarbonisation of heat.

Costs of decarbonisation options beyond 2030 are highly uncertain. Latest evidence suggests costs of low-carbon heat that are above DECC's central carbon values in many applications, but within the range set by their high values. That could mean that low-carbon heat should have a limited role even in 2050, but this evidence is likely to change as deployment experience moves on and as challenges in other sectors also become clearer.

It is important therefore that our central scenario to 2030 includes sufficient rollout of heat pumps and heat networks to ensure that the option to rollout these options across the building stock by 2050 is retained. This is achieved by our central scenario, but would be called into question by any lower deployment to 2030.

Heat networks in the central scenario

Our heat networks assessment is based on the cost-effective potential over the fifth carbon budget period.

We also consider what level of rollout would be required to 2030, in order to keep in play the higher range of ambition to 2050:

- We commissioned Element Energy to look at the range of build rates for schemes based on international evidence. This suggested that the maximum feasible annual growth rate would be around 20% per year, based on the international benchmarking of the early 'emerging' scheme phase.[49]
- This would imply a minimum contribution from heat networks of around 33 TWh overall in 2030 in order to keep in play the more ambitious levels of heat network deployment for 2050.

Our central heat network trajectory achieves this level in 2030, but our Barriers scenario does not, implying higher levels of effort in other areas.

Solid wall insulation in the central scenario

In our fourth carbon budget advice in 2010, we assumed that it was cost-effective to insulate 3.5 million solid walls by 2030. Based on new evidence on costs and energy savings (Section 2), we have revised this potential to two million solid wall properties in our central scenario, which would deliver direct abatement savings of 1 $MtCO_2$ by 2030. Uptake comprises:

- Around one million homes that are cost-effective assuming DECC's central carbon values (Chapter 1). Uptake is focused on properties not connected to the gas grid. We estimate that this could overlap with over 200,000 UK fuel poor households that live in uninsulated solid wall properties and use electricity, oil or coal to heat their homes. These households tend to experience the most acute levels of fuel poverty (for example, in England the average fuel poverty gap is £790 for this group compared to the fuel poor average of £370).
- A further one million homes that are not cost-effective to insulate are largely small or medium-sized, some of which are on the gas grid. DECC's latest fuel poverty statistics indicates that as many as 920,000 fuel poor in England (equivalent to 40% of the fuel poor) live in properties of this type - uninsulated solid wall properties with mains gas. Insulating these homes is not cost-effective solely on central carbon values, but still help to meet the fuel poverty targets that have been set in England and the devolved administrations (Box 3.15). It will also help prepare for heat-pump roll-out, which requires properly insulated homes to operate efficiently.

Other energy efficiency measures in the central scenario

- **Cavity wall and loft insulation**: uptake is focused on measures that offer good carbon savings potential, and are low-cost. We assume that almost all of the potential for cavity wall and loft top-up insulation is delivered by 2030, equivalent to around six million and nine million respectively, giving a combined direct abatement of 3 $MtCO_2$ by 2030.
- **Other measures**: our central scenario also includes a range of other measures that reduce the use of space heating, hot water use and electricity (Box 3.16).

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[49] Element Energy, Frontier Economics and Imperial College London (2015), *Research on district heating and local approaches to heat decarbonisation*, Main report.

Combined, the uptake of these energy efficiency measures delivers 6 $MtCO_2$ of direct abatement by 2030.

Box 3.15: Fuel poverty targets and costs to achieve them

In 2014, a statutory instrument was adopted in England which sets out a new fuel poverty objective of ensuring that as many (as is reasonably practicable) of the homes of people living in fuel poverty have an energy performance certificate (EPC) rating of Band C, by 31st December 2030. To keep the target on track, interim milestones have also been set for an E rating by 2020 and a D rating by 2025.

Analysis conducted by CSE for the Committee in 2014, which fed into our response to DECC's consultation on a new fuel poverty strategy, indicated that effective targeting of energy efficiency and low-cost heat measures to the fuel poor could significantly reduce fuel poverty levels in England, from around 11% in 2013 to below 5% by 2030. Furthermore, this could be achieved while also meeting the fourth carbon budget.

Our analysis estimated that meeting the Government's EPC target of C by 2030 would require annual funding of at least £1.2 billion a year. Current funding commitments under the ECO (nominally around £0.7 billion annually for England) fall short of this, and are only partially focused on fuel poverty. We therefore recommended more funding would need to be made available in order to achieve the Government's target. We note that this is driven primarily by social reasons, rather than climate policy.

The devolved administrations have very ambitious targets for the elimination of fuel poverty though (Chapter 4 of the Advice Report) these will be challenging to meet. However, the devolved governments have more extensive fuel poverty programmes than England.

Box 3.16: Summary of carbon savings from energy efficiency measures (Central scenario)

In addition to the insulation of two million solid wall homes, the central scenario has a range of other energy efficiency measures that contribute to direct abatement savings by 2030. This includes some measures that also contribute to meeting Government fuel poverty targets:

- **Cavity wall and loft insulation:** we assume that almost all of the potential for low-cost cavity wall and loft top-up insulation is delivered in the 2020s. For cavity walls, this includes four million easy-to-treat walls and two million hard-to-treat walls where the cavity can be treated cost-effectively. Cavity walls that would require more expensive solid wall treatment are excluded.
- **Other fabric measures**: measures are focused on reducing heat loss from flooring, doors and windows through the installation of floor insulation, insulated doors and draught strips.
- **Glazing**: this covers two types of glazing improvements – switching from single to double glazing, where energy savings would be higher, and from pre-2002 double to new double glazing.
- **Heating controls**: these comprise three controls: thermostatic radiator valves, timers and thermostats. The largest savings potential comes from installing TRVs.
- **Hot water efficiency measures**: insulating hot water tanks, the installation of hot water cylinder thermostats, and the use of reduced flow showers all save hot water use,
- **Behavioural change**: turning down the thermostat by one degree centigrade and switching lights off are low-cost changes households can make.

Box 3.16: Summary of carbon savings from energy efficiency measures (Central scenario)

- **Lighting:** Savings from switching from incandescent lamps to compact fluorescents and from halogens to LEDs are focused on indirect emissions. There is however, a corresponding increase in direct emissions of 1 $MtCO_2$ by 2030 due to the heat replacement effect. This 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.
- **Appliances:** Driven by end of lifetime replacements and tightening EU energy efficiency standards, we expect a high uptake of the most efficient cold and wet energy efficient appliances (e.g. fridges and dishwashers). This will provide significant electricity saving but would increase direct emissions by 0.8 $MtCO_2$ by 2030.

Annual direct emissions savings from all the residential energy efficiency measures considered for this report could save 6 $MtCO_2$ by 2030.

In addition, we estimate that take-up of energy efficiency measures can reduce electricity use by around 30 TWh by 2030. Electricity demand reduction is driven by the large uptake of the most efficient white appliances, electric ovens and televisions which deliver over 60% of the savings by 2030. A further 6.8 TWh is due to householders switching to more efficient lighting.

Source: Supporting research is set out in Element Energy and Energy Savings Trust (2013) *Review of potential for carbon savings from residential energy efficiency*, and discussed in CCC (2013) *Fourth Carbon Budget* review, both available online at https://www.theccc.org.uk/publication/fourth-carbon-budget-review/

Alternative central scenarios

A range of alternative scenarios could deliver the same level of heat abatement across the fifth carbon budget period. Given the absence of any alternative technologies that could be deployed to deliver savings in residential energy efficiency, this scenario for the residential sector is focused on heat measures.

We set out three alternative scenarios. We consider two variants where higher uptake of district heating displaces heat pumps in new-build, and where hybrid heat pumps play a greater role in existing homes on the gas grid in the 2030s.

A third variant considers the case where hydrogen becomes the dominant form of heating by 2050.

District heating and local action

In this scenario, greater progress is made in rolling out heat networks, which displace around 0.5 million heat pumps in new-build properties to 2030, leaving uptake of 1.8 million heat pumps overall.

This could reflect consumer preferences for heat networks, a greater role for local stakeholders or relatively higher barriers affecting heat pump uptake.

This amounts to 1 $MtCO_2$ additional abatement from district heating in 2030, displacing abatement from heat pumps in new-build at £130 t/CO_2.

Hybrid heat pumps

Hybrid heat pumps could play a transitional role for existing homes on the gas grid, by familiarising consumers with heat pump technology whilst retaining the functionality of gas heating, and smoothing electricity demand profiles at a system level. They are particularly suitable for retrofit, as new properties can be designed optimally for the heat pump and avoid the cost of connecting to the gas grid.

In our central scenario, only 330,000 heat pumps are installed in homes on the gas grid by 2032. In this alternative scenario, the same emission savings would be achieved by 440,000 hybrid ASHP-gas boilers, reflecting the comparable cost-effectiveness of hybrid and air-source heat pumps.

It is possible that additional uptake of heat pumps in oil or LPG-heated properties could be displaced by hybrid heat pumps with oil or LPG. We have not included this. Assuming they operate in heat pump mode for 75% of the load, achieving the same level of abatement would similarly require uptake of four such hybrids for every three conventional heat pumps removed from the scenario.

Hydrogen

This scenario looks at converting a large portion of the gas grid to using hydrogen, starting from 2025.

By 2030, around 1.4 million homes on the gas grid have converted to hydrogen boilers, displacing uptake of heat pumps and biomass boilers. A further 0.7 million are served by hydrogen heat networks, along with a mix of other low-carbon heat sources. Heat pumps and biomass are rolled out in homes not connected to the gas grid.

This leaves open the possibility of extensive rollout through the 2030s and 2040s.

Risks – Barriers scenario

This scenario examines the case where barriers to uptake persist in buildings:

- *Heat pumps.* We assume that consumer awareness of the technology improves, but low confidence persists – in part reflecting lower durability of heat pumps.
  - We model a 7.5% discount rate, instead of the social discount rate of 3.5%. Given that heat pumps are capital-intensive, the impact of this is to reduce the valuation of the future fuel and carbon cost savings.
  - We assume that ASHPs last 15 years, rather than assuming a range between 16 and 20.
  - We align with lower RHI uptake projections to 2021.
  - Together, these assumptions reduce uptake of heat pumps in retrofit properties by 2030 to 400,000, showing that the results are highly sensitive to these assumptions.[50] In the case of new-build, we assume no uptake until 2030 (Box 3.13). This leads to a total of 0.7 million heat pumps in 2030 – falling short of the critical path for 2050.

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[50] This is additional to existing heat pumps, roughly around 100,000.

- *Heat networks.* We assume that barriers to uptake persist for heat network development, with perceived levels of risk reflected in higher discount rates of 7.5%. Heat networks continue to compete for customers with incumbent forms of heating, but only half the households in a given area are assumed to connect to the heat network over 15 years, rather than the higher connection rate of 90% in the central scenario. This leads to 9 TWh of heat piped to homes in 2030.
- *Solid wall insulation:* insulation is restricted to cost-effective uptake only. Take-up is halved to around one million homes by 2030 compared to the central scenario, but direct abatement is reduced by more than half due to the large share of electrically heated homes being insulated.
- *Other energy efficiency measures:* solid floor insulation, improved glazing and insulated doors are excluded from this scenario, while the uptake of all other measures remains unchanged from the central scenario.

Scenario abatement is set out in Table 3.2.

Further opportunities – the Max scenario

This scenario looks at what can be achieved if there is a need to go further in buildings decarbonisation to make up for a shortfall in other sectors.

There is considerable potential to go further than included in our central scenario (e.g. there are several million new-build homes and homes off the gas grid that do not have low-carbon heating in our central scenario). We have constructed our Max scenario by using the high DECC carbon values trajectory, which would imply a larger amount of cost-effective abatement:

- *Heat pumps.* The higher carbon values lead to some small additional uptake in retrofit. This combines with more ambitious uptake in new-build, where heat pumps are installed in 50% of new homes from 2020 (Box 3.13), giving an overall total of 3.3 million heat pumps in 2030.
- *Heat networks.* Our high rollout scenario achieves 54 TWh of heat from heat networks in 2030, of which 20 TWh is domestic heat (around two million homes).
- *Solid wall insulation:* uptake is increased beyond the central scenario to 2.75 million.

Scenario abatement is set out in Table 3.2.

Residential buildings – total abatement and rate of change

Our central scenario reduces emissions to 60 $MtCO_2$ in 2030, down from 71 $MtCO_2$ in 2014 on a temperature-adjusted basis. For domestic buildings, this implies a decrease of around 1 $MtCO_2$ per year between 2025 and 2030.

Beyond 2030, a step change in abatement will be required, as major inroads have to be made into the replacement gas boiler market (Figure 3.6).

Table 3.2: Residential sector scenarios to 2030 – direct abatement ($MtCO_2e$)

Measure	**Central**	**Barriers**	**Max**
Heat pumps, retrofit	2	0.5	2.5
Heat pumps, new-build	1.5	0.5	2.5
Heat networks	2	1	3
Biomass boilers	1	0.0	1
Domestic energy efficiency	6	4	7
Total abatement	**13**	**7**	**16**
Implied residual emissions	**60**	**66**	**56**

Notes: There are around 0.4 $MtCO_2e$ additional emissions from methane and N_2O in 2030. Numbers are rounded to the nearest half unit.

b) Public and commercial buildings

Central scenario

Heat networks in the central scenario

Public and commercial buildings serve as key anchor loads for networks, leading to uptake of 27 TWh of heat demand in the central scenario (just over a quarter of total non-domestic heat demand).

Heat pumps in the central scenario

Our scenarios consider the remaining cost-effective potential in buildings not connecting to heat networks. This includes uptake of heat pumps displacing electric and oil heating from 2020, and gas heating from the late 2020s. Where heat pumps are not taken up off-grid, we assume sales of biomass boilers, based on consumer preferences under the non-domestic RHI.

By 2030, all off-gas heating sales are replaced by heat pumps, with gas boilers sales displaced from 2029 in public buildings and 2030 in commercial properties. This amounts to 19 TWh of heat pumps (around a fifth of heating) by 2030.

Energy efficiency

Our scenarios include the efficiency savings from our 2008 report – which we scale according to the change in energy demand projections – together with some additional savings from Product Policy (efficient appliances and lighting).

We assume 10 TWh of gas savings from Mechanical Ventilation Heat Recovery to 2030 (2 $MtCO_2$ abatement), based on a review of DECC Product Policy Savings.

- We include gas savings based on estimates of the portion of the non-domestic stock which is mechanically ventilated, the portion of heat demand which is determined by ventilation losses, and the technical potential to recover heat from mechanical ventilation (currently up to 85-90%).[51]
- In the non-residential sector, a significant part of the building volume is ventilated by balanced units without heat recovery. This means that the ventilation systems are easily retrofitted with MVHR, at a low overall cost. Whilst detailed figures for the UK are not available, across Europe around 40% of the non-domestic building stock was mechanically ventilated in 2012, with only around 7% including some form of heat recovery.[52]

Our central scenario for non-domestic buildings is summarised in Table 3.3.

Table 3.3: Non-residential central scenario to 2030

Measure	**Uptake (TWh)**	**Direct abatement ($MtCO_2$)**	**Electricity savings (TWh)**
Heat pumps	18.5	1	9
Heat networks	27.5	3.5	-1
Biomass boilers	2.5	0.5	2
Energy efficiency	-	5	20.5
Total abatement		**10**	
Implied residual emissions		**11**	

Notes: There are around 0.1 $MtCO_2e$ additional emissions from methane and N_2O in 2030. Numbers are rounded to the nearest half unit.

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[51] European Council for an Energy Efficient Economy (2012) *Draft working document on Ecodesign requirements for ventilation units.* Available online at: http://www.eceee.org/ecodesign/products/domestic_ventilation/Summary%20Document%20Ventilation%20October%202012.pdf

[52] As above.

Alternative central scenarios

A range of alternative scenarios could deliver the same level of heat abatement in non-residential buildings across the fifth carbon budget period.

District heating and local action

This scenario has a similar impact as for homes, with an increase of 1 $MtCO_2$ savings from heat networks displacing building-scale heat. By 2030, an additional 7 TWh of heat from low-carbon heat networks displaces two-thirds of the uptake of heat pumps and biomass boilers in oil- and gas-heated buildings in the Central scenario.

This implies that most low-carbon heat is delivered through networks, with some heat pumps uptake replacing inefficient electric heating.

Hydrogen

In this scenario, the low-pressure gas network is converted to hydrogen from around 2025, with just under 15% of services heat demand met by hydrogen by 2030 (either boilers or in conjunction with heat networks). This roll-out displaces around half the non-residential heat from low-carbon heat networks in 2030 (10 TWh), along with all heat pumps in buildings connected to the gas grid in our central scenario in 2030 (3 TWh).

We assume that hydrogen for heat is rolled out in conjunction with heat networks and a mix of heat pumps and biomass boilers in buildings not connected to the gas grid.

Risks – Barriers scenario

Uptake in this scenario is lower due to an assumed persistence of barriers.

- **Heat pumps.** Negative perception of heat pumps limits the total sales to 50% from 2020 in buildings where heat pumps are cost-effective.[53]
- **Heat networks.** The higher discount rate and assumed lower connection fraction lead to uptake of just 16 TWh in 2030, just over half the uptake in the central scenario.
- **Biomass boilers.** We include only bioenergy taken up under the RHI to the end of 2015/16, assuming no further drivers for biomass boiler uptake in the 2020s.
- **Energy efficiency.** Uptake of low-cost measures is delayed by five years relative to the central scenario.

Abatement in the Barriers scenario is set out in Table 3.4.

Further opportunities – the Max scenario

The Max scenario makes more rapid progress through the 2020s and 2030s, again reflecting use of the DECC High set of carbon values:

- **Heat pumps.** With higher carbon values, heat pumps are cost-effective relative to gas from 2023 in public buildings, and 2024 in commercial buildings. Uptake in off-gas segments follows the same trajectory as in the central scenario.

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[53] The abatement is more than half that of the central scenario, due to the higher fraction of sales of building-scale technologies, which is a result of lower heat network rollout.

- **Heat networks.** With maximum implementation, heat networks supply 34 TWh of heat in 2030, or around a third of demand. This includes a larger share of biomass-heat. The total abatement in 2030 is significantly higher than from heat pumps.
- **Biomass boilers.** As in the central scenario.
- **Energy efficiency.** There is insufficient evidence to support a more ambitious energy efficiency trajectory. Max is in line with the central scenario.

Abatement in the Max scenario is set out in Table 3.4.

Non-residential buildings – total abatement and rate of change

The central scenario has remaining emissions of 11 $MtCO_2$ in 2030, down from 23 $MtCO_2$ in 2014 on a temperature-adjusted basis. Our scenario implies a fall of 0.5 $MtCO_2$ per year on average between 2025 and 2030. There is potential for the reduction to increase after 2030, once low-carbon heating technologies have achieved cost parity and given stock turnover rates.

Table 3.4: Non-residential scenarios to 2030 – direct abatement ($MtCO_2$)

Measure	**Central**	**Barriers**	**Max**
Heat pumps	1	1	2
Heat networks	3.5	2	4.5
Biomass boilers	0.5	0.5	0.5
Energy efficiency	5	5	5
Total abatement	**10**	**8**	**12**
Implied residual emissions	**11**	**13**	**9**

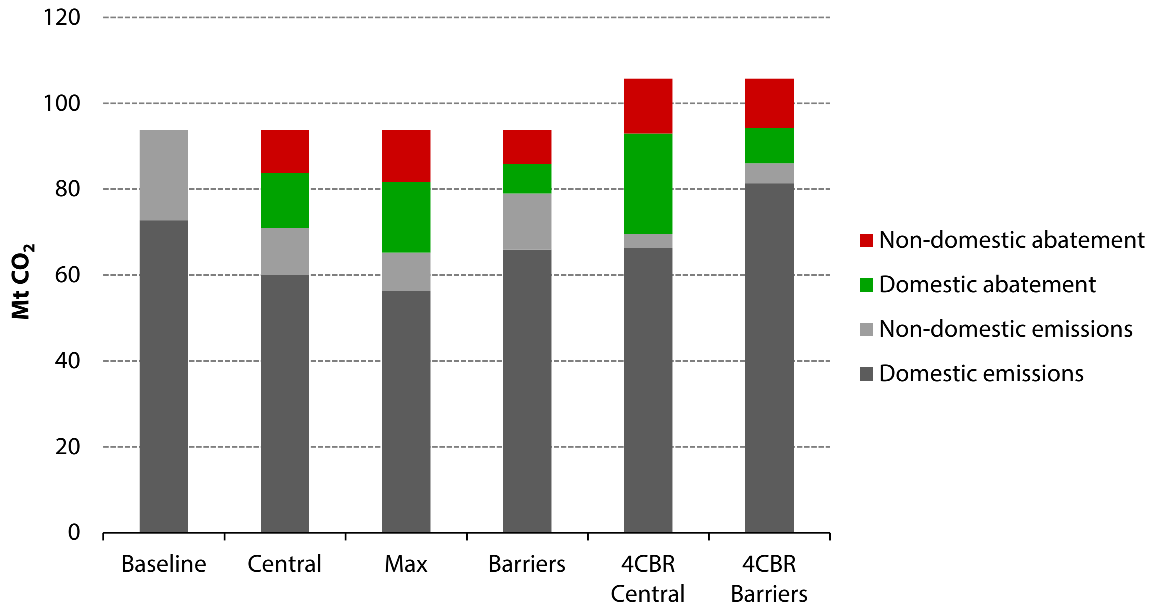
Note: There is around 0.1 $MtCO_2e$ additional emissions from methane and N_2O in 2030.

c) Total abatement potential from buildings

The sum of direct abatement potential from the range of energy efficiency and low-carbon heat measures is 23 $MtCO_2$ in 2030 (Figure 3.4), which compares to 36 $MtCO_2$ in our fourth carbon budget review scenarios. Because baseline emissions are lower, residual emissions are 72 $MtCO_2$ in 2030, compared to 70 $MtCO_2$ in our 2013 advice. This implies a decrease of around 1.4 $MtCO_2e$ (2%) annually between 2020 and 2030.

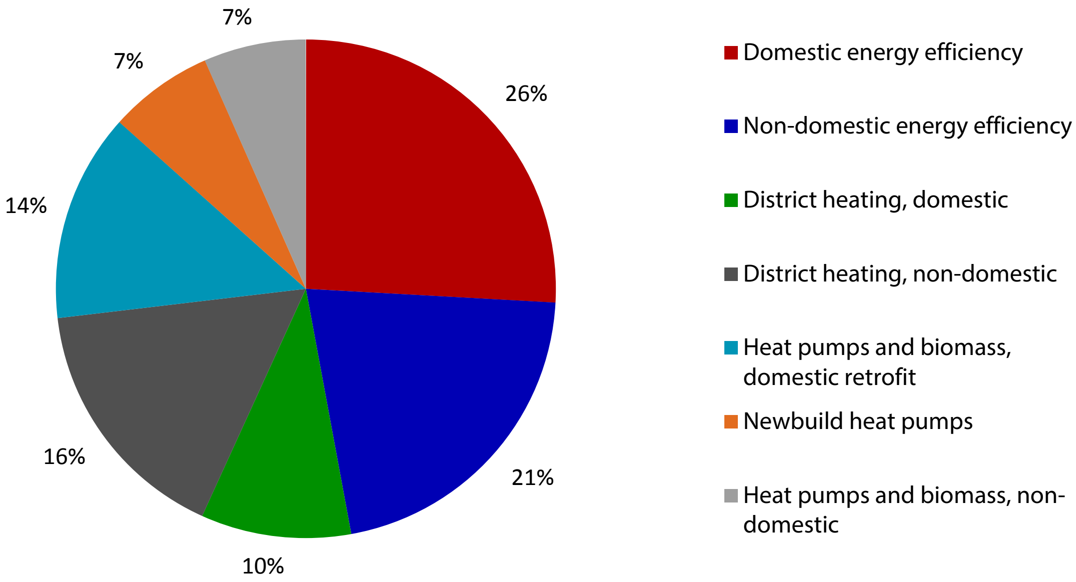
The share of abatement is evenly balanced between domestic and non-domestic energy efficiency, heat pumps and heat networks. It reflects lower cost efficiency measures being taken up earlier, and a strategy of supporting a portfolio of technologies (Figure 3.5). Our alternative hydrogen scenario also highlights the value in developing this option further, so as to be in a position in the 2020s to better assess the viability of deploying hydrogen at scale for heating.

Figure 3.4: Direct abatement in buildings in fifth carbon budget scenarios to 2030, compared to fourth carbon budget review



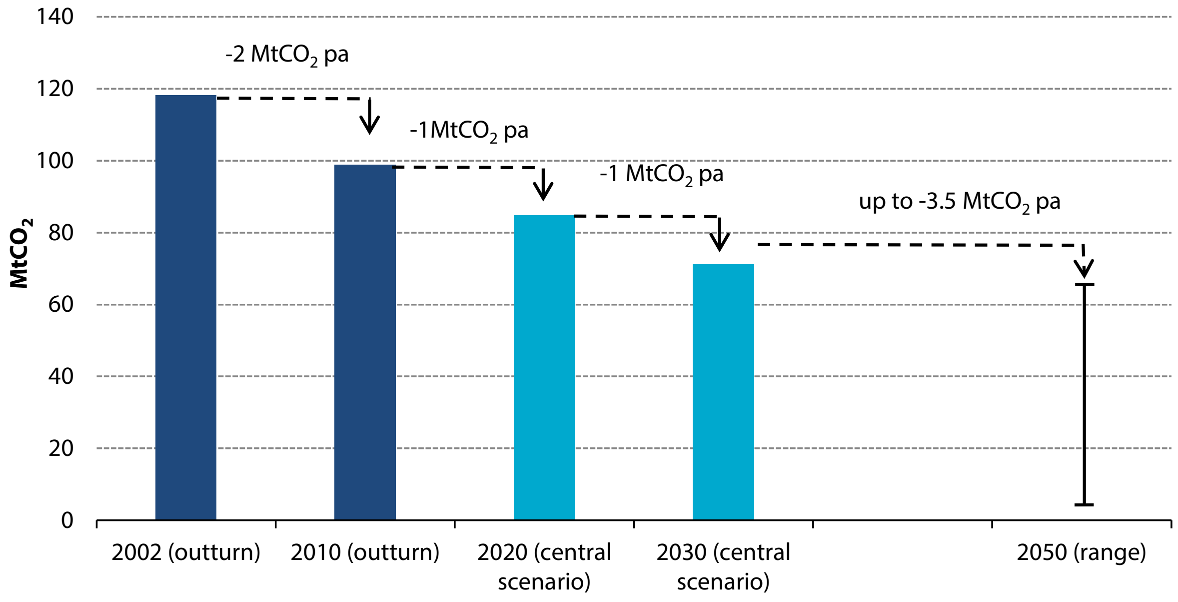
Source: CCC analysis.

Figure 3.5: Total abatement in 2030, central scenario



Source: CCC analysis.

Figure 3.6: Rate of change in direct buildings emissions (2002-2050)



Source: CCC analysis.
Notes: $MtCO_2$ per annum reductions based on average for the period. Outturn data are temperature-adjusted. 2002 is the earliest year that emissions have been calculated on a temperature-adjusted basis.

5. Costs and impacts

We build up our estimate of scenario costs based on abatement costs for individual low-carbon heat and energy efficiency options, and consider a range of sensitivities (Table 3.5). The measures in our Central scenario imply resource cost savings of £0.9 billion in 2030 as many of the energy efficiency measures more than pay for their installation costs in saved fuel costs:

- Low-carbon heat technologies with total emission reductions of 13 $MtCO_2$ (of which 12 $MtCO_2$ are direct emissions) would result in a cost of £0.6 billion, at an average cost of around £34/tCO_2. This includes some more costly measures which are required to keep on track to meeting the 2050 target: specifically 2 $MtCO_2$ abatement from heat pumps in new-build homes, at an average cost of £130/tCO_2.
- For domestic energy efficiency measures, emissions savings of 15.5 $MtCO_2$ (of which direct emissions are 6 $MtCO_2$) would deliver overall cost-savings of £0.6 billion (i.e. a cost saving alongside the carbon saving averaging around £36/tCO_2). This allows for some measures with costs above central carbon values, but with benefits for fuel poverty alleviation and preparation for heat pumps.
- In public and commercial buildings, energy efficiency measures have the potential to reduce total emissions by 11 $MtCO_2$, at a cost saving of £0.9 billion in 2030.

The resource cost savings in 2030 would fall in a low gas price world to around £0.1 billion, and increase in a high gas price world (to around £2.3 billion). In a central gas price world, the range of cost savings depending on capital costs sensitivities is £0.0 billion to £1.8 billion.

Although the measures in our central scenario save costs overall, the measures deployed in the 2020s are relatively more expensive. Taken on their own, buildings measures in the 2020s have a cost. Delaying action until after the 2020s would reduce these costs, but increase emissions. We estimate a saving in net present value terms from delaying action of £30-35 billion over the period 2020-2050. However, the cost of the additional emissions in this scenario valued at the Government's carbon values would be over £40 billion. This could include lock-in to high cost gas boilers through the 2030s and 2040s, along with additional costs for scrapping boilers in the 2040s to meet the 2050 target.[54]

Avoiding delay is therefore the preferable path, with a total net present value of £5-10 billion.

The abatement scenarios can help deliver additional benefits such as energy affordability, lower levels of air pollutants and improved comfort levels in homes.[55] Providing measures are targeted effectively, the insulation measures in our scenario help to achieve carbon budgets and reduce fuel poverty.[56]

Table 3.5: Cost ranges of Central scenario in 2030

Scenario	**Costs (£bn)**
Central	-0.9
Central – high fossil fuel prices	-2.3
Central – low fossil fuel prices	-0.1
Central – high capital costs	0.0
Central – low capital costs	-1.8

Source: CCC analysis.

6. Delivering the scenarios

Our central scenario for the fifth carbon budget period sets out the level of savings in the buildings sector required to help meet the cost-effective path. In the absence of future policy commitment, the market alone will not deliver the significant improvement in energy efficiency

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[54] In our 2013 *Fourth Carbon Budget Review* advice, we calculated costs of boiler scrappage in the mid-2040s to replace it with a heat pump would have an effective cost of between £75-220/tCO_2, depending on the type of building.

[55] Air quality benefits are not costed within our scenarios, but were assessed in 2013 as part of the supporting evidence for the Fourth Carbon Budget Review. See Ricardo-AEA (2013) '*Review of the impacts of carbon budget measures on human health and the environment*' and Imperial College (2013) '*Analysis of the air quality impacts of potential CCC scenarios*', both available online at: https://www.theccc.org.uk/publication/fourth-carbon-budget-review/

[56] CCC (2014) '*Fuel Poverty Strategy Consultation Response*'. Available online at: https://www.theccc.org.uk/publication/letter-fuel-poverty-strategy-consultation-response/

and shift to low-carbon heating systems that is needed, even where there are economic benefits to change and where financial barriers are addressed.

To address these concerns, the options are broadly:

- **Taxation.** There is currently a significant imbalance between how gas and electricity are treated with respect to both carbon pricing and VAT which is part of the reason why gas is so much cheaper than electricity for heating.[57] Longer-term, introducing a carbon price for heat in homes would reduce the cost of low-carbon heat compared to conventional alternatives, and make energy efficiency more cost-effective. The impact on consumers could be offset through reducing other taxes, though the distributional impacts would need careful consideration and compensatory payments/measures for low-income households may be needed. Given the difficulties, other policies may be considered.
- **Incentive-based.** In the absence of a meaningful carbon price on gas and oil heating, continued support is required of nascent low-carbon heat markets in order to be able to deliver at scale through the 2020s and 2030s. A lack of progress under the RHI suggests that more work is needed in addressing barriers to uptake. Some form of incentive is likely to be needed to support heat networks for the same reason, as well as further support for energy efficiency, especially for the fuel poor.
- **Regulations.** These could be tied to heating system replacement (e.g. as proved very successful in boiler replacement) or to sales, lettings and extensions/refurbishments (as for Minimum Standards in the private-rented sector and for non-domestic buildings). In particular, regulation of new-build properties would be relatively straightforward and could help develop supply-chains and improve consumer awareness and confidence. Our scenarios also suggest a potential role for regulation in non-domestic buildings in the 2020s in order to unlock cost-effective uptake.

In order to achieve a significant shift away from incumbent technologies, effective delivery may require a move towards regulation in the long-term, combined with an incentive/subsidy regime to ensure that required changes are not seen as punitive.[58] Such an approach could go beyond the emissions objectives of current policy (e.g. RHI, ECO) at a lower cost to the taxpayer and to bill payers, while improving the quality of the housing stock for private renters and home-owners.

The scenarios have implications for the next few years. The immediate priorities were set out in our 2015 Progress Report to Parliament:

- **Low-carbon heat:** Develop an action plan to address the significant shortfall in low-carbon heat. Short-term, this should commit to extend the Renewable Heat Incentive to 2020, or until a suitable replacement is found; longer-term it should link support for low-carbon heat with energy efficiency, support for heat networks and wider decisions about infrastructure for heat.
- **Energy efficiency:** Set out the future of the Energy Company Obligation beyond 2017 ensuring it delivers energy efficiency while also meeting fuel poverty targets.

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[57] The VAT discount on domestic gas consumption can be seen as a form of implicit subsidy for gas. For further discussion, see Advani, A., Bassi, S, Bowen, A., Fankhauser, S., Johnson, P., Leicester, A., Stoye, G. (2013) *Energy use policies and carbon pricing in the UK*; Vivid Economics (2012) *Carbon taxation and fiscal policy consolidation in Europe*.

[58] Our scenarios assume for example that by 2030, low-carbon technologies would be installed in 100% of new-build properties, which suggests some form of regulation in place to act as a backstop for the market.

- **Commercial sector**: Simplify and rationalise existing policies for energy efficiency improvement, with a view to strengthening incentives, by the end of 2016.
- **Zero Carbon Homes:** We recommended implementation of zero-carbon standards without further weakening, with incentives in place to encourage low-carbon heat sources. In the absence of the zero-carbon home standard, there is a new policy gap on new-build properties, and no mechanism for encouraging low-carbon heat in new properties.

Government is currently reviewing the policy framework for commercial and public buildings, including the CRC and CCL, as well as reporting requirements under ESOS. Further work is also underway on additional policy on both low-carbon heat for retrofit and energy efficiency, in order to meet the fourth carbon budget. We will continue to monitor progress in these areas in our annual Progress Reports to Parliament.

To 2030, our scenarios underline the importance of government intervention in addressing barriers to uptake – both financial and non-financial:

- **Social vs private cost-effectiveness.** Our analysis prices in the carbon externality and uses the social discount rate of 3.5% (real) to assess measures over the lifespan of the measure. However, households and businesses will in general use higher discount rates and shorter investment horizons, implying a role for Government intervention (for example in providing information and low-cost financing options).
- **Addressing barriers to uptake.** Our Barriers scenario assesses the impact of not making significant inroads into addressing consumer barriers, or putting in place a supportive set of policies for heat networks. This would put progress off-track for meeting the 2050 target, implying additional costs beyond 2030 and would be inconsistent with the legal requirements of the Climate Change Act.

The scenarios also have a number of technology-specific implications:

- **Boiler efficiency.** The impact of the 2005 Boiler regulations which require that boilers are replaced with condensing boilers is factored in to our scenarios. However, for these emission savings to be realised, the boilers need to be working properly in condensing mode - that is around (or below) 55°C. Further government intervention may be required to achieve this.
- **Achieving scale in deployment of heat pumps.** Low uptake of heat pumps under the RHI to date suggests that new approaches may be required to unlock cost-effective abatement from replacing high-carbon fuels over the next decade.
- **Heat networks.** Uptake in the Central and Max scenarios is reliant on a significant proportion of buildings connecting within a local area. This suggests a more proactive approach to planning may be needed, as part of a broader policy package.
- **Hydrogen.** Hydrogen offers a potential route for decarbonising whilst making use of the existing gas grid infrastructure. However, the detailed costs, feasibility and implications are not currently well understood. Further work on costs and potential over the next few years would help better inform decision-making in the 2020s, including the implications for investment in the gas grid.

Given the importance of decarbonising heating for meeting carbon budgets, we will publish a more detailed assessment in 2016 on low-carbon heating to inform our annual progress monitoring.

Chapter 4: Industry

Introduction and key messages

In this chapter, we examine scenarios to 2030 for the abatement of emissions from industry, which accounts for about a quarter of UK greenhouse gas (GHG) emissions. Industry includes manufacturing, construction, water and waste management, refining of petroleum products and other energy supply (extraction and production of oil, gas and solid fuels). Indirectly, industry also accounts for a third of power sector emissions.

Much of UK industry competes in global markets. The actions required to reduce emissions have to take into account the challenges industry faces in those markets. The Committee has heard and received extensive evidence about the competitive environment faced by industry and has reflected this in its recommendations.

At the same time, actions to address emissions around the world also create opportunities for UK industry: to produce existing products differently to meet the demands of a low-carbon world and to produce new products to fill new demand e.g. low-temperature detergents, low-resistance tyres and lightweight materials in aircraft and cars.

Industrial emissions can be reduced through energy efficiency, bioenergy, electrification and industrial carbon capture and storage (CCS). In recent years, there has been uptake in bioenergy ahead of the indicator we use to monitor progress, continued development of more energy efficient production processes and the launch of a business case for an industrial CCS cluster. However, underpinned by an appropriate policy framework, effort needs to increase to support investment in large-scale projects such as industrial CCS and for industry to take a long-term and strategic lead in how to compete in a carbon-constrained world.

Compared to a scenario with delayed action in the 2020s, this scenario for the non-traded part of industry would save £2 billion in present value terms under central fossil fuel and carbon value assumptions. It will also be important to avoid delay of measures in sectors covered by the EU ETS, especially progress with applying CCS to industrial installations, given the need for progress in these areas to meet the 2050 target in the Climate Change Act.

Key findings:

- **Our central abatement scenario** estimates that direct industrial GHG emissions could reduce from 109 $MtCO_2e$ in 2014 to 88 $MtCO_2e$ by 2030. Our Barriers and Max scenarios give a range of 81 to 94 $MtCO_2e$ remaining emissions in 2030.
- **Government policy to date** is unlikely to encourage sufficient low-carbon investment in industry because it does not address many of the barriers to implementing key low-carbon opportunities (e.g. there is no well developed infrastructure strategy for CCS in energy-intensive industries). New policy will be required to address these barriers, possibly based on long-term sector agreements and financing.

Introduction and key messages

- **Industrial CCS** development and deployment on a large scale is required to decarbonise industry and meet the 2050 target. Such development requires a strategic approach in order to take advantage of synergies with the power sector so that industrial clusters connect to power sector CCS infrastructure, reducing both investment cost and risk.
- **Energy efficiency** investment reduces emissions and energy costs for businesses. For the private sector to invest, there needs to be confidence that an appropriate policy framework is in place, to incentivise large-scale projects that have payback periods in excess of five years, rather than the typical investment criterion of two to three years. Innovative technologies that have the opportunity to significantly reduce energy demands will require support through development and early deployment to commercialisation.
- **Low-carbon space and process heat** through fuel switching to bioenergy and electricity (as the power sector decarbonises) will further reduce industrial emissions. The switch to these fuels will need government intervention to 2030. To 2050, bioenergy may be best used with CCS in order to remove emissions from the carbon cycle.

We will return to policy challenges in our 2016 Progress Report.

We set out the analysis that underpins these conclusions in the following sections:

1. Overview of emissions from the industrial sector
2. Options for reducing emissions
3. Existing ambition and projected emissions without further policy
4. Abatement scenarios
5. Costs and impacts
6. Delivering the scenarios

1. Overview of emissions from the industrial sector

Current emissions

Industry includes manufacturing, construction, water and waste management, refining of petroleum products and other energy supply (extraction and production of oil, gas and solid fuels).

Direct emissions from industry accounted for around a fifth of UK greenhouse gas (GHG) emissions in 2014 (109 $MtCO_2e$), of which over 90% are CO_2 (Figure 4.1).[59]

- Manufacturing[60] and refining emissions comprise:

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[59] Industry also accounts for a further 11 $MtCO_2e$ emissions from use of F-gases, these emissions are covered in Chapter 7.

[60] From now on when we refer to manufacturing we also include construction and water and waste management sectors.

- Combustion emissions, from burning fuel for purpose of production of low-and high-grade heat, drying/separation, space heating and electricity generation for own use (Figure 4.2). Almost a third of combustion emissions are unclassified (i.e. not attributed to a sector or segmented by use).
- Process emissions from chemical reactions within industry (e.g. calcination of limestone in the production of cement).

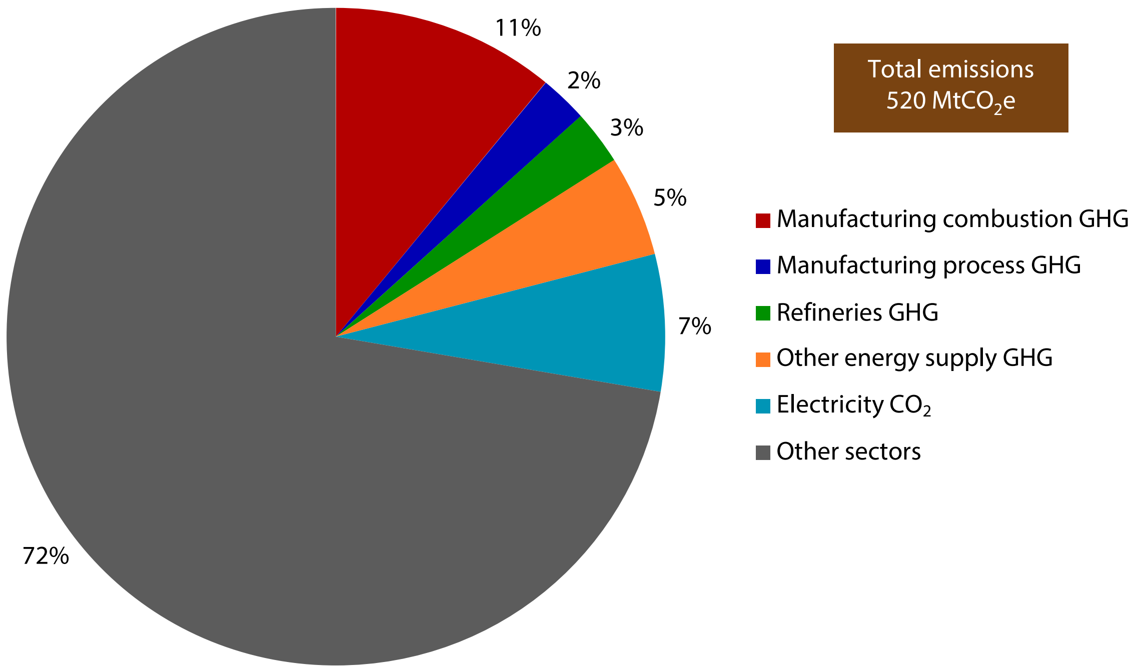
- Other energy supply emissions are made up of two-thirds are CO_2 from combustion of fuels or gas flaring; one-third are non-CO_2 emissions from gas leakage and coal mining.

Industry also consumes around a third of UK electricity produced.

Within the manufacturing and refining sectors, around four-fifths of all CO_2 emissions and two-thirds energy consumption is accounted for by eight industries, which make up almost a sixth of UK GHG emissions (Figure 4.3).

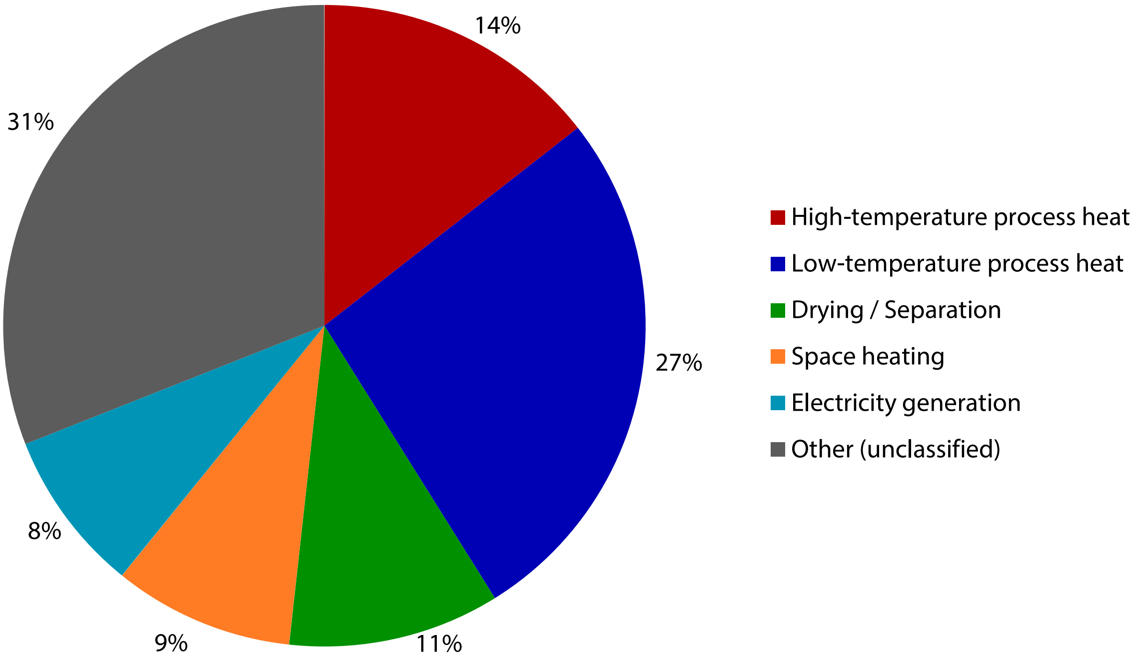
Industry production and emissions are not evenly spread across the UK. The fifth carbon budget advice report details the role of industry in the devolved administrations. For instance, in Wales, industry accounted for 34% of total emissions in 2013, with nearly half of these from Port Talbot steelworks.

Figure 4.1: Industry as a percentage of total UK GHG emissions (2014)



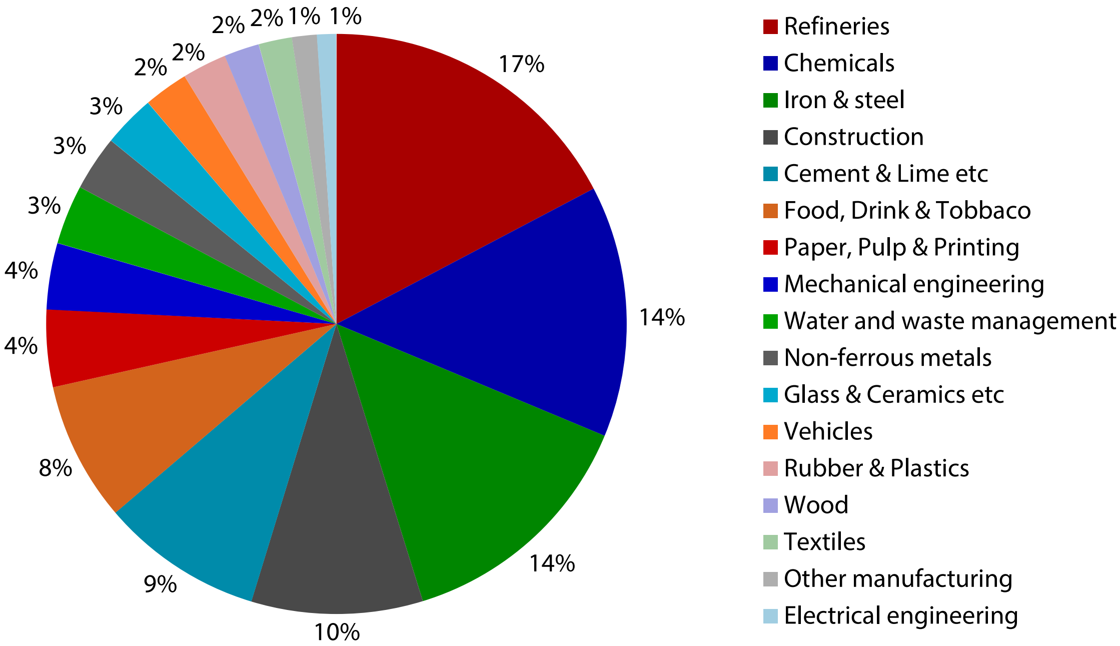
Source: DECC (2015) *Provisional UK greenhouse gas emissions national statistics*; CCC analysis
Notes: Electricity emissions are industry's share of power sector emissions based on energy consumption.

Figure 4.2: Manufacturing and refining direct CO_2 from combustion by use (2014)



Source: DECC (2015) *Energy Consumption United Kingdom*; CCC analysis
Note: 'Electricity generation' refers to electricity generated and consumed on-site.

Figure 4.3: Manufacturing and refining CO_2 by sector (2012)



Source: ONS Environmental Accounts; CCC analysis

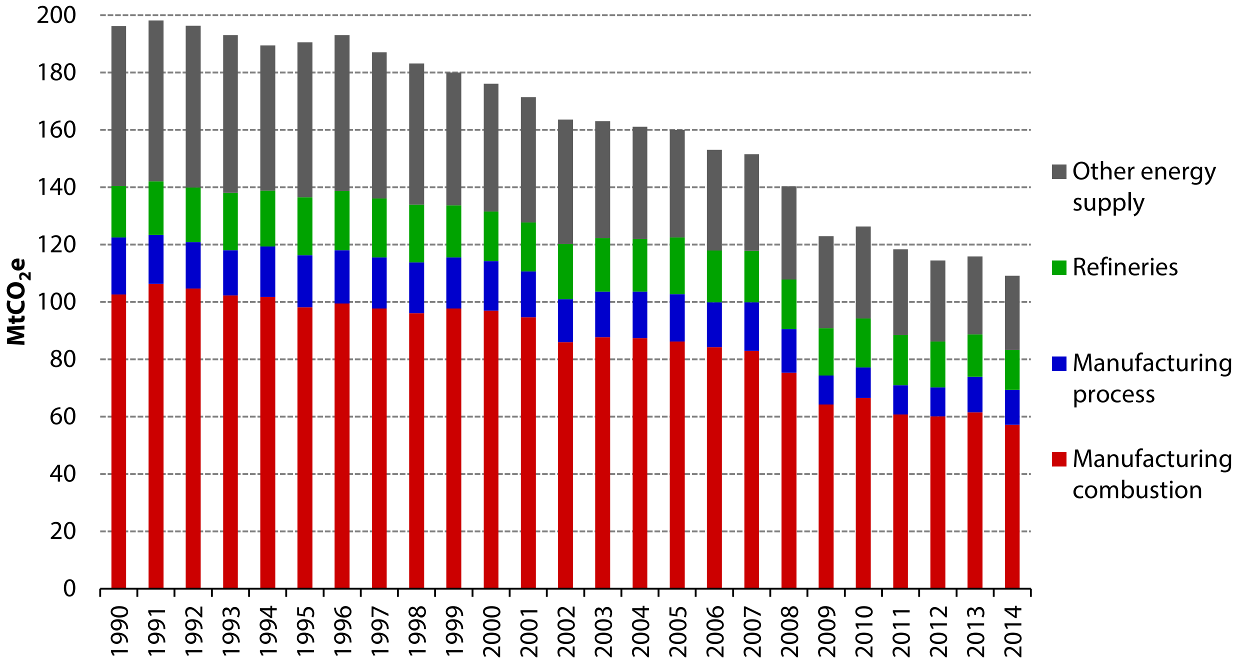
Emission trends

Industrial direct GHG emissions have reduced substantially since 1990, across manufacturing, refining and other sectors (Figure 4.4):

- Manufacturing CO_2 emissions (process and combustion) have fallen 43% since 1990. This has been partly due to energy intensity improvement and switching to lower carbon fuels, but also to the impact of the recession on the more carbon-intensive sectors. In 2014, we commissioned Ricardo-AEA to produce a decomposition model for energy and emissions in the UK manufacturing and refining sectors. This allows us to analyse the factors that contribute to a change in emissions:
  - Between 1990-2007, manufacturing CO_2 emissions fell 18%, while manufacturing output grew 8%. This fall was due to an improvement in energy intensity of production and a shift in energy consumption to less carbon-intensive fossil fuel (from coal/oil to gas) or to electricity,
  - Between 2007-2009, manufacturing CO_2 emissions fell 26%. This reflects a 12% reduction in manufacturing production during the recession, and its disproportionate impact on carbon-intensive sectors,
  - Between 2009-2012, manufacturing CO_2 emissions fell 6%. This fall was due to continued structural movement towards a less carbon-intensive mix of industrial output, with some improvement in energy intensity and shift to less carbon-intensive energy.
- Refineries CO_2 emissions have fallen due to a 30% contraction in UK refinery production of fuels, with the UK now shifting from being a net exporter to a net importer of fuel,
- Other energy supply CO_2 emissions have fallen 14% since 1990 reflecting reduced extraction of fossil fuels within the UK,
- Non-CO_2 emissions in industry have fallen since 1990 reflecting the introduction of technologies to abate N_2O emissions in industrial processes and reduced methane emissions from the gas distribution network and coal mines.

Overall, industry direct emissions fell 44% over the period 1990-2014.

Figure 4.4: Industrial GHG emission trends (1990-2014)



Source: NAEI (2015) *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990-2013;* DECC (2015) *Provisional UK greenhouse gas emissions national statistics;* CCC analysis.
Notes: Excludes emissions from F-gases (Chapter 7).

Emission baseline projection

In the absence of additional policy, DECC project[61] industrial GHG emissions to fall by 16% from 2010 to 2035, while industry gross value added is assumed to grow by 30% (Figure 4.5).[62] Half of this fall in emissions is from other energy supply, 30% from reduction in manufacturing combustion emissions and 20% from reduced refining emissions.

The DECC projections take into account the latest information such as the most recent energy and emission statistics and economic activity forecasts. For instance, refining production has reduced, meaning that the UK has shifted from being a net exporter to a net importer of fuel. The DECC projections assume that refinery production remains at this lower level to 2035.

However, some recent developments are not taken into account. For example, whilst the DECC projection assumes a 20% reduction in iron & steel GVA over the period 2015-2035, it does not take explicit account of the recent closure of Redcar steelworks in the Teesside region. According to EU Emission Trading System (EU ETS) data, Redcar emitted nearly 6 $MtCO_2$ in 2014 (out of around 20 $MtCO_2$ emissions from the UK iron & steel sector).

We take the DECC emissions projection as our starting point to assess abatement potential. Clearly, the scale of abatement potential will reductions in the baseline, but residual emissions may then be lower as a result.

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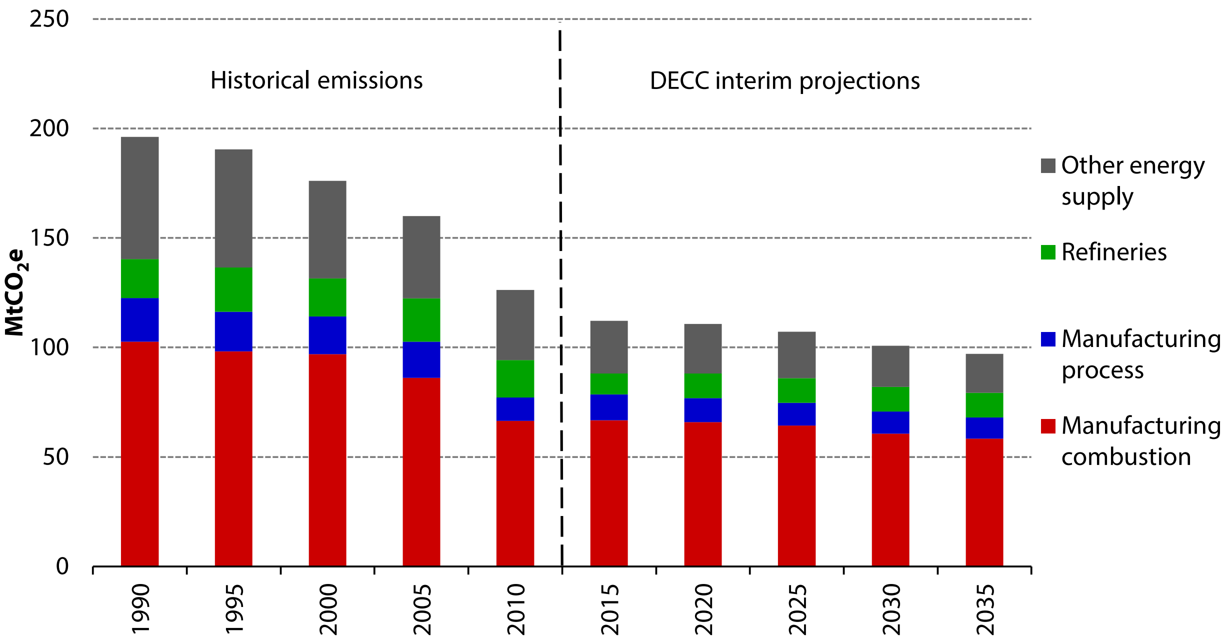
[61] DECC interim projections (October 2015)

[62] Gross value added (GVA) is the measure of the value of goods and services produced, and in this context is used as a proxy for industrial output.

Figure 4.5: DECC baseline emissions interim projections to 2035



Source: DECC interim projections (October 2015).

Consumption emissions

Based on the *Climate Change Act 2008*, in our advice we use a production-based approach to counting emissions. This follows the approach adopted around the world, including within the relevant UN frameworks.

The production-based approach does not include the embedded emissions from imported goods and services, and therefore the emissions from UK consumption. We addressed this issue in our 2013 report on the UK's carbon footprint,[63] finding that in the period from 1990 there has been a large increase in imported goods and services as a result of economic growth and globalisation and these have emissions associated with them (Box 4.1).

Reduction in these emissions from imported goods will depend on actions taken elsewhere and on the success of ongoing international negotiations.

Box 4.1: UK consumption and its carbon footprint

The 'carbon footprint' refers to emissions that are associated with the consumption spending of UK residents on goods and services, wherever in the world these emissions arise along the supply chain, and those which are directly generated by UK households through private motoring and home heating. These emissions are often referred to as 'consumption emissions' to distinguish them from estimates relating to the emissions produced within a country's territory.

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[63] CCC (2013) *Reducing the UK's carbon footprint and managing competitiveness risks*, https://www.theccc.org.uk/publication/carbon-footprint-and-competitiveness/

Box 4.1: UK consumption and its carbon footprint

The Government has produced estimates of UK emissions on a consumption basis. These are classified as experimental statistics because of inherent uncertainties in the estimation, which requires consideration of where imported goods are coming from and emissions in their supply chains.

The estimates suggest (Figure B4.1):

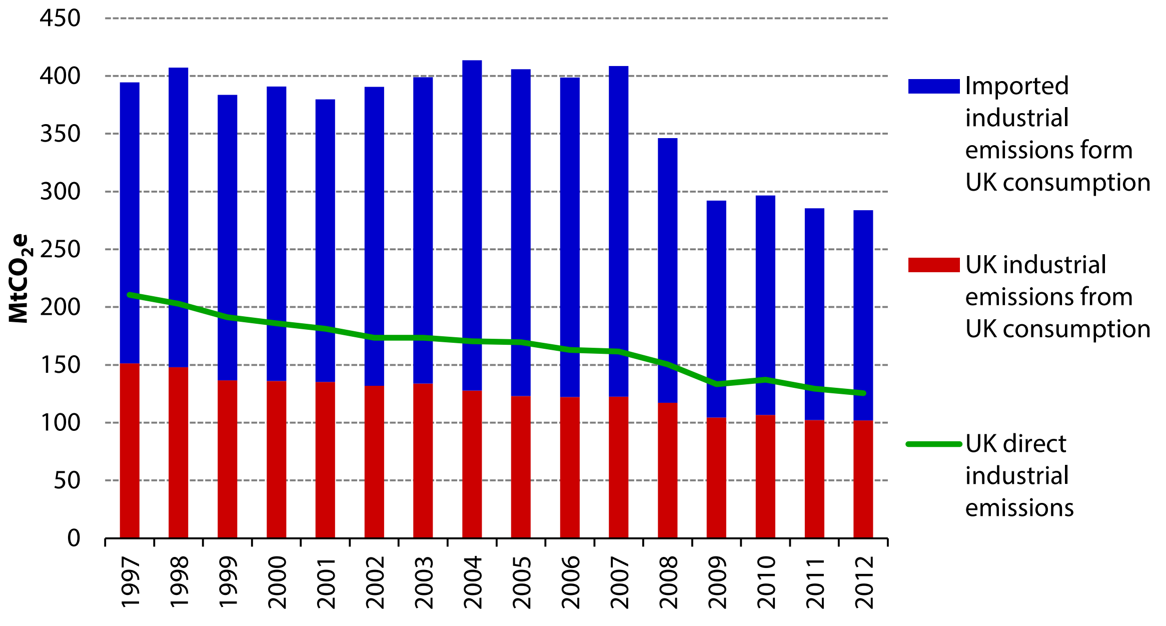
- UK emissions on a consumption basis exceed those on a production basis,
- Whilst industrial emissions on a production basis fell by around 20% between 1997 and 2007, consumption emissions rose 4%,
- Consumption emissions have fallen from 2007-2012 more sharply than production emissions, largely due to the recession. Emissions attached to imports fell 36%.

In our 2013 report we concluded:

- There is uncertainty in estimates, but the UK has a carbon footprint substantially larger than its production emissions, reflecting the relatively small share of manufacturing in UK GDP,
- There is a need for international action to cut global emissions, as a consequence of which the UK's carbon footprint would fall,
- It is appropriate to account for carbon budgets on the basis of production emissions, given accounting conventions and available policy levers.

Consumption emissions should be monitored to check whether these are falling in line with required global action, or whether further action is required.

Figure B4.1: UK industrial product consumption carbon footprint



Source: Defra (2015) *UK's Carbon Footprint 1997 – 2012*; CCC analysis.

Source: Defra (2015) *UK's Carbon Footprint 1997 – 2012*; CCC analysis.

2. Options for reducing emissions

The industrial sector is diverse, covering the production of bulk steel in large blast furnaces through to the manufacturing and packaging of thousands of food items we consume each day. Industry is also diverse across sub-sectors: no two sites are the same even when they produce the same type of product. This creates a challenge in estimating the potential abatement of emissions and the costs involved.

In our advice on the *Fourth Carbon Budget Review*[64] in 2013 we set out an assessment of the options for reducing emissions from industry to 2030. Since then, we have reassessed options for emission abatement in industry, their costs and potential for deployment. Overall, the evidence drawn upon to identify cost-effective abatement in industry is the most detailed, robust and realistic to date. However, some gaps and uncertainties remain, especially for the longer term. This section sets out that updated evidence.

2050 Roadmaps

Our assessment of industrial cost-effective abatement has drawn on the 'Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050'.[65] Parsons Brinckerhoff and DNV GL were appointed by the DECC and BIS to produce a set of decarbonisation roadmaps for eight heat-intensive sectors that cover 70% of manufacturing and refining emissions, with a cross-sector report identifying conclusions that apply across multiple sectors and technology groups.[66] The roadmaps, published in March 2015, are based on a collaborative process featuring contributions from industry sector trade associations, their members, officials from DECC and BIS, and other experts.

The purpose of each roadmap is to establish decarbonisation pathways that could be possible, while ensuring sectors remain competitive. The pathways give a view of the range of technology mixes that the sector could deploy over coming decades to enable transition towards a low-carbon economy.

The roadmaps considered hundreds of potential options, focused around energy efficiency, fuel switching to bioenergy or electricity for process heat, and industrial CCS:

- **Energy efficiency.** Upgrades and replacements to existing processes and equipment to improve their energy efficiency.
- **Bioenergy use in industry.** Switching away from direct combustion of fossil fuels to biogas/biomass for use in process heat.
- **Electrification of process heat.** Through electric kilns, boilers and melting of glass, in conjunction with the decarbonisation of the power sector.
- **Carbon Capture and Storage or Use (CCS/CCU).** Capture of waste CO_2 from large point sources, transport to a storage site where it will not enter the atmosphere, or use in other industrial processes.

As part of the roadmaps study, the uptake and impact of these abatement options were

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[64] CCC (2013) *Fourth Carbon Budget Review*, https://www.theccc.org.uk/publication/fourth-carbon-budget-review/.

[65] WSP and Parsons Brinckerhof, DNV GL (2015), *Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050*, https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

[66] Sectors include: cement, ceramics, chemicals, food & drink, glass, iron & steel, oil refining, and paper & pulp.

discussed in detail with the sectors and academic experts, creating a range of abatement pathways for each sector.

A part of our assessment of this evidence base has involved further discussions with industrial sectors on potential abatement, the roadmap pathways, improving the quality of the data where possible and the development of our scenarios.

To complement the roadmaps studies we have drawn on more detailed analysis of the potential abatement from industrial CCS by Element Energy and the Teesside industrial CCS cluster business case. These studies, alongside the roadmaps, allowed us to assess the latest cost estimates for CCS in industry, the relative technology readiness of CCS, the ease of application and the potential uptake.

The rest of this section summarises the main options identified in the roadmaps, and further abatement in space heating and off-road mobile machinery.

Energy efficiency

Improving the process of producing goods can save both emissions and energy, and thus reduce firm's costs. There are many forms of energy efficiency which are specific to each industrial sector:

- **Energy and process management**: a range of improvements including energy management, utilities, improved process control, and maintenance.
- **Best available and innovative technology**: improved equipment and insulation (e.g. motors, pumps, compressors, fans), and advanced technologies (e.g. innovative furnace designs or new ways to produce steel such as those in the 'Ultra-low CO_2 steelmaking' project (ULCOS), which covers smelter technologies such as HIsarna).
- **Waste heat recovery and use:** most of the available heat to recover is lower grade. To use it effectively requires either matched heat sinks nearby, or else the heat needs to be upgraded to higher grade heat or electricity. Low-grade industrial waste heat can be used in district heating schemes, providing heat to local housing or non-domestic buildings (Chapter 3).
- **Material efficiency**: food waste and packaging reduction, reducing yield losses, scrap densification or shredding and reuse of steel, lighter bricks and reduced product weight (ceramics sector), and increased cullet use through recycling (glass sector).
- **Clustering**. Integration between industrial sites to optimise the use of energy and resources. For example, clustering could help co-locate industries that use lower grade heat (food and drink, semiconductor manufacturing etc.) with industries that have low-grade heat available (iron and steel, pulp and paper etc.).

Our scenarios have identified a range for abatement potential from energy efficiency based on uptake pathways developed for the 2050 roadmaps and our assessment of their cost-effectiveness against assumed carbon values (Chapter 1).

Bioenergy use in industry

Biomass technology for decarbonisation is the use of bio materials to provide a fuel or feedstock replacing current fossil fuel sources. Biomass absorbs CO_2 during growth, so there is the potential to reduce emissions compared to fossil fuel sources. Biomass can also be used as a feedstock replacement, for example in the chemicals and cement sectors.

There are a number of complexities regarding biomass use as a decarbonisation option from an industrial perspective including availability, consistency of quality, price and policy support. We have considered how bioenergy could be used in space/process heat and in off-road mobile machinery.

Bioenergy used for space and process heat

Currently the Renewable Heat Incentive (RHI) provides incentives for consumers to install renewable heating, such as biomass boilers. As reported in our *2015 Progress Report*,[67] industrial uptake of low-carbon heat technologies has been in line with our indicators. However, funding for the RHI is only guaranteed to 2016.

Our assessment takes account of the impact that the RHI to 2016 will have on bioenergy use in industry to 2030; further uptake of bioenergy for use in process heat using the 2050 roadmap analysis, and space heating by replacing oil boilers and conventional electric heating for buildings.

To 2050, scarce biomass resources should ideally be diverted to use in conjunction with CCS in order to remove emissions from the carbon cycle (Chapter 1). This could be applied in industry or in the power sector and could offset emissions from hard-to-treat sectors such as aviation and agriculture. The 2050 roadmaps identified potential for using bioenergy with CCS in the chemicals, cement, food & drink and paper & pulp sectors.

Biofuels use in off-road mobile machinery

Off-road mobile machinery comprises a wide range of vehicles and machinery powered by petrol or diesel whose primary function is not transport on public highways. This includes mobile generators, cranes, tractors, refrigeration units on HGVs and forklifts.

These machines mainly use gas oil as fuel, with some using petrol and diesel. Under the Renewable Transport Fuels Obligation (RTFO)[68] there will be an increase in biofuel blended with petrol/diesel, reducing the emissions of these machines.

To 2030 we expect that biofuel will be primarily used to abate emissions in road transport. However, as road transport shifts further to electricity as a power source after 2030, waste-based biofuel may become available to be used to replace gas oil used in off-road mobile machinery.

Low-carbon electric space and process heat

As electricity from the grid continues to decarbonise to 2030 and beyond, there is potential to reduce the use of fossil fuels and therefore emissions through low-carbon electrification of space and process heat.

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[67] CCC (2015) *Meeting Carbon Budgets – Progress in reducing the UK's emissions: 2015 Report to Parliament*, https://www.theccc.org.uk/publication/reducing-emissions-and-preparing-for-climate-change-2015-progress-report-to-parliament/

[68] See Chapter 5 for more details on the RTFO.

Electrification of process heat

Our analysis using the 2050 Roadmaps has found that even though electrification of low or high-temperature process heat can be very energy efficient, given the current forecasts of electricity prices this is not a cost-effective abatement option. We have, however, included electrification of process heat in our Max scenario as an illustration of the abatement potential:

- **High-temperature process heat.** We have identified potential for applications of electrification in the glass (electric melting) and ceramics (electric kilns) sectors.
- **Low-temperature process heat.** We have identified potential for applications of electrification in the food & drink sector (baking and separation).

Electrification of heat could be considered when replacing equipment, but the extent to which investments in electrified technologies are made will depend on firms' confidence that there will be secure, affordable decarbonised electricity in the future.

Heat pumps for space heating

Heat pumps are a high efficiency form of electric heating which operate like a fridge in reverse, by using electricity to extract heat from the environment. There is potential for heat pumps to replace oil/gas and conventional electric space heating.

As with bioenergy, the RHI incentivises the uptake of heat pumps as a low-carbon form of heating, although to date uptake in industry has been low. Heat pumps have high initial capital costs, but they are expected to become cost-effective in a growing number of electric and oil-heated buildings over the next decade (deployment in non-domestic buildings is discussed in depth in Chapter 3).

Industrial CCS

Carbon Capture and Storage (CCS) technology is most frequently considered in the context of power generation. However, application of CCS to large industrial sites may be feasible and cost-effective in energy-intensive sectors where there are few alternative abatement options, such as: iron and steel, refining, cement, chemicals and industrial Combined Heat and Power (CHP).

There are currently nine industrial CCS projects under development internationally. Of these, the Emirates Steel plant in Abu Dhabi is the world's first iron and steel project to apply CCS at large scale and is scheduled to be completed by 2016.

We previously commissioned Element Energy to assess the viability of CCS in industry.[69] The study found that CCS could be both widely applicable in energy-intensive industries and cost-effective to 2050. The overall results suggested CCS could reduce emissions from energy-intensive industry by 5 $MtCO_2e$ in 2030 and 36 $MtCO_2e$ in 2050.

Since the publication of this research, a further report by Element Energy considered the potential of demonstrating industrial CCS in the UK for four sectors by 2025: cement, chemicals, iron & steel and refining.[70] Based on this work, we have considered two further aspects to industrial CCS uptake in our abatement scenarios:

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[69] Element Energy (2010) *Potential for the application of CCS to UK industry and natural gas power generation for Committee on Climate Change*,

[70] Element Energy (2014) *Demonstrating CO_2 capture in the UK cement, chemicals, iron and steel and refining sectors by 2025: A Techno-economic Study for DECC and BIS*,

- **Capture technology and integration.** The technical and commercial maturity of CO_2 capture for storage or utilisation varies. There are uncertainties around the eventual cost and performance of the capture technologies. Additionally there are novel capture technologies which are especially effective when integrated in the main process of the industrial site, but that are only feasible for new-build facilities because they would require significant process and facility redesign in retrofit applications.
- **Geographical location.** We have previously stated that if industrial CCS were to link in with power sector CCS transport and storage infrastructure, the cost of abatement would be lower. In addition, the CCS costs are lower if applied to a cluster of industrial sites. There are potential locations in the UK for industrial CCS clusters including Teesside, around the Humber, Grangemouth and the North West of England.

Funding of £1m was awarded by the Government to the Teesside Collective, an industrial cluster, to develop a feasibility study on CO_2 capture, transport and storage from multiple sources in Teesside. This study suggested potential for an initial industrial cluster of four sites, including the Redcar steelworks, initially capturing 3 $MtCO_2$ per year. Since publication Redcar has closed. However, the report set out the feasibility of carbon capture, transport and storage from multiple sources within a cluster, and explored investment models and funding mechanisms.

CCS in industry is a key option to meet the 2050 target. However, there is a risk of investing in infrastructure for a site that could close. Given the limited progress with industrial CCS in the UK and internationally we have previously recommended that the UK Government develop a forward looking and strategic approach to commercialisation of industrial CCS alongside the power sector, including ensuring industry can link into planned infrastructure. This would minimise the infrastructure investment risk and help lay the foundations for deep cuts in industry emissions in the period to 2030 and beyond.

Hydrogen

The predominant demand for hydrogen today from industry is as an industrial feedstock. The highest demands are for ammonia production for fertiliser (50%) and in oil refineries and chemical industries (40%), where hydrogen is mostly used as feedstock in hydrogenation processes, and as a reducing agent to remove impurities at different scales.[71]

The roadmaps identified only a small future strategic role for hydrogen in UK industry. This may have been because the possibility of the supply of large quantities of modestly priced hydrogen had not been considered.

We commissioned E4tech and UCL to review the potential for using hydrogen in different sectors of the economy.[72] The study found that in the future, hydrogen could be used to supply low-temperature heat and significant quantities of high-temperature heat for industrial processes. In the iron and steel sector, coal could almost completely be substituted by hydrogen. In the cement (non-metallic minerals) sector, hydrogen use could be envisaged in combination with CCS technologies, where hot gases could be recycled and low-value hydrogen recovered.

The cost and availability of hydrogen is highly uncertain. However, for the purposes of our alternative scenario, we have considered the potential for hydrogen to replace gas use to provide low-and high-temperature process heat (Section 4).

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[71] Wawrzineck, K. & Keller, C., (2007) *Industrial hydrogen production and technology - Linde engineering.*

[72] E4tech et al (2015) *Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target*, available at https://www.theccc.org.uk/.

Challenges to reducing emissions

While many options are financially cost-effective over their lifetime, even without including carbon values, firms face barriers in investing in these emission saving technologies and fuels:

- **Refurbishment cycles**. The abatement opportunities that we have identified for carbon-intensive industry in the 2020s typically have long lead times. Given the difficulty of retrofitting, investment in low-carbon opportunities will need to be in line with refurbishment cycles.
- **Risk and skills**. The more substantial abatement options will involve changing the production process of the business and temporary disruption in production. When applying innovative technologies, this creates risks to businesses and a need for skilled staff to successfully adapt production and minimise disruption.
- **Infrastructure and markets**. Some abatement will need provision of infrastructure or creation of markets outside the control of specific industries. For example, to take full advantage of the potential abatement from industrial CCS, there needs to be adequate CO_2 transport and storage infrastructure.
- **Capital constraints**. Many of the cost-effective opportunities in energy-intensive industry have substantial upfront requirements for capital. Within global companies, abatement projects need to compete against investments around the world.

For the required investment in cost-effective abatement to be achieved, there needs to be a mechanism for reflecting the value of carbon (e.g. a robust carbon price), with long-term certainty to ensure that this investment is prioritised in a capital-constrained world.

Conclusion

For our assessment of the cost-effective path to 2030 and 2050, we have considered the evidence base against DECC’s interim baseline emission projection, and abatement costs with respect to assumed carbon values.

Further options which could provide scope for additional emissions reduction, or an alternative to deliver emissions reductions if CCS were not to become viable, include fuel switching to hydrogen sourced from low-carbon production (Section 4). There are also options such as materials efficiency and reducing consumption of materials, but these currently lack a robust evidence base for both costs and abatement potential.

Given the diverse nature of industrial sectors and complex production processes, considerable uncertainty remains around the total abatement potential from these sectors; however the depth of the evidence on which this assessment is based is considerably improved from previous advice reports.

3. Existing ambition and projected emissions without further policy

According to DECC interim projections (October 2015), industry direct GHG emissions in the absence of policy would be 111 $MtCO_2e$ in 2020 and 100 $MtCO_2e$ in 2030, based in part on ongoing economic trends (Section 1).

There are a number of policies to reduce emissions through energy efficiency and shifting to bioenergy and electricity for space and process heat:

- **EU Emission Trading System (EU ETS).** Total EU verified emissions have been consistently below the allocation of allowances, largely because of the recession, causing the market value of carbon to fall and remain at a low level. The combination of a limited carbon price signal and uncertainty over the EU ETS in the 2020s means the incentives for energy-intensive industries to prepare for and make long-term investments in line with the fourth carbon budget are weak. We have previously stated that structural reform of the EU ETS is necessary.
- **Energy efficiency.** A number of policies are in place or planned to encourage electricity and non-electricity energy efficiency. We have previously suggested rationalisation of business energy taxes and policies to promote energy efficiency, and the Government has recently announced a review of the business energy efficiency tax landscape.[73]
  - ***Products Policy, Climate Change Agreements (CCAs) and Carbon Reduction Commitment (CRC)***.
    - Products policy acts to improve the energy efficiency of machinery and equipment through regulated standards and labelling,
    - CCAs are voluntary agreements that allow eligible energy-intensive sectors to receive up to 90% reduction in the Climate Change Levy[74] if they sign up to stretching energy efficiency targets agreed with government,
    - The CRC is a mandatory carbon emissions reporting and pricing scheme to cover large public and private sector organisations in the UK.
    - There is considerable potential for overlap between products policy and CCAs, as investing in the latest equipment will improve energy efficiency with little additional effort required. We have in previous advice suggested that the CCA targets are not stringent enough.
  - ***Building regulations & Private Rented Sector Regulations***. These should improve the energy efficiency of buildings to a specified minimum standard. Non-domestic buildings are already covered to some degree by other policies (i.e. the CRC and CCAs). However, these policies do not cover the entire non-domestic building stock.
  - ***Energy Savings Opportunity Scheme (ESOS)***. This is a requirement for all large businesses in the UK to undertake comprehensive assessments of energy use and energy efficiency opportunities at least once every four years. The extent to which they will lead to uptake of the top cost-effective measures identified remains uncertain. We have previously recommended that the Government should assess the case for enhancing the audits (e.g. through signposting to finance, follow-up support, mandatory reporting and benchmarking).

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[73] The review considers the interactions between the Climate Change Levy (CCL), the Carbon Reduction Commitment Energy Efficiency Scheme (CRC), taxes on other fuels – e.g. heating oils, Climate Change Agreements (CCA), mandatory greenhouse gas (GHG) reporting, the Energy Saving Opportunity Scheme (ESOS), Enhanced Capital Allowances (ECAs), and the Electricity Demand Reduction (EDR) pilot.

[74] The Climate Change Levy (CCL) is a tax on energy delivered to non-domestic users in the United Kingdom. Its aim is to provide an incentive to increase energy efficiency and to reduce carbon emissions.

- **Bioenergy and low-carbon heat.** The Renewable Heat Incentive (RHI) encourages consumers to install renewable heating in place of fossil fuels. As reported in our *2015 Progress Report*, industrial uptake of low-carbon heat technologies has been in line with our indicators. However, funding for the RHI is only guaranteed to 2016. The Government needs to put in place a policy framework to ensure investment in large-scale industrial low-carbon heat projects to achieve supply-chain growth and deliver the increased uptake consistent with meeting carbon budgets.

Current Government ambition is set out in the annual DECC updated energy and emission projections. We previously identified that some of these policy savings are at risk due to:

- **Design and delivery problems**: this includes EU Products Policy, Building regulations, ESOS and the Private Rented Sector Regulations.
- **Lack of funding**: the RHI post-April 2016 is the main unfunded policy.

We now consider abatement in our fifth carbon budget scenarios to 2030 and 2050.

4. Abatement scenarios

Our approach to building scenarios is out in Chapter 1.

The starting point for our analysis is DECC's interim emission projections (Section 1).

Based on the 2050 roadmaps project we have assessed the cost-effective abatement potential used in our scenarios for those sectors covered (Table 4.1).

In addition, we have identified a range for the abatement potential from industrial CCS based on the Element Energy studies, work by AMEC[75] on the Teesside Collective business case for the deployment of CCS at a major steelworks, and discussion with sectors on the long-term potential in the 2050 roadmaps:

- **Central scenario.** There is initial deployment of CCS to a few sites in an industrial cluster by 2030. By 2050, there is further deployment of CCS to industrial clusters, but this is not applied to all of the sites of the four energy-intensive sectors.
- **Barriers scenario.** Deployment of CCS is delayed until after 2030. By 2050, technological and application barriers mean there is some CCS deployment only in the iron & steel, chemicals, and cement sectors.
- **Max scenario.** There is initial deployment in all four energy-intensive sectors by 2030. By 2050, application and geographical barriers have been overcome (either through low-cost transport or use of captured carbon) meaning that CCS is applied to all iron & steel, chemicals, cement and refineries, plus larger CHP units in the food & drink and paper & pulp sectors.

We now discuss the identified abatement across industry.

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[75] *Teesside Collective reports: Blueprint for Industrial CCS in the UK* (2015), http://www.teessidecollective.co.uk/teesside-collective-blueprint-for-industrial-ccs-in-the-uk/

Table 4.1: Cost-effective direct emission abatement to 2030 and 2050 in our Central scenario from the '2050 Decarbonisation Roadmaps'

Sector & direct emissions	Abatement to 2030	Abatement to 2050	Barriers and Max scenario
Iron & Steel (2012 = 17.8 $MtCO_2$)	Reducing yield losses, upgrading steam/power systems, stove flue gas recycling, retrofit one large site with top gas recycling and initial CCS.	Rebuild using advanced technologies being developed in the 'Ultra-low CO_2 steelmaking' project, such as HIsarna. Deployment of CCS across all major steelwork sites.	Barriers: no advanced technology, no CCS by 2030 and uptake by 2050. Max: more CCS deployment by 2030 and 2050.
Refining (2012 = 16.4 $MtCO_2$)	Conventional energy efficiency improvements such as advanced process control, heat exchanger upgrades, heat optimisation and additional CHP.	CCS at refineries located near transport and storage infrastructure, capturing emissions from fluid-catalytic cracking, hydrogen plant and power generation stacks.	Barriers: no CCS uptake by 2050. Max: initial CCS uptake by 2030 and full deployment across major refineries by 2050.
Chemicals (2012 = 12.2 $MtCO_2$)	As DECC baseline emission projection implies significant carbon intensity improvement, abatement only includes uptake of bioenergy for fuel and some initial CCS.	Further CCS deployment with use of bioenergy as a fuel which generate negative emissions.	Barriers: lower uptake of bioenergy and no CCS to 2030, lower uptake of both by 2050. Max: greater uptake of bioenergy by 2030 and full use of CCS by 2050.
Cement (2012 = 5.4 $MtCO_2$)	DECC baseline projection implies reduction in emissions to 2030, so no additional abatement included.	Use of CCS in 50% of major sites with use of bioenergy, to generate negative emissions.	Barriers: half the CCS and bioenergy uptake by 2050. Max: CCS across all major sites with use of bioenergy by 2050.
Food & drink (2012 = 5.4 $MtCO_2$)	Energy efficient equipment, energy management and use of bioenergy.	Upgrading of steam production systems, but bioenergy shifts to other power and industrial sites with CCS.	Barriers: no use of bioenergy by 2030 or steam system upgrade by 2050. Max: limited CCS use with CHP and uptake of electrification by 2050.
Paper & pulp (2012 = 3.1 $MtCO_2$)	Bioenergy with CHP/boiler, improved energy management and process control, and heat recovery.	Further abatement from innovative heat recovery systems, but redirection of bioenergy to other sectors unless used in CCS CHP units.	Barriers: no uptake of innovative heat recovery systems. Max: bioenergy used in CHP with CCS
Glass (2012 = 1.6 $MtCO_2$)	Increased use of recycled glass, waste heat recovery, improved conventional furnace design and process control, with batch pelletisation/briquetting.	Greater uptake of options with further abatement from innovative furnace design and batch reformulation.	Barriers: no uptake of innovative furnace designs. Max: switch to electric melting.
Ceramics (2012 = 0.9 $MtCO_2$)	Uptake of best available technology, improved process control and heat use.		Max: move to electric kilns.

Source: 2012 direct emissions from DECC interim projections (October 2015); *Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050*; CCC analysis.

Central scenario

Outlook to 2020

To 2020, we have identified 4 $MtCO_2e$ of cost-effective abatement (Table 4.2). This abatement comes from improved energy management and process control in the more carbon-intensive manufacturing and refining sectors, with further uptake of bioenergy/electrification of space and process heat.

There are challenges to achieve this level of abatement to 2020. The energy efficiency improvement will require continued investment in best available technology by industry even where there is uncertainty over UK capacity, e.g. refineries, iron & steel and paper & pulp. For bioenergy and electrification of space heat, uptake will have to accelerate.

This level of abatement is achievable as we have not assumed RHI funding post-2016, which could contribute further savings and energy efficiency improvements reflect available technology.

If achieved, this will reduce emissions in industry from 126 $MtCO_2e$ in 2010 to 107 $MtCO_2e$ in 2020, a 2 $MtCO_2e$ reduction per year (Figure 4.7).

The path from 2020 to 2030

To 2030, we have identified 13 $MtCO_2e$ of cost-effective abatement (Table 4.3).[76] This abatement comes from improved energy efficiency, including retrofitting a steel plant (as in the roadmaps), upgrading machinery and further waste heat recovery. There is greater uptake of bioenergy for process heat, especially in the chemicals and paper sector. An initial industrial CCS cluster is deployed by 2030.

There are challenges to achieve abatement. The energy efficiency improvement will have to increase with new innovative technologies coming to market, such as top gas recycling in iron and steel. Bioenergy and low-carbon heat uptake will continue to require financial support to 2030 to replace gas, and there will need to be support for industrial CCS with an approach that links commercialisation to the power sector infrastructure.

However, the scenario is more cautious than in previous advice (Box 4.2); the energy efficiency improvement is cost-effective if capital investment is available, uptake of bioenergy does not assume extension of the RHI post-2016 and the industrial CCS deployment is the same magnitude as the initial business case for Teesside.

If achieved this will reduce emissions in industry to 88 $MtCO_2e$, a 2 $MtCO_2e$ reduction per year (Figure 4.7). Most of the abatement identified is in the traded sector (Figure 4.6).

Alternative scenario

For our alternative scenario, we consider the impact of using hydrogen produced with CCS instead of using CCS directly on industrial installations. This reflects an uptake scenario from the E4tech study which is characterised by early, consistent and long-term commitment to the extensive use of hydrogen across the economy. The study suggests that this could provide low-carbon high-temperature and low-temperature heat for iron and steel production, non-metallic

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[76] The Advice Report and Chapter 1 include an additional 4 $MtCO_2$ of abatement from biomethane in the gas grid within the non-traded part of the industry sector for ease of presentation. In reality, this abatement would occur across a range of end-use sectors, so we do not include it in this chapter.

minerals, non-ferrous metals, paper, chemicals and food and drink:

- Industry use of hydrogen begins to develop and dedicated hydrogen transmission pipelines begin to be built in the mid-2020s. There is also a significant use of hydrogen as a low-carbon fuel for high- and low-temperature heat in industry, notably in food and drink, non-ferrous metals and non-metallic minerals, as a replacement for natural gas. Hydrogen consumption sums to around 3% of total national industrial fuel demand in 2030 and equates to abatement of 2 $MtCO_2e$.
- To 2050, hydrogen is used substantially as a low-carbon fuel for high- and low-temperature heat in industry, and accounts for about 50% of industrial fuel use and could reduce emissions by up to 33 $MtCO_2e$.

The costs and availability of hydrogen are highly uncertain. For this scenario to be achieved there would need to be strategic, anticipatory investments in hydrogen-enabling infrastructure to occur in advance of the actual materialisation of hydrogen demand.

Barriers scenario

The Barriers scenario reflects a lower uptake of key low-carbon technologies. This could be because currently promising technologies, such as industrial CCS, do not perform well or are more expensive than expected, or because there is limited policy effort to support demonstration or deployment.

For industry, the Barriers scenario mainly excludes industrial CCS and more advanced energy efficiency deployment, with reduced bioenergy and heat pump uptake.

To 2030, we have identified 6 $MtCO_2e$ of cost-effective abatement, 7 $MtCO_2e$ lower than in the Central scenario (Table 4.2).

Overall, industrial emissions in 2030 are 94 $MtCO_2e$.

Max scenario

Our Max scenario pushes the limits of what is potentially feasible and cost-effective. For example, with industrial CCS, we assume that technological development means maximum technical capture of emissions per site and that geographical location to transport and storage infrastructure is no longer a restriction. Also, we include the impact of electrifying process heat, which is not cost-effective in our central case.

To 2030, we have identified 19 $MtCO_2e$ of cost-effective abatement, 6 $MtCO_2e$ higher than in the Central scenario (Table 4.2).

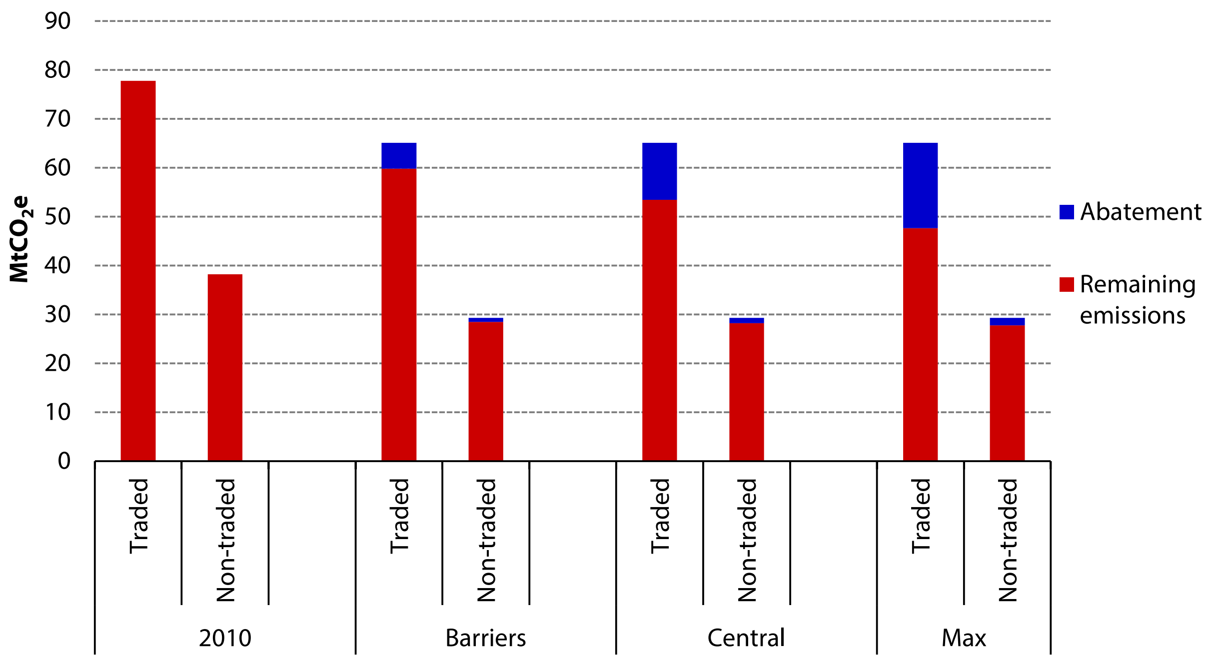
Overall, industrial emissions in 2030 are 81 $MtCO_2e$.

Table 4.2: Fifth carbon budget industry scenario GHG emission abatement ($MtCO_2e$)

	2020	2030		
		Central	Barriers	Max
Baseline emissions	111	100		
Energy Efficiency	2	5	3	6
Bioenergy for space/process heat	2	4	2	6
Electrification of space/process heat	-	1	1	2
Carbon capture and storage/use	-	3	-	5
Total abatement	4	13	6	19
Remaining emissions	107	88	94	81

Source: DECC interim projections (October 2015); CCC analysis
Note: Figures may not add up due to rounding.

Figure 4.6: Traded and non-traded industrial emissions in 2010 and 2030 for fifth carbon budget abatement scenarios



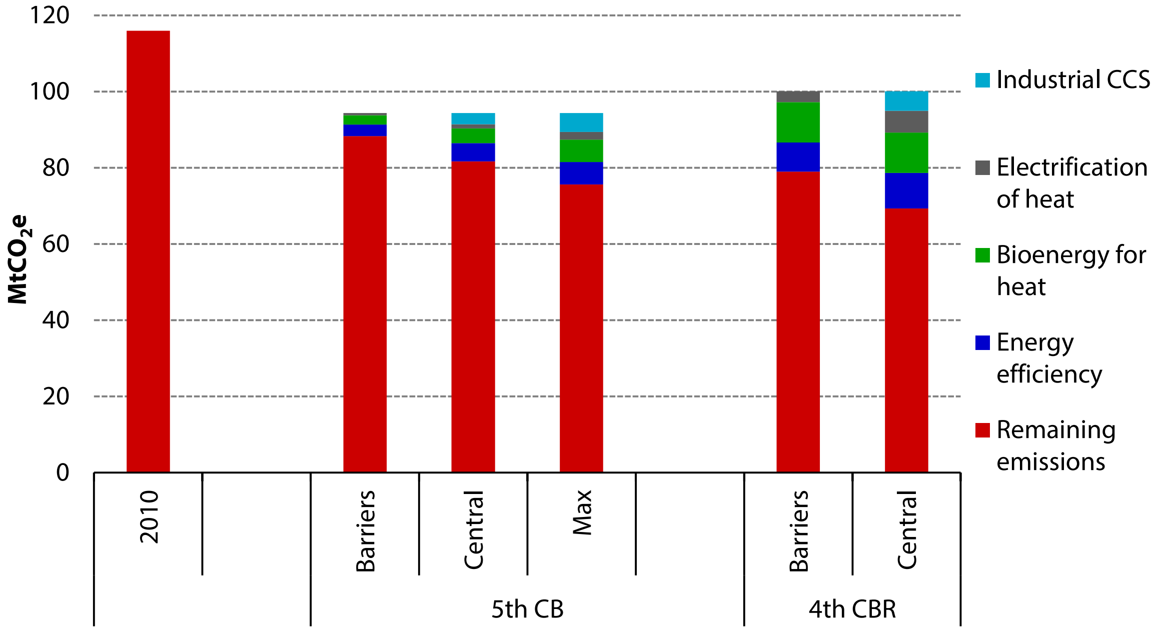
Source: DECC interim projections (October 2015); CCC analysis.

Box 4.2: Industry CO_2 emissions - 2030 fifth carbon budget advice scenarios compared to fourth carbon budget review

The abatement to 2030 is lower than identified in the fourth carbon budget review (Figure B4.2).

- **Energy efficiency** abatement for energy-intensives and refineries is 4 $MtCO_2$ lower given the roadmaps detailed assessment; we have also taken out the option to switch one of the large steel plants to be an electric arc furnace (EAF).
- **Bioenergy and electrification of space and process heat** abatement is 11 $MtCO_2$ lower with uncertainty over the RHI post-2016.
- **Industrial CCS** abatement is 2 $MtCO_2$ lower, based on AMEC work for Teesside Collective business case.

Figure B4.2: Industry CO_2 emissions - 2030 fifth carbon budget advice scenarios compared to fourth carbon budget review



Source: DECC interim projections (October 2015); CCC analysis.

Source: CCC analysis.

Preparing for 2050

To 2050, we have identified further potential for cost-effective abatement:

- **Energy efficiency** such as advanced technologies to produce steel, process design for food & drink, and increased use of recycled glass.
- **Bioenergy** is only used in industries with CCS, such as chemicals and cement, in order to remove emissions from the carbon cycle. In addition, there is potential for waste-based biofuel to be available to be used in off-road mobile machinery as road transport has shifted to electric vehicles.
- **Electrification** of space heating through heat pump uptake.
- **Industrial CCS** deployed further in the iron & steel, chemicals, cement and refinery sectors.

There are challenges to achieve this level of abatement to 2050. Widespread use of new technologies that improve industrial processes to save significant energy and emissions would have to be made across industry and linked to rebuilding of production sites, such as waste heat recovery and new steel making technologies. A number of industrial CCS clusters would have to be developed across the UK, linked in with power CCS infrastructure and multiple phases of CCS applied to different industrial processes.

This abatement is nevertheless achievable. Over the next 35 years, many industrial sites will be rebuilt or need major upgrades and so there will be opportunities to install the latest technology. Our industrial CCS scenarios are focused around clusters which have potential to become centres of low-carbon industrial activity.

We have identified potential to 2050 that could reduce emissions by 1-2 $MtCO_2e$ per year over 2030-2050, to 47-74 $MtCO_2e$ (Figure 4.7).

Remaining emissions

Our analysis has found that by 2050 industrial GHG emissions could reduce by 62%-76% from 1990 levels. However, there will still be significant residual emissions:

- **Energy-intensive manufacturing and refining sectors covered in roadmaps CO_2.** Emissions in 2050 are between 6-33 $MtCO_2e$. The Max scenario reduction in emissions reflects a combination of bioenergy and CCS which generate negative emissions.[77]
- **Non-roadmap manufacturing sectors CO_2.** Emissions in 2050 are 20-21 $MtCO_2e$. This includes energy and emissions that are labelled as 'unclassified' in government statistics. More information is required to properly identify abatement potential.
- **Manufacturing and refining non-CO_2**. Emissions in 2050 are 3 $MtCO_2e$.[78]
- **Other energy supply GHG**. Emissions in 2050 are 18 $MtCO_2e$.

Further study is required to identify additional abatement from industry.

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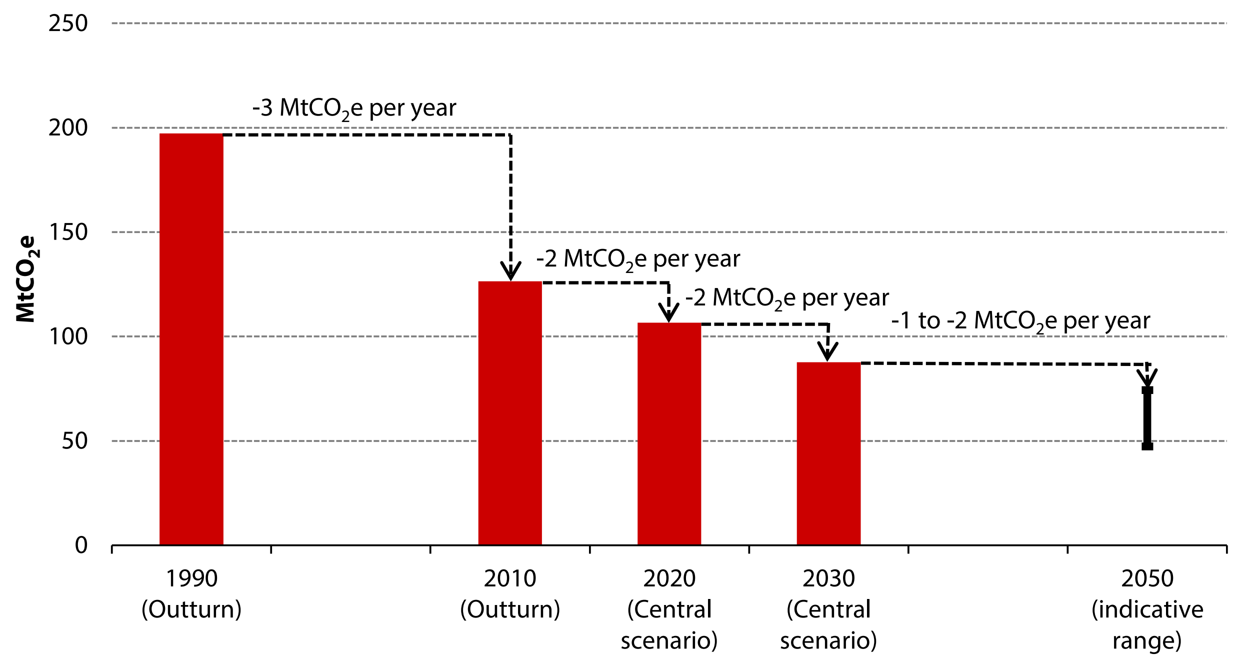
[77] The 2050 Roadmaps may not accurately calculate the negative emissions from bioenergy used with CCS, so this could be seen as an underestimate.

[78] Excluding F-gases which are covered in Chapter 7.

Figure 4.7: UK industry abatement and rate of emissions reduction (1990-2050)



Source: DECC interim projections (October 2015); CCC analysis.

5. Costs and impacts

Scenario costs

Many of the measures in our Central scenario are lower cost than the Government's projected carbon values or are required to prepare for 2050. A delay in their deployment would therefore increase costs. We have quantified the cost for such a delay for measures in sectors not covered by the EU ETS:

- On average, many of the options in our Central scenario to improve energy efficiency or replace conventional electric space heating with heat pumps save money even before carbon savings are included (Table 4.3).
- Overall, our updated scenario will reduce costs by £0.6 billion relative to the baseline scenario in 2030. To the extent that technology costs or fossil fuel prices are different to our central assumptions, cost savings could be £0.4 to £0.9 billion (Table 4.4).
- Delaying action to reduce emissions in the non-traded part of industry over the 2020s would increase emissions. The cost of the additional emissions in this scenario valued at the Government's carbon values would be nearly £2 billion. Avoiding delay is therefore the preferable path.
- It will also be important to avoid delay of measures in sectors covered by the EU ETS, especially applying CCS to industrial installations, given the need for progress in these areas to meet the 2050 target in the Climate Change Act.

- Many of the options here require up-front private sector capital investment. Over the lifetime of the asset this investment may be cost-effective for abatement or even save firms money, but have longer pay back periods than the private sector is used to. This is of particular relevance to CCS which requires substantial investment.

It is therefore appropriate to aim to deliver abatement in the industry sector, as set out in our Central scenario. This will require policies to be strengthened and extended into the 2020s to ensure that incentives for investment are in place and that barriers to deployment are addressed. Our key policy recommendations are covered in the next section.

Decarbonisation raises both challenges and opportunities for the competitiveness of UK firms. Differences in the level and timing of effort and policy around the world could lead to UK firms facing higher costs than their international competitors.

Chapter 4 of the fifth carbon advice report details our assessment of the competitiveness situation. Overall, competitiveness risks to energy intensive sectors from low-carbon policies are manageable. Impacts in the fifth carbon budget period are likely to be lower given increased international pledges and action to implement low-carbon measures. It will be important to closely monitor these after the Paris 2015 agreement, during the development of Phase IV of EU ETS and in the lead up to the fifth carbon budget period. For some sectors, action to tackle climate change may create future opportunities. The Committee will continue to monitor the need for compensation to be awarded to affected industries.

Table 4.3: Fifth carbon budget abatement costs

Options	Cost per tonne CO_2e abated in 2030 (weighted average)	Importance to 2050
Energy efficiency and waste heat recovery	-114	Further energy-efficiency of carbon-intensive industry is essential to meet the 2050 target. The measures included are cost-effective.
Bioenergy for space and process heat	32	Decarbonising heat in industry to 2050 requires building up capacity and supply-chains through the 2020s, particularly in the case of heat pumps.
Low-carbon electric space heat	-26	
Industrial CCS	67	CCS in industry is a key option to meet the 2050 target and an approach is required to develop industrial CCS demonstrations compatible with deployment in the 2020s.

Source: CCC analysis

Table 4.4: Fifth carbon budget Central scenario cost saving in 2030, with capital cost and fossil fuel price sensitivities

Central	Low capital costs	High capital costs	Low fossil fuel prices	High fossil fuel prices
£0.6 bn	£0.7 bn	£0.4 bn	£0.4 bn	£0.9 bn

Source: CCC analysis
Notes: Capital cost sensitivities assume capital costs are +/- 25% of central, fossil fuel price sensitivities based on DECC interim long-run variable costs of energy supply (November 2015).

6. Delivering the scenarios

As set out in Section 4, our Central scenario for the fifth carbon budget period sets out the level of savings in the industry sector required to help meet the cost-effective path. However, in the absence of future policy commitment, the market alone will not deliver the required improvement in energy efficiency, shift to low-carbon heat or deployment in industrial CCS.

The scenarios have implications for the next few years. Our immediate priorities were set out in our *2015 Progress Report*:

- **Develop joint work with industry into action plans**: publish plans setting out specific actions and clear milestones to move abatement efforts forward along the paths developed with industry in the "Roadmaps".
- **Complete roll-out of "Roadmaps" to other industrial sectors**: taking account of lessons learned, roll-out roadmaps to industrial sectors not covered in first wave.
- **Join-up industrial CCS with power sector projects**: set an approach to commercialisation of industrial CCS alongside the approach adopted for the power sector, including ensuring industry can link into planned infrastructure.
- **Evaluate effectiveness of compensation to at-risk industries for low-carbon policies**: independent evaluation of industries that are at-risk and effectiveness of the compensation framework.

The Government is currently reviewing the policy framework for commercial and public buildings, including the CRC and CCL, as well as reporting requirements under ESOS. We will continue to monitor progress in these areas in our annual Progress Reports to Parliament.

Chapter 5: Transport

Introduction and key messages

Domestic transport accounted for 21% of total UK emissions covered by carbon budgets in 2013. In this chapter we present new evidence on the options for decarbonising transport and our updated assessment of the sector's contribution to the cost-effective path to the UK's 2050 target. Our analysis suggests that between 1990 and 2030 domestic transport CO_2 could fall by 44% to 67 $MtCO_2$. This is broadly similar to our previous assessment, which suggested emissions could fall to 69 $MtCO_2$ by 2030. Compared to a scenario with delayed action in the 2020s, this scenario would save around £70 billion in present value terms under central fossil fuel and carbon value assumptions.

The key messages of the chapter are:

- **Demand for travel**. Demand for road travel is expected to increase significantly over the next two decades, with total road vehicle-km projected to increase by 23% between 2010 and 2030.
- **Conventional vehicle improvements**. Cost-effective technologies are available to improve the efficiency of conventional vehicles. New evidence indicates that the gap between test-cycle and real-world emissions could persist to 2030 and could be wider than previously thought. In our central scenario, the real-world CO_2 intensity (gCO_2/km) of new vehicles falls by 37% for cars, 33% for vans and 24% for Heavy Goods Vehicles (HGVs) between 2010 and 2030.
- **Ultra-Low Emission Vehicle (ULEV) uptake**. Electric cars, vans, small HGVs and buses are expected to become cost-effective in the mid-2020s, with costs in 2030 lower than previously estimated. In our central scenario, around 60% of new car and van sales are a plug-in hybrid or battery electric vehicle by 2030. In the longer term hydrogen fuel cells could be used in long-distance HGVs.
- **Biofuels**. Biofuel production is set to increase to 2020 to meet EU targets and we expect an increasing proportion to come from more sustainable, advanced feedstocks. New cost projections suggest that biofuels might not become cost-effective by 2030. However, there remains a case for their limited use during the 2020s.
- **Demand-side measures**. There are opportunities to moderate the expected growth in demand for car travel, particularly in urban areas. There are also opportunities for freight operators to reduce their fuel consumption and CO_2 emissions through improved logistics, driver training and use of fuel saving technologies fitted to existing vehicles.
- **Aviation.** Our previous planning assumption for aviation emissions to be around 2005 levels in 2050 (i.e. 37.5 $MtCO_2$), allowing an increase in demand of around 60%, remains appropriate. International aviation emissions should not formally be included in carbon budgets at this stage, though carbon budgets should continue to be set on track to a 2050 target inclusive of these emissions. We will provide further advice following the International Civil Aviation Organisation (ICAO) negotiations in 2016, and recommend that Government revisit inclusion at that point.
- **Shipping.** The scope of the budget should be broadened to include international shipping, with an additional 40 $MtCO_2e$ added to the fifth carbon budget, reflecting projected emissions on a bunker fuel basis and under currently agreed international policies.

Introduction and key messages

- **Uncertainties**. To address uncertainties we consider scenarios with lower and higher levels of abatement. Emissions in 2030 range from 60 $MtCO_2$ to 82 $MtCO_2$ across these scenarios. Given the inherent uncertainties in the projections for specific technologies and measures, we also set out alternative ways of meeting the same level of emissions reduction as our Central scenario using different combinations of measures.
- **Wider impacts**. The implications of our scenarios go beyond reducing CO_2 emissions. Uptake of ULEVs and reductions in urban car travel will help to improve local air quality. In addition, there are opportunities for the UK automotive industry to build on existing strengths in the manufacture of ULEVs and benefit from further growth in their sales.

We set out the analysis underpinning these conclusions in six sections:

1. Overview of transport emissions
2. Options for decarbonising transport
3. Existing ambition and projected emissions without further policy
4. Abatement scenarios
5. Costs and impacts
6. Delivering the scenarios

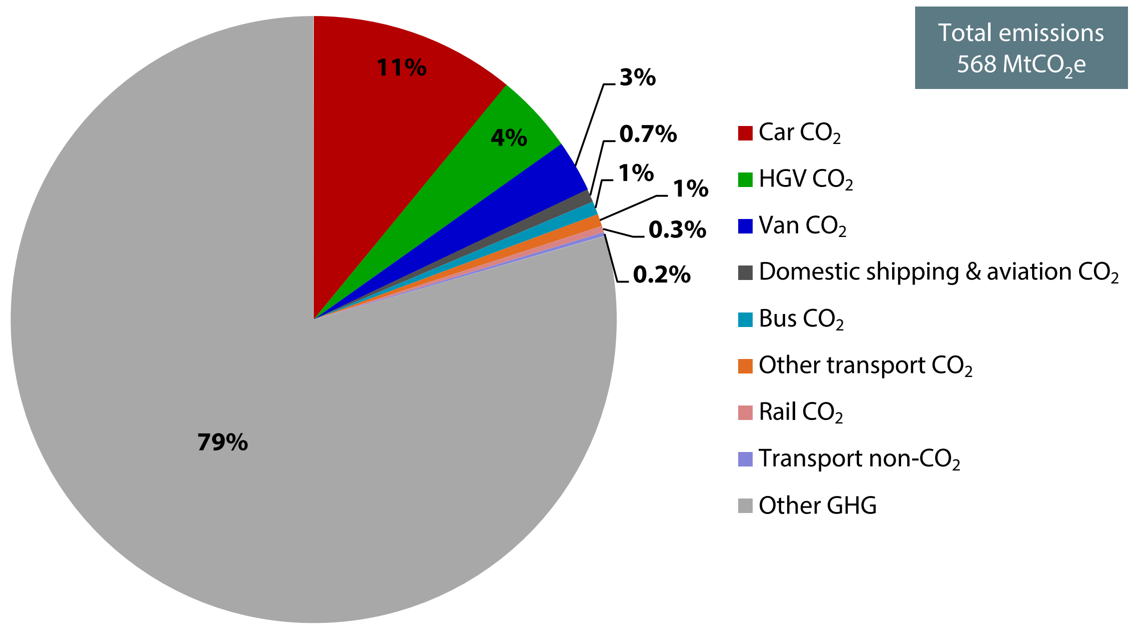
1. Overview of transport emissions

Domestic transport greenhouse gas (GHG) emissions were 117 $MtCO_2e$ in 2013, accounting for 21% of total UK GHG emissions (Figure 5.1). Within domestic transport, 94% of GHG emissions come from surface transport CO_2, the remaining 6% being due to domestic aviation and shipping CO_2 and non-CO_2 emissions:

- Surface transport CO_2 emissions were 109 $MtCO_2$. Cars accounted for the majority of these emissions (57%), followed by HGVs (22%), vans (14%), buses (4%), rail (2%) and other surface vehicles (1%).
- All other domestic transport CO_2 emissions were 6 $MtCO_2$. Domestic shipping accounted for 2.2 $MtCO_2$ and domestic aviation accounted for 1.8 $MtCO_2$.
- Non-CO_2 emissions from domestic transport were 1.1 $MtCO_2e$, around 1% of the total. These are mainly N_2O and CH_4 resulting from the combustion of fossil fuels.

Emissions from international aviation and shipping were 41 $MtCO_2$ in 2013. These are not currently formally included in carbon budgets, but are covered by the UK's 2050 target to reduce emissions by at least 80% relative to 1990.

Figure 5.1: Domestic transport as a percentage of total UK GHG emissions (2013)



Source: NAEI (2015).

Domestic transport GHG emissions increased by 9% from 1990 to 2007, but then fell, partly as a result of the recession, and were 4% below 1990 levels in 2013 (Figure 5.2). Focussing on surface transport as the main source of emissions (94% in 2013), emissions changes have been driven by a combination of increasing demand, falling CO_2 intensity (gCO_2/km) and the use of biofuels:

- Car CO_2 emissions fell by 13% between 1990 and 2013. This was due to a 24% decrease in the CO_2 intensity of the car fleet, as distance travelled by cars increased by 15%.
- Since 1990, van emissions have increased by 67%, to 16 $MtCO_2$ in 2013. There has been strong growth in demand, with vehicle-km increasing by 72%, partially offset by a fall in fleet CO_2 intensity of 3%.
- HGV emissions were 24 $MtCO_2$ in 2013, increasing by 2% since 1990. HGV vehicle-km increased by 1%, and the CO_2 intensity of the fleet increased by 0.5% on a vehicle-km basis. However, total tonne-km carried by GB registered HGVs increased by 6%[79] over that period, which suggests that the CO_2 intensity of the fleet fell on a tonne-km basis[80].
- Biofuels have been used to partially displace fossil fuels in road transport since 2002, contributing to the CO_2 intensity decrease. In 2013 biofuels made up 3% of road transport fuel by energy.

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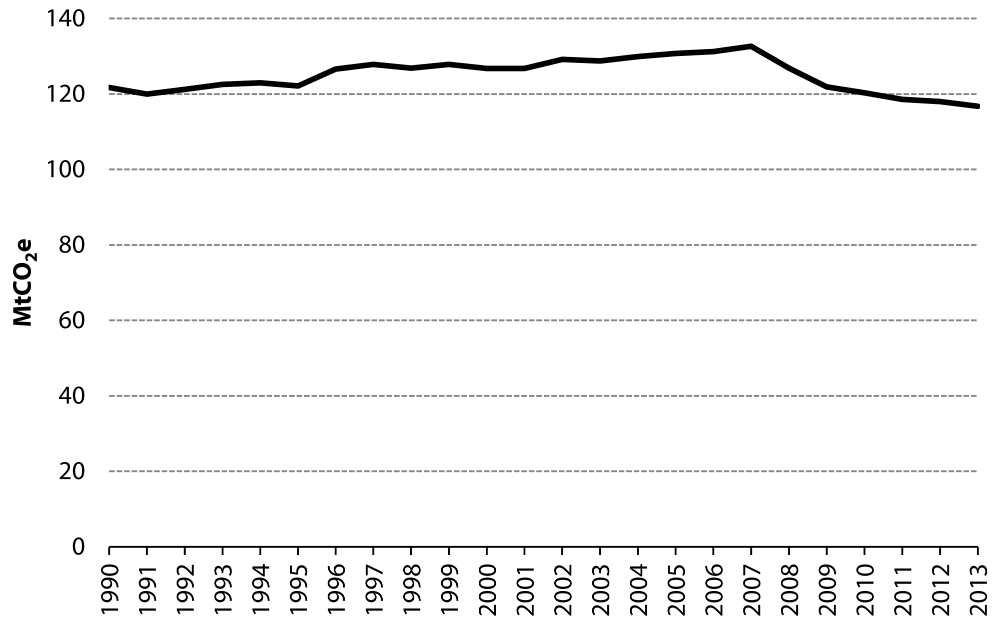
[79] DfT (2015) *Road Freight Statistics*

[80] It is not possible to calculate the change in CO_2 per tonne-km over the period due to the different coverage of the Road Freight Statistics and the National Atmospheric Emissions Inventory.

Figure 5.2: Domestic transport GHG emissions (1990-2013)



Source: NAEI (2015).

Given transport's high share of total emissions and the availability of options to decarbonise transport, there is scope to significantly reduce transport emissions to 2030 and keep open the option to fully decarbonise surface transport by 2050. We now consider the latest evidence on projected emissions and options to reduce these, and then set out an updated assessment of abatement to 2030 in section 4.

Expectations for emissions without abatement action

The starting point for constructing our emissions reduction scenario is an assessment of how demand and associated emissions are expected to change in the absence of policies to mitigate climate change. For road transport, we use DfT's National Transport Model (NTM) for our baseline projections of vehicle-km and emissions, which has been updated with the most recent projections of GDP and fuel prices. The latest fuel price forecasts are lower than those used in our fourth carbon budget review[81] and this is reflected in our new projection of total vehicle-km, which increases by 23% between 2010 and 2030, compared to 18% in our previous projection. For rail, we use DECC projections[82], which suggest baseline rail emissions could increase by 17% between 2010 and 2030 with no abatement action. Overall, surface transport CO_2 emissions[83] reach 126 $MtCO_2$ by 2030 in the absence of policies to mitigate climate change (Figure 5.3). Uncertainties in these projections are covered later in the chapter.

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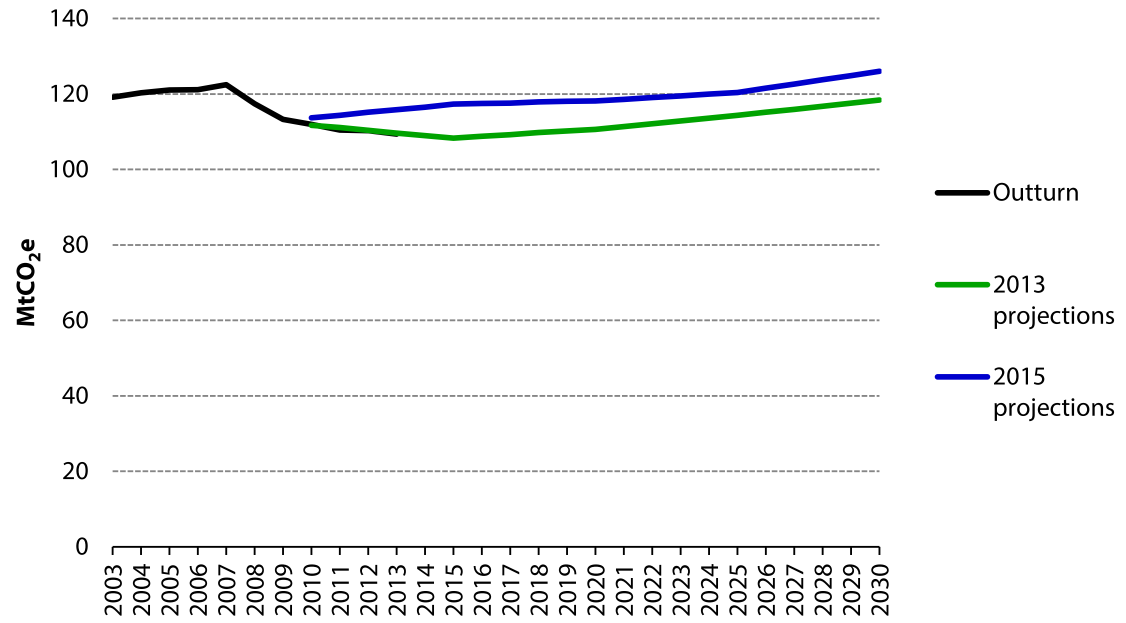
[81] CCC (2013) *Fourth carbon budget review*

[82] DECC interim projections (October 2015)

[83] Domestic aviation and shipping and non-CO_2 are considered separately.

Figure 5.3: UK surface transport CO_2, outturn and baseline projections (2003-2030)



Source: NAEI (2015); DfT projections for CCC (2013, 2015); DECC interim projections (October 2015).
Notes: The baseline emissions trajectory assumes no policies to mitigate climate change after 2010.

The Government has committed to several policies that are expected to reduce these emissions during the 2020s (section 3). In addition, there are options available to further reduce emissions to 2030 and beyond, to which we now turn.

2. Options for decarbonising transport

This section sets out latest evidence on the cost, feasibility, risks and uncertainties of options for decarbonising transport. The level of deployment of each option in our scenarios is addressed in section 4. We consider in turn:

a) Options for decarbonising surface transport.

b) Options for decarbonising aviation and shipping.

When assessing the costs of abatement, we compare the social costs of different measures to the Government's projected carbon values (Chapter 1). However, there are some specific considerations for the transport sector (Box 5.1).

Box 5.1: Cost-effectiveness of measures to decarbonise surface transport

The total social cost of a measure is the net present value of all costs (e.g. capital, running and other costs) over the lifetime of the measure, discounted using the social discount rate of 3.5%. In road transport, it is important to distinguish between the social and private costs as there are big differences in the cost of fuel if considered from a social rather than a private perspective. Private costs of petrol and diesel include fuel duty and VAT, which make up around 60% of the fuel price, but are not part of social costs (as they are a transfer from the driver to the exchequer).

As the private cost of fuel is much greater than the social cost, fuel efficiency improvements should look more cost-effective from a private perspective than from a societal perspective. However, when choosing a new vehicle, consumers typically consider fuel costs over a much shorter period than the lifetime of the vehicle and heavily discount the later years.

Source: CCC analysis.

a) Options for decarbonising surface transport

Conventional vehicle efficiency

The efficiency of new conventional cars and vans has improved in recent years, but there is scope for further improvements through measures such as aerodynamics, hybridisation and engine downsizing. We have updated our assessment of car and van efficiency and costs using the results of a forthcoming study by Ricardo Energy and Environment[84] (Box 5.2). We have also commissioned a new study from Element Energy and the International Council for Clean Transportation (ICCT), providing updated evidence on the growing gap between test-cycle and real-world emissions (Box 5.3). Our analysis suggests that there is significant, cost-effective potential for these measures to 2030, with more limited opportunities in the long term:

- Between 2010 and 2014, average new car test-cycle CO_2 intensity fell from 144 gCO_2/km to 125 gCO_2/km, as measured on the current test-cycle, the New European Driving Cycle (NEDC). The CO_2 intensity of new vans fell from 205 gCO_2/km to 182 gCO_2/km.
- Conventional car and van efficiency could feasibly improve by around 41% and 37% on a test-cycle basis and 37% and 33% on a real-world basis respectively between 2010 and 2030:
  - This is equivalent to an average test-cycle CO_2 intensity of 86 gCO_2/km for new cars and 127 gCO_2/km for new vans in 2030 assuming they are tested using the World Harmonised Light-duty vehicle testing Procedure (WLTP), planned for introduction in 2017[85].
  - By 2030 real-world CO_2 emissions for conventional vehicles could be 26% higher than test-cycle emissions, compared to our previous estimate of 21%.
  - This results in an average real-world CO_2 intensity of 108 gCO_2/km for new cars and 160 gCO_2/km for new vans in 2030. While there is scope to reduce this gap in future, it is appropriate to assume real-world CO_2 intensities at this level in the absence of an improved testing procedure (Box 5.3).

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[84] We commissioned Ricardo Energy & Environment to peer review our analysis. More information is available at: www.theccc.org.uk/.

[85] These values are not directly comparable to our previous estimates of 80 gCO_2/km for cars and 120 gCO_2/km for vans as they assumed vehicles were tested using the NEDC, which typically produces lower CO_2 intensity results.

- The average abatement costs of these efficiency improvements are £13t/CO_2 for cars and -£27t/CO_2 for vans for new vehicles in 2030. These cost estimates are higher than our previous estimates (-£80t/CO_2 for cars and -£110t/CO_2 for vans), mainly reflecting the increased gap between real-world and test-cycle emissions and lower projected fuel prices.
- The potential for further conventional efficiency improvements and cost reductions after 2030 is likely to diminish. By 2050 we estimate the real-world CO_2 intensity of the new conventional cars could fall to 85 gCO_2/km at an abatement cost of £4/tCO_2. For new vans, the abatement cost of reducing the real-world CO_2 intensity to 117 gCO_2/km increases to £2/tCO_2 in 2050.

There are also significant opportunities to improve the efficiency of conventional HGVs through measures such as heat recovery, low rolling resistance tyres and weight reduction. Our projections are based on a study[86] we commissioned from AEA in 2012 (little new evidence has become available since then):

- Efficiency could improve by around 13% for small rigid HGVs and by around 33% for larger, articulated HGVs between 2010 and 2030. This is equivalent to a real-world CO_2 intensity of 580-660 gCO_2/km.
- These efficiency improvements are cost-effective, with an average abatement cost of -£79/tCO_2 for a new HGV in 2030. There is significant variation depending on the size of the HGV, with a 2030 abatement cost of £17/tCO_2 for new small rigid HGVs; whilst for new articulated HGVs efficiency improvements could be cost-saving at -£151/tCO_2. The high annual mileage of articulated HGVs makes it relatively more cost-effective to improve their efficiency compared to other vehicles.

Our estimates of conventional vehicle efficiency improvements in 2030 and the associated abatement costs are summarised in Table 5.1. These are all cost-effective relative to the average carbon value projected over the lifetime of a new vehicle in 2030. Improving the efficiency of conventional vehicles is therefore a low-regrets measure and is included in our scenarios.

Table 5.1: Conventional vehicle efficiency improvements in 2030

Mode	Average new vehicle CO_2 intensity in 2030 (gCO_2/km)	Percentage improvement 2010-2030	Average new vehicle abatement cost in 2030 (£/tCO_2)
Cars	108 (86)	37% (41%)	13
Vans	160 (127)	33% (37%)	-27
HGVs	627	24%	-79

Source: CCC analysis.
Notes: CO_2 intensity values are on a real-world basis (test-cycle values shown in brackets).

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[86] AEA (2012) *A review of the efficiency and cost assumptions for road transport vehicles to 2050.*

Box 5.2: New evidence on the cost and efficiency of cars and vans

The European Commission has commissioned Ricardo Energy & Environment to review the future costs of CO_2 reductions from cars and vans. The study will be published later in 2015. Key findings from the study include:

- Opportunities to implement efficiency improvements in conventional cars and vans will increase to 2025 and the costs of these improvements will fall. By 2030, scope for additional conventional efficiency improvements and cost reductions is likely to decrease.
- Efficiency technologies applicable to plug-in electric vehicles, such as weight reduction, aerodynamics and low rolling resistance tyres will help to reduce overall vehicle cost as they enable a smaller battery to be used for a given electric range.
- The inclusion of off-cycle technologies, such as improvements to air conditioning systems, could offer an additional 4-10 percentage point CO_2 savings from conventional vehicles.

A key output of the study is a database of projected performance and cost of CO_2 and energy saving technologies out to 2030, which we have used to update our vehicle cost and efficiency projections. The database was created collaboratively with a group of automotive industry stakeholders.

Source: Ricardo Energy and Environment (Forthcoming) *Improving understanding of technology and costs for CO_2 reductions from cars and LCVs in the period to 2030 and development of cost curves.*

Box 5.3: The gap between real-world and test-cycle emissions

For several years, there has been growing evidence that the gap between real-world and test-cycle emissions for new cars has been increasing. The European Commission recognises the problems with the existing testing procedure (the NEDC) and has proposed the introduction of a new procedure (the WLTP) in 2017. This is expected to reduce the emissions gap, but the extent of this reduction is uncertain.

We commissioned Element Energy and the ICCT to review the evidence on the emissions gap, estimate the impact of introducing the WLTP and examine whether there is any scope for the emissions gap to grow again in future. The study found that there is a considerable emissions gap, which has been growing over time. The WLTP will help to close the gap but there is a risk that it could increase again to 2030. In the longer term an improved testing procedure will be needed to close the gap:

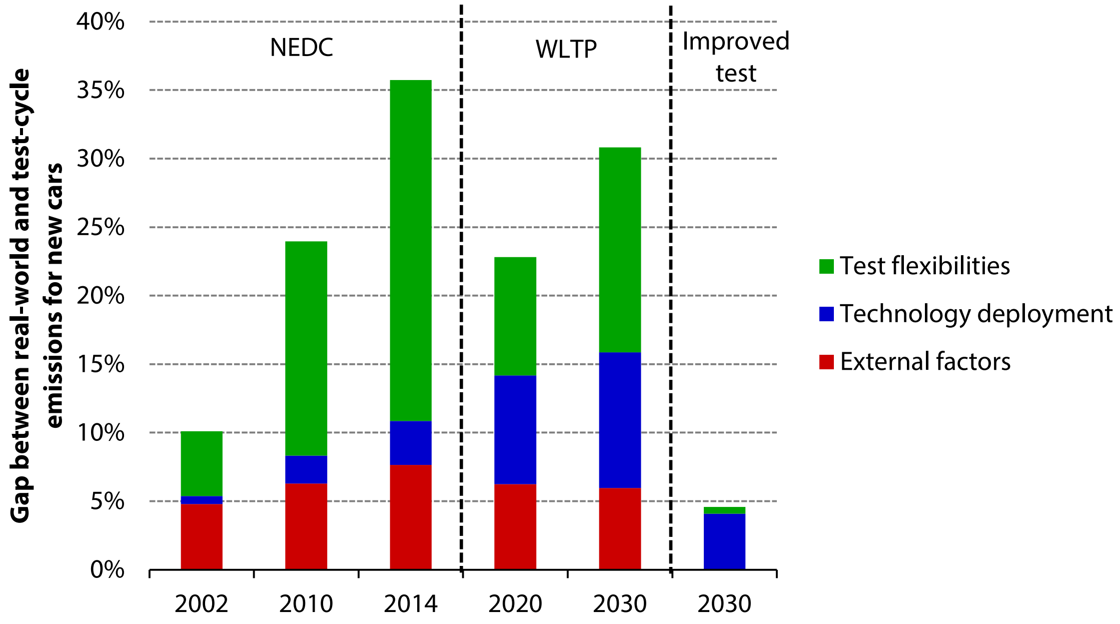
- The report suggests that the emissions gap has grown from 10% in 2002 to around 35% in 2014. This closely matches an historical analysis of data of real-world driving taken from several large European datasets.
- The different factors contributing to the emissions gap are:
  - **Flexibilities** in the testing procedure that can be exploited by vehicle manufacturers, such as tyre preparation, selection of test track, ambient test conditions or using an unrepresentative test vehicle.
  - **Deployment of new technologies** that perform better on the test-cycle than in the real-world, such as start-stop and hybrid systems.
  - **External factors**, such as driving style and use of auxiliary systems, including heating and air conditioning that are not used during the test.

Box 5.3 (cont.): The gap between real-world and test-cycle emissions

- The introduction of the WLTP testing procedure could reduce the gap to around 23% by 2020. However, further flexibilities and changes in vehicle technology could mean that it grows again to around 31% by 2030 (Figure B.5.3). This is partly due to an increasing market share of plug-in hybrid vehicles, which were found to have a gap of 35%, compared to 26% for conventional vehicles under the WLTP.

There are further opportunities to reduce the size of the gap. For example vehicles could be tested on real roads using a Portable Emissions Monitoring System (PEMS) and be randomly tested after purchase in order to minimise scope for using specially prepared vehicles. These measures could reduce the gap to around 5% by 2030 (Figure B5.3).

Figure B5.3: Gap between real-world and test-cycle emissions under different testing procedures



Source: Element Energy and the ICCT (2015) *Quantifying the impact of real-world driving on total CO_2 emissions from UK cars and vans*

These conventional improvements remain the most cost-effective and feasible measure in the short term and will play an important role in decarbonising the fleet to 2030. However, by 2030, scope for further cost-effective efficiency improvements will decline and ultra-low emission vehicles will need to make a more significant contribution to reducing emissions.

Ultra-Low Emission Vehicles

Achieving deep emissions reductions in the transport sector by 2050 will require the use of ultra-low emission vehicles (ULEVs). ULEVs are vehicles with zero or near-zero tailpipe emissions, which make use of electricity from an increasingly decarbonised power sector, either to recharge the vehicle's battery or to produce hydrogen for the vehicle's fuel cell.

Electric vehicles (EVs)

Electric cars and vans

Our projections of the cost, efficiency and other characteristics of electric cars and vans have also been updated using the Ricardo Energy & Environment study[87]. There is a greater potential to improve the efficiency of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) than our previous analysis suggested. This could help to reduce the size of the battery required for a given range and consequently reduce the projected costs of batteries (Box 5.4). Taken together with projected fuel costs, our analysis suggests that new electric cars and vans are likely to become cost-effective from a social perspective during the 2020s:

- **Efficiency**. There are more significant opportunities to improve efficiency through measures such as reducing weight and improving aerodynamics. For example, the real-world efficiency of BEV cars could reach 0.48 MJ/km by 2030 and PHEV car efficiency could reach 0.98 MJ/km. Our previous real-world efficiency estimates were 0.57 MJ/km for BEVs and 1.01 MJ/km for PHEVs by 2030.
- **Range**. The average electric range of BEVs could reach 175km, 240km and 300km for small, medium and large cars and 300km for vans by 2030. For PHEVs the electric range stays constant at 30km and approximately 50% of distance is assumed to be covered in electric mode[88]. These estimates are broadly the same as those used in our fourth carbon budget review.
- **Social costs**. Whilst falling battery costs will significantly reduce the costs of EVs (Box 5.4), our analysis suggests that EV capital costs will remain higher than those of conventional vehicles in 2030. However, EVs have significantly lower running costs due to their high efficiency and the lower cost of electricity compared to petrol and diesel.
  - The average new BEV car in 2030 will have a capital cost premium of around £2,400 compared to an equivalent conventional car. A new PHEV will have a capital cost premium of around £1,200. For vans, we estimate that BEVs and PHEVs will have a capital cost premium of around £2,500 and £600 respectively.
  - In 2030, the average new BEV car will save around £2,100 in discounted fuel costs (before fuel taxes and ignoring the cost of carbon emissions) over its lifetime and a PHEV will save around £900. For vans, the equivalent fuel savings are £4,800 for a new BEV and £3,000 for a new PHEV.
  - Overall, the total social costs of electric cars are expected to be broadly similar to those of conventional cars in 2030 (Figure 5.4). Electric vans are expected to have lower overall social costs than conventional alternatives by 2030.
- **Private costs**. From a private perspective, EV fuel cost savings are more significant due to the inclusion of fuel taxes, but fuel savings in future years are likely to be heavily discounted by consumers.
  - With a private discount rate of 7.5% the average new BEV car in 2030 would have private

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[87] Ricardo Energy and Environment (Forthcoming) *Improving understanding of technology and costs for CO_2 reductions from cars and LCVs in the period to 2030 and development of cost curves.*

[88] Consistent with our uptake modelling based on a study we commissioned from Element Energy in 2013 (section 4) and broadly in line with the forthcoming Ricardo Energy and Environment report.

fuel cost savings[89] of around £7,300 over its lifetime and an equivalent PHEV would save £3,900, meaning EVs have lower overall private costs than conventional cars (Figure 5.4).

  - Consumers typically make purchasing decisions based on fuel cost savings over shorter periods than the vehicle lifetime. If the period over which fuel cost savings are considered is reduced to five years, EVs have slightly higher overall private costs than conventional cars in 2030 (Figure 5.4).
  - In addition to economic costs, consumers will consider perceived costs associated with vehicle characteristics, such as range, refuelling time and access to infrastructure. These factors are included in our uptake modelling (section 4).

- **Abatement costs**. Our cost projections suggest that by 2030 average abatement costs for new BEVs will be £34/tCO$_2$ for cars and -£51/tCO$_2$ for vans. For PHEVs these costs are £10/tCO$_2$ for cars and -£74/tCO$_2$ for vans. Abatement costs for all new electric cars and vans fall below our projected carbon values during the 2020s. After 2030 our analysis suggests costs will continue to fall for BEVs but opportunities to reduce the costs of PHEVs will lessen.

Our updated analysis confirms that electric cars and vans are likely to become cost-effective during the 2020s. Importantly, these results suggest that by 2030 electric cars will have broadly similar abatement costs to conventional efficiency improvements and electric vans will be cost saving. After 2030, EVs will become increasingly cost-effective while at the same time there will be fewer opportunities for further conventional efficiency improvements.

Box 5.4: Electric vehicle battery costs

Battery costs currently make up around 50% of the cost of a BEV car. Reductions in these costs will be a key driver in helping EVs compete with conventional cars. In 2012 we commissioned Element Energy to develop a model to estimate future battery costs. New analysis of the emerging market for EVs suggests that battery costs may be falling more rapidly than previously thought.

- Analysis based on the Element Energy study from 2012 suggests that the costs of a 30kWh battery pack (typically used in a medium sized BEV car at present) could fall by over 60% from around £12,000 in 2013 to around £4,000 in 2030.
- A recent study* found that battery costs fell by around 14% per year between 2007 and 2014 and suggested that they could reach $200/kWh by 2020. For a 30kWh battery this is equivalent to the total pack cost falling to under £4,000, a decade earlier than our projections assumed.
- Given the small size of the current market for EVs, there is uncertainty around whether current trends are a reliable indicator of future costs. The Element Energy study involved a more detailed consideration of the different factors that would influence battery costs if production were to be scaled up, so we retain these more conservative cost estimates. However, we have assessed the potential impact of lower battery costs on the level of EV incentives required as a sensitivity to our central assumptions (section 4).

The costs of battery technology are evolving very rapidly and should be closely monitored to continually assess the cost-effectiveness of the technology.

Source: Element Energy (2012) *Cost and performance of EV batteries*; *B. Nykvist and M. Nilsson (2015) *Rapidly falling costs of battery packs for electric vehicles*, Nature Climate Change.

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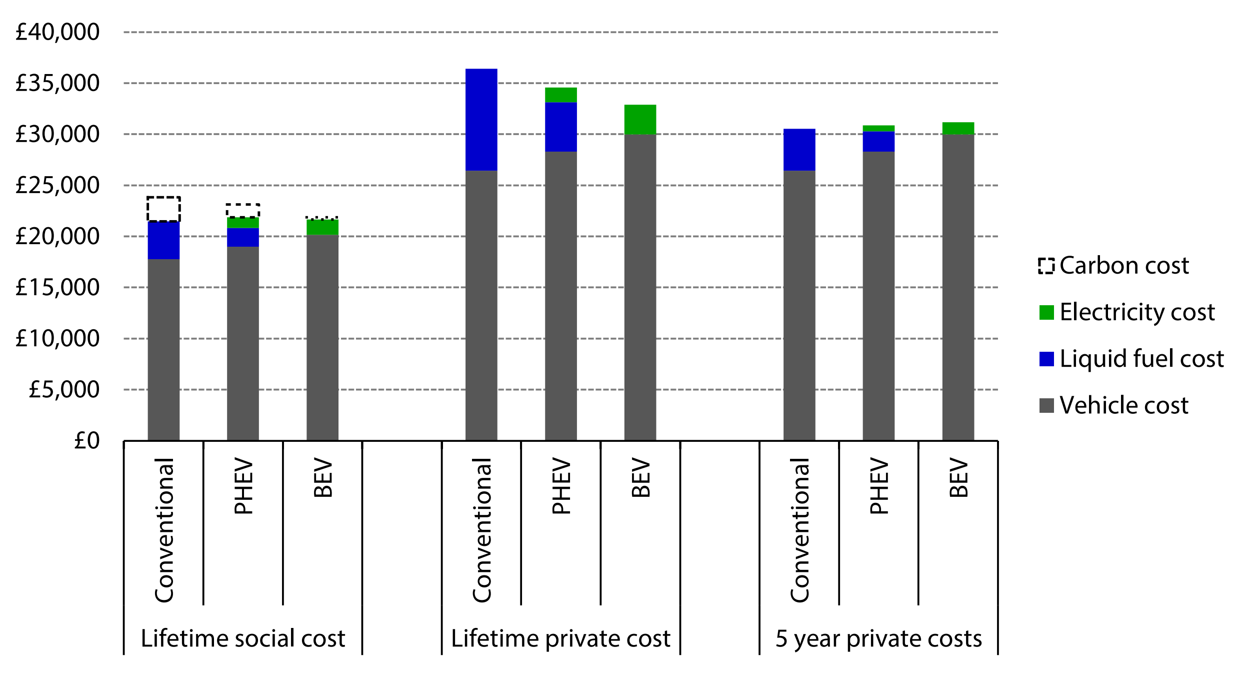
[89] This includes fuel duty, VAT and additional electricity costs from low-carbon power generation.

Figure 5.4: Conventional and electric car costs from a social and private perspective in 2030



Source: CCC analysis.
Notes: Costs are for a new medium sized car in 2030 in 2014 prices. The vehicle lifetime is assumed to be 14 years. Private vehicle costs include VAT and manufacturer margin. Private fuel and electricity costs include fuel duty, VAT and the additional costs of low-carbon power generation. We use a discount rate of 3.5% for social costs and 7.5% for private costs.

Electric HGVs and buses

Whilst long-distance HGVs and buses are difficult to electrify, as they require large, heavy batteries, plug-in electric small urban delivery trucks and buses are a technically feasible option. Our analysis suggests they could become cost-effective during the 2020s:

- Electric HGVs and buses were not included in our fourth carbon budget review scenarios due to uncertainty over their technical feasibility. However, there is an emerging market for plug-in electric small HGVs and buses, driven partly by the need to improve air quality in cities:
  - Manufacturers such as Tevva[90] and Paneltex[91] have recently released small HGVs either partially or fully powered by electricity. Depending on the degree of hybridisation, these electric trucks have batteries of 60-100kWh, providing electric range of up to 190km.
  - Transport for London (TfL) has been using single decker fully electric buses for several years and plans that every single decker bus operating in Central London will be zero-emission by 2020 in order to reduce air pollution in its Ultra-Low Emission Zone[92]. TfL is also trialling fully electric double decker buses[93].

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[90] http://www.tevva.com/
[91] http://www.paneltex.co.uk/electric.html
[92] https://tfl.gov.uk/modes/driving/ultra-low-emission-zone
[93] https://www.london.gov.uk/media/mayor-press-releases/2015/06/pure-electric-double-decker-london-bus-trial-announced-at-world

- We estimate that small PHEV HGVs could have an electric range of 100km by 2030, which would allow them to operate in electric mode approximately 50% of the time[94]. Small BEV HGVs could have an electric range of 240km by 2030, which may not be suitable for all applications so uptake is likely to be relatively limited until after 2030. We estimate that BEV buses could have a range of 250km by 2030.
- Our analysis suggests that in 2030 new small PHEV and BEV HGVs will have abatement costs of £20/tCO_2 and -£12/tCO_2. Our estimated abatement cost for a BEV bus in 2030 is £12/tCO_2.

Electric vehicle summary

Our updated evidence indicates that EVs will become cost-effective from a social perspective in the 2020s and have similar abatement costs to conventional efficiency improvements in around 2030. At the same time their electric range is likely to increase, helping to make them a more attractive option to drivers. If fuel taxes are included then the fuel cost savings are even more significant from a consumer perspective; the implications of this for EV uptake are covered in more detail in section 4. Our estimates of the costs and characteristics of EVs compared to conventional vehicles in 2030 are summarised in Table 5.2.

Table 5.2: Costs and characteristics of electric vehicles in 2030

Mode		Capital cost premium (£)	Lifetime social fuel cost saving (£)	Lifetime private fuel cost saving (£)	Electric range (km)	Average new vehicle abatement cost in 2030 (£/tCO_2)
Cars	**PHEV**	£1,200	£900	£3,900	30	10
	BEV	£2,400	£2,100	£7,300	230	34
Vans	**PHEV**	£600	£3,000	£10,100	30	-74
	BEV	£2,500	£4,800	£17,000	300	-51
Small HGVs	**PHEV**	£12,100	£9,800	£45,400	100	20
	BEV	£19,000	£22,700	£96,300	240	-12

Source: CCC analysis.
Notes: For cars, figures are averages weighted according to 2013 sales splits for fuel type (petrol or diesel) and size (small, medium or large).

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[94] Based on CCC analysis of HGV trip lengths from Road Freight Statistics.

Hydrogen fuel cell vehicles

While plug-in electric vehicles will be a feasible ULEV option for many short range and light-duty applications, hydrogen fuel cells are likely to become a feasible zero-emission solution for longer range and heavier vehicles. However, barriers to the adoption of fuel cell vehicles are significant given the new infrastructure required to produce and distribute the hydrogen. We have updated our cost and feasibility projections for the use of different types of fuel cell vehicle, informed by a new study we commissioned from E4tech and UCL to review the potential for using hydrogen in different sectors of the economy[95].

Our analysis suggests that while fuel cell cars are likely to have a high capital cost premium in 2030, buses could be cost-effective by that time. Further research and development will be needed to bring fuel cell HGVs into the market by 2030:

- The costs of hydrogen fuel cell cars and vans are expected to fall but a high capital cost premium will remain in 2030 (around £6,000 for a medium sized car) and a higher running cost premium (around £700 for a medium sized car) compared to conventional vehicles. In addition, refuelling infrastructure is likely to be sparsely distributed around the country, meaning that fuel cell cars and vans are only likely to be used for applications with fixed routes or that return to a specific location near a hydrogen refuelling station.
- Hydrogen fuel cell buses are already in use in a number of cities in the UK[96]. As buses tend to refuel at centralised depots, they do not require widespread refuelling infrastructure, which makes them an ideal candidate for using hydrogen. By 2030, fuel cell buses are projected to become cost-effective, with abatement costs of £42/tCO_2. This is slightly higher than the costs of electric buses, but it may not be feasible to operate electric buses with a limited range on longer bus routes, in which case fuel cell buses may be more suitable.
- Hydrogen fuel cells are a technically feasible option for large, long-distance HGVs although further research and development is needed before vehicles can be brought to market. Without significant improvements to the density of hydrogen storage, long-distance HGVs would need to carry a large hydrogen storage tank. It is likely that this would require large HGVs to be redesigned, potentially as longer vehicles, so that they are able to carry both the fuel storage tank and a payload equivalent to that carried by a conventional HGV. Taking account of the low level of technology readiness, we do not anticipate hydrogen fuel cell HGVs coming to market until around 2030. Given the uncertainties, it is important to consider alternative options for reducing emissions from HGVs (Box 5.5).

With relatively high costs and a lack of refuelling infrastructure, widespread uptake of hydrogen fuel cell vehicles is unlikely before 2030. Beyond 2030 there is scope for their deployment, particularly in strategically important applications such as large, long-distance HGVs where there are technical barriers to electrification.

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[95] E4tech et al (2015) *Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target*

[96] *UK's largest hydrogen production and bus refuelling station opens in Aberdeen*. Available at: http://www.aberdeencity.gov.uk/CouncilNews/ci_cns/pr_hydrogenfuel_110315.asp

Box 5.5: Low carbon options for large, long-distance HGVs

In addition to hydrogen fuel cell HGVs, there are other low carbon HGV options that could potentially be used over the long term.

Natural gas fuelled HGVs

Natural gas fuelled HGVs could offer tailpipe emissions savings of around 10% compared to diesel fuelled HGVs, but higher lifecycle emissions and emissions of methane from the vehicle could reduce these savings.

- There is a wide variation in lifecycle emissions from the production and transportation of natural gas depending on whether it is produced in the UK or imported. In many cases it can have higher lifecycle emissions than diesel.
- There is some evidence that methane can leak through the exhaust while the HGV is in-use (methane slip), particularly in retrofitted dual-fuel vehicles. As methane has a global warming potential 25 times greater than CO_2 even a small amount of methane slip can offset GHG savings.
  - A 2014 Ricardo-AEA study for DfT found that a dual-fuel vehicle substituting 60% of its diesel for LNG has well-to-tank GHG savings of around 6%, but if more than 2% of the methane entering the tank leaves the vehicle unburned this would completely offset the GHG saving.
  - Biomethane could offer more significant savings, but the available resource is likely to be better used in the power and buildings sectors (Box 5.6).

Given the relatively small potential CO_2 savings available and the potential risks, it is important that lower carbon options for HGVs are fully explored rather than relying on natural gas use in HGVs to help meet the 2050 target.

Wireless recharging through the road

Large, long-distance HGVs are not suitable for conventional electrification as they would require an excessively large battery for long-distance movement of goods. However, recent developments in wireless power transfer have opened up the possibility of fitting HGVs with smaller batteries that can dynamically recharge via coils beneath the surface of the road whilst on the move. This technology has been proven to work on buses in South Korea[97] and in 2015 Highways England published a feasibility study for introducing the technology on key sections of the UK's road network[98]. The study found that there were no significant technical barriers to implementing such a system, but there are high capital costs associated with installing the infrastructure (around £5m per km of motorway in present value terms over 20 years). Over the next few years, Highways England is funding off-road and on-road trials of the technology to further explore its feasibility.

Biofuels

Biofuels offer a potential solution for difficult-to-decarbonise sectors, such as aviation and HGVs. However, by 2050 there will be an increasingly limited supply of sustainable bioenergy as international demand grows. Given high levels of uncertainty over lifecycle emissions and future cost reductions, continued use of biofuels in HGVs in 2050 should be seen as an option to be used only if others fail to materialise.

Source: CCC analysis.

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[97] IEA (2015) *EV City Casebook*

[98] TRL (2015) *Feasibility study - powering electric vehicles on England's major roads*

Biofuels

Biofuels can be blended with conventional petrol and diesel and are typically counted as zero carbon at the point of combustion. Key considerations for the potential increased use of biofuels are supply, sustainability and costs:

- **Supply**. Biofuels can come from a range of different feedstocks, such as waste materials, food crops or other non-food biomass. Supply and uptake of biofuels are currently driven by EU regulation. In the long term the supply of biofuels available for transport is likely to be limited:
  - Biofuels derived from food crops are typically referred to as first generation whereas biofuels derived from non-food crops are generally referred to as second generation or advanced biofuels. Advanced biofuels are unlikely to be available at scale until the 2020s due to high costs and difficulties scaling up production processes.
  - Uptake of biofuels is currently driven by the EU Renewable Energy Directive (RED) target, under which 10% of transport energy must come from renewable sources by 2020.
  - Constraints on the availability of land and increasing international demand for bioenergy mean that the available resource will be limited in the long term. In addition, there is competition for this limited bioenergy resource from other sectors within the UK, where it could be better used (Box 5.6).
- **Sustainability**. The sustainability of biofuels must be assured. The extent to which biofuels reduce total GHG emissions depends on a wide range of factors, such as how the biofuel is manufactured and transported and what was displaced from the land used to produce the biofuel. The GHG savings from biofuels used in the UK is increasing due to EU sustainability criteria, but this does not take account of emissions from indirect land use change (ILUC):
  - Evidence from our 2011 Bioenergy Review[99] suggested that lifecycle emissions could significantly reduce GHG tailpipe savings and in some cases increase overall GHG emissions. Crop-derived biofuels typically have the lowest GHG savings, whereas waste-derived and advanced biofuels can offer more significant savings.
  - The RED target is likely to be met largely through crop-derived and waste-derived biofuels but sustainability concerns have led the EU to cap the contribution of crop-derived biofuels at 7%. Certain waste-derived and advanced biofuels that meet sustainability criteria are double counted, which means that the uptake of biofuels is likely to be less than 10% in 2020.
  - A key concern over the use of biofuels is that they contribute to emissions from ILUC. This can occur when the growth of bioenergy crops displaces an existing economic activity to new land, leading to additional emissions being released. ILUC emissions are more difficult to measure, resulting in a wide range of estimates.
  - The sustainability of biofuels used in the UK has been increasing over time, with average GHG savings of 69% in 2013/14[100], excluding ILUC emissions. The Government does not routinely estimate ILUC emissions but, in their 2014 Draft Post-Implementation Review of the Renewable Transport Fuels Obligation, DfT estimated that ILUC emissions reduced the

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[99] CCC (2011) *Bioenergy Review*

[100] DfT (2015) *Renewable Transport Fuel Obligation statistics*

average GHG savings of UK biofuels from 67% to 56% in 2012/13[101].

- **Costs**. Biofuel costs are typically higher than those of conventional fuels but there is some scope for their costs to fall:
  - We have updated our biofuel cost projections using the outputs of a report published by the Low Carbon Vehicle Partnership in 2015[102]. These projections are largely based on recent trends in biofuel prices, which have not fallen as anticipated. Under central assumptions, the projections suggest that there could still be a cost premium over conventional fuels in 2030 of around 10 pence per litre for first generation biofuels and around 30 pence per litre for advanced biofuels. Previous projections suggested that biofuels could reach cost parity with conventional fuels by 2030.
  - By 2030 we assume bioethanol is 70% crop-derived and 30% advanced biofuel, while biodiesel is 60% waste-derived, 30% crop-derived and 10% advanced biofuel. Assuming a 100% GHG saving, this implies abatement costs of £112t/CO_2 for bioethanol and £106/tCO_2 for biodiesel. Real-world abatement costs are likely to be higher given the probability that GHG savings will be less than 100%.

Box 5.6: Bioenergy competition with other sectors

Beyond 2030 there will be increasing competition between different sectors, such as power, buildings and transport, for a limited bioenergy resource, due to limits on available land and increasing demand for bioenergy from other countries. While it is appropriate to have limited biofuel use in surface transport in the medium term, it may not be best place to use them in future.

- If Carbon Capture and Storage is developed, this could be combined with bioenergy to provide a negative emissions technology (Chapter 1).
- In future, liquid biofuels could be better used in aviation and shipping where low-carbon options are more limited.
- Gaseous biofuels could be injected directly into the gas grid for use in power and buildings without additional compression or liquefaction often required for use in surface transport, which carries an energy penalty. Biogas use in power with CCS would have the additional benefit of providing negative emissions.

Source: CCC analysis.

Uncertainty and longer-term considerations

Our analysis implies that biofuels are unlikely to be cost-effective compared to carbon values by 2030. However, these cost projections are highly uncertain. EU regulation will drive increases in biofuel production to 2020 and with this investment in place there is a case for continued but limited use of biofuels to 2030:

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[101] DfT (2014) *Draft Post-Implementation Review of the Renewable Transport Fuels Obligation*

[102] LowCVP (2015) *Transport Energy Task Force: Options for transport energy policy to 2030*

- The “low” scenario cost projections from the Low Carbon Vehicle Partnership study imply abatement costs of £21/tCO$_2$ for bioethanol and £7/tCO$_2$ for biodiesel based on 100% GHG savings. Even with real-world GHG savings as low as 30% it would be cost-effective to use biofuels under this scenario.
- The RED target will increase production of biofuels to 2020. Given the investment required to meet this target, biofuel use would likely be maintained at a constant level during the 2020s.
- There is also a case for supporting biofuel production in the medium term to help bring down the costs of advanced biofuels for potential future applications, such as in aviation or in HGVs if other low carbon options fail to develop.

In summary, biofuel use will need to be increased by 2020 to meet EU renewable energy targets, with scope for an increasing proportion to come from more sustainable, advanced feedstocks. New cost projections suggest that biofuels might not become cost-effective by 2030 but there is a wide range of uncertainty and there remains a case for their limited use during the 2020s.

Behaviour change in passenger transport

Whilst a supply of low-carbon technologies and fuels is crucial to reducing emissions from transport, individual behaviour can also affect emissions through choosing to avoid a journey, choosing a lower carbon mode or altering driving style.

Reducing demand for car travel

We have assessed the potential for reducing demand for car travel by estimating which car trips might be amenable to avoiding or shifting to lower carbon alternatives. The costs of these reductions are highly uncertain but could be entirely offset by societal benefits, such as reduced congestion and improved air quality:

- An evaluation of DfT’s Sustainable Travel Towns programme[103] suggests that measures such as public information campaigns can reduce urban car travel by 5-7%. Deeper cuts are likely to require more significant interventions such as increased provision of cycling infrastructure or more reliable and convenient rail and bus services.
- Analysis of the National Travel Survey (Box 5.7) suggests that through switching to other modes, car-km could be reduced by 3-10% below the baseline scenario, with a central estimate of 5%. This is equivalent to 14-36% of trips, as we assume that the shortest trips are most amenable to modal shift.
- Estimating the costs, impacts and benefits of measures to reduce demand for car travel is difficult due to a number of factors, including the long time periods involved and variability between schemes.
  - **Costs depend on location and measures employed**. Scheme cost will vary with the type of measure selected, for example infrastructure may have higher upfront costs than an information campaign. Higher population density in urban areas can result in infrastructure and public transport services costing less per person than in rural areas.
  - **Impacts depend on the location and length of the project**. Urban journeys are typically shorter and therefore more amenable to shifting away from the car. Whilst new infrastructure may have a positive impact for a number of years, expenditure on bus

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[103] Sloman, L. et al (2010) *The effects of Smarter Choice programmes in the Sustainable Travel Towns: full report*

services or information campaigns may only have an impact for as long as they are funded.

  - **The benefits of reduced car travel go beyond CO_2 savings**. A recent DfT study estimated that CO_2 savings contribute just 1% to the total benefits of the Local Sustainable Transport Fund[104]. The majority of the benefits were found to be due to reduced congestion but other benefits included health, road safety, noise reduction and improved air quality. The Sustainable Travel Towns evaluation estimated that improvements to health, plus time and cost savings, resulted in a benefit of around £9 for every £1 spent.

- Given the potential for additional benefits and the difficulties in accurately estimating the costs of reducing demand for car travel, we assume that the savings in our scenarios from such measures come from cost-effective schemes, with zero overall cost to society.

We do not prescribe the exact mechanisms by which the demand reduction in our scenarios is achieved, but it is likely to require a combination of investment in public transport, cycling and walking infrastructure, use of public information campaigns and/or better land-use planning. The specific levels of car-km reduction included in our scenarios are described in section 4.

While policies can help to reduce or avoid car usage, demand for travel is also influenced by a range of other socio-economic factors, such as new business-models for car usage and developments in autonomous vehicle technology:

- Car clubs and car sharing have the potential to reduce demand for car travel.
  - Drivers have been found to reduce their annual car mileage by around 22% after joining a car club[105]. However, the effectiveness of car clubs in reducing emissions depends in part on the availability of a reliable public transport network.
  - Alternative business models are being developed offering consumers new opportunities to travel by car without owning one. For example, new on-demand travel services such as Uber, a taxi service delivered through a smartphone app, and DriveJoy, a peer-to-peer car rental business. The impact of such services on demand for travel is uncertain.
- Autonomous vehicle technology is beginning to emerge and the Government is preparing new regulation to enable its use on UK roads[106]. The impacts of the technology on CO_2 emissions from road transport are highly uncertain due to trade-offs between increased efficiency and increased convenience that could increase demand.
  - Autonomous vehicles should be able to optimise driving style to increase efficiency. If vehicles are also connected, traffic flows could be further optimised to reduce congestion. Without the need for a driver, autonomous vehicles could also be radically redesigned to reduce their weight and improve efficiency.
  - Despite the potential benefits, on-demand, cheap, driverless vehicles could increase demand for car travel. Though highly uncertain, initial estimates suggest demand could increase by as much as 160%[107]. However, fully driverless car technology is unlikely to be widely available before 2030 and the impact of an increase in demand on emissions could be managed if there is a significant shift to EVs.

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[104] DfT (2014) *Value for Money Assessment for the Local Sustainable Transport Fund.*

[105] Carplus (2014/15) *Annual survey of car clubs. England and Wales (excluding London).*

[106] DfT (2015) *The Pathway to Driverless Cars: Summary report and action plan.*

[107] MacKenzie, D. et al (2014) *A First-order Estimate of Energy Impacts of Automated Vehicles in the United States.*

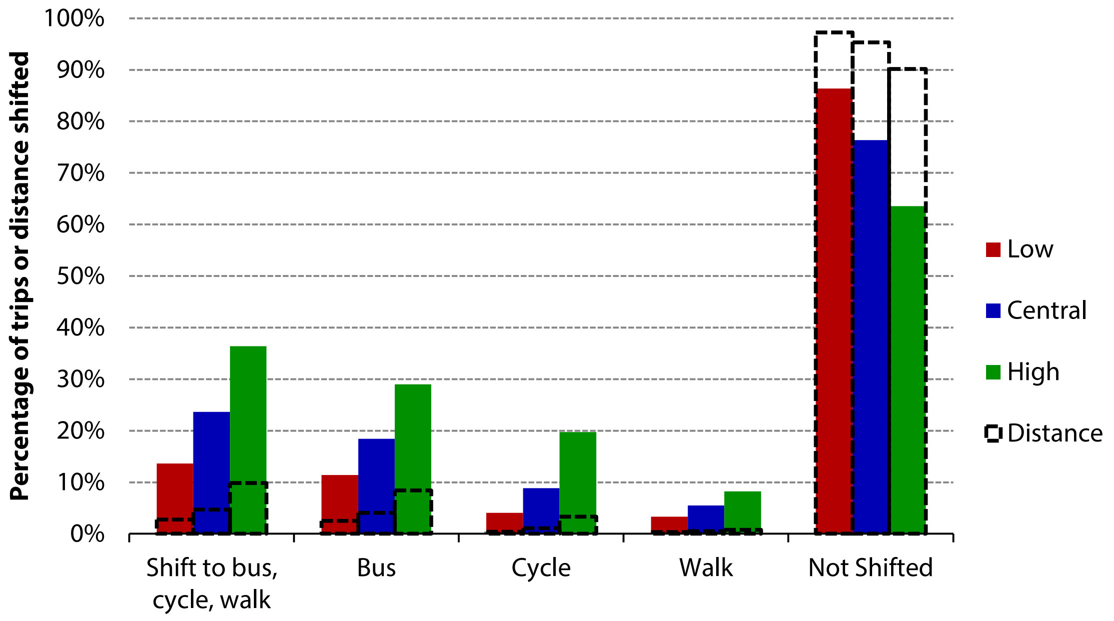
As the extent and impact of these factors is not yet fully understood, we have not explicitly included them in our scenario. However, it will be important to monitor developments and review their potential impact on future emissions.

Box 5.7: Opportunities to shift car journeys to low or no carbon alternatives

The National Travel Survey (NTS) provides a representative picture of trips (mode, length, duration, purpose, location etc.) taken across Great Britain. Using this data we have identified a set of car trips that might be amenable to switch to a lower carbon mode. The trips were assessed against a number of criteria including distance, time of day, purpose, age of traveller and an urban/rural identifier. This analysis suggests that 24% of car trips with the shortest length, representing 5% of car kilometres, could be switched to bus, cycling or walking given the appropriate policy support and investment. Around 26% of urban trips could be shifted away from the car compared to only 16% of rural trips.

We assume that in a low scenario 14% of total car trips could switch (3% of car kilometres) and in a high scenario this could increase to 36% of total car trips (10% of car kilometres) (Figure B5.7).

Figure B5.7: Opportunities to shift car journeys to low or no carbon alternatives



Source: CCC analysis of National Travel Survey data.

More fuel efficient driving

As car emissions vary with factors such as speed and acceleration, improving driving style can play an important role in reducing emissions. Measures to encourage more fuel efficient driving include fitting cars with technology to promote "eco-driving" and enforcing the speed limit:

- Since 2014 it has been mandatory for new cars to be fitted with Gear Shift Indicators (GSIs), which have been found to reduce fuel consumption by an average of 1.5%[108]. In September 2015, the European Parliament voted in favour of mandatory inclusion of fuel consumption meters (FCMs), which can reduce fuel consumption by 0.3-1.1% by providing the driver real-time information on the fuel efficiency of their driving[109]. In total, these technologies could reduce fuel consumption by around 2%.
- Driving at higher speeds can reduce fuel efficiency due to factors such as additional air resistance. We have analysed the potential to reduce emissions by enforcing the speed limit at 70mph on motorways and dual carriageways, taking account of the fraction of drivers who currently break the speed limit and the fraction of vehicle-km on these road types. This analysis suggests that full enforcement of the speed limit could reduce overall fuel consumption by around 2%. Reducing the speed limit to 60mph on these roads could reduce fuel consumption by around 7%.

Improvement in freight operations

Emissions from road freight can be reduced by the actions of freight operators, through retrofitting existing vehicles with fuel saving technologies, training drivers to drive more efficiently, reducing vehicle-km through more efficient logistics and shifting to less carbon intensive modes such as rail. We have commissioned a new study from the Centre for Sustainable Road Freight (CfSRF) to assess the scope of such demand-side measures (Box 5.8). Based on this analysis we have estimated the potential to reduce CO_2 emissions:

- Cost-effective opportunities to improve fuel efficiency through retrofitting and driver training are available. However, these vary by vehicle type and there is uncertainty over how feasible it will be to roll-out these measures across the whole sector.
  - Analysis based on the study from CfSRF suggests that measures, such as driver training and retrofitting aerodynamic improvements, are cost-effective from both a social and private perspective. Further roll-out of such measures could improve efficiency by around 13% for small rigid HGVs and 22% for large articulated HGVs by 2030. Around 65% of these savings come from improved driver training with the remainder coming from retrofitting.
  - Given the time and resources required to implement such a comprehensive package of measures, there is a wide range of uncertainty over the extent to which smaller operators will be able to do this. We estimate that the measures could be feasibly implemented on 50-100% of HGVs, with a central estimate of 80%.
- Improved logistics and shifting freight to rail could reduce emissions by 9% for small rigid HGVs and 11% for articulated HGVs by 2030. The majority of these savings are from improved logistics, with fuel savings of less than 1% from modal shift. If more challenging barriers could be overcome, such as assuring the safety of longer, heavier vehicles, these savings could be increased to 11% for small rigid HGVs and 25% for articulated HGVs.

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[108] European Parliament (2015) *Reduction of pollutant emissions from road vehicles.*

[109] European Parliament (2015) *Reduction of pollutant emissions from road vehicles.*

Box 5.8: Opportunities for improvements to freight operations in the HGV sector

We commissioned the CfSRF to assess the opportunities and barriers to reducing emissions from road freight through improvements to freight operations:

- The study used a model of the UK freight sector, splitting freight activity by economic sector, vehicle type and journey type. Different measures were applied to eligible groups of vehicles, with estimates of the relevant uptake rates and fuel savings based on a literature review and a series of freight sector focus groups. The model was then used to estimate emissions savings to 2035 under a range of scenarios.
- The costs of measures applied to individual vehicles (retrofitting technologies and driver training) were assessed from both social and private perspectives. These costs were found to be similar as the higher discount rate and shorter payback for private costs was offset by higher cost savings due to the inclusion of fuel taxes. It was more challenging to estimate the costs of logistics measures, which are implemented at a fleet level, with significant variation in their nature and scale. Instead, freight operators were surveyed on feasible uptake rates for different measures, which were then assumed to be cost-effective in that application.
- The study found that these measures could save 5-7 $MtCO_2$ by 2035, with a central estimate of 6 $MtCO_2$. Around 42% of the estimated savings in 2035 came from improvements to logistics operations, such as improved routing, use of consolidation and distribution centres, higher lading factors, a reduction in empty running and use of longer, heavier vehicles. Another 42% came from driver monitoring and fuel efficiency training, which was found to be highly cost effective. The remaining savings came from technological improvements to existing vehicles, such as retrofitting of aerodynamic fairings or low rolling resistance tyres.
- A further 0.5 $MtCO_2$ could be saved by shifting 35% road freight transport over 300kms onto rail by 2035, in line with the EU's target for rail freight.
- Three key non-financial barriers need to be overcome to achieve these savings:
  - **Attitudes to collaboration**. Measures such as use of consolidation and distribution centres require collaboration between freight operators. Barriers include concerns over sharing commercially sensitive data, identification of potential collaborative partners and a lack of clarity around competition law.
  - **Regulation for longer-heavier vehicles**. Currently, longer, heavier vehicles are only allowed to operate on UK roads as part of a Government trial. Before they could be used more widely, this trial must complete its assessment of the circumstances in which they can be used safely.
  - **Land use planning**. There is little data on freight movements at local authority level, which can mean that local transport plans and land use policies do not enable more efficient urban freight solutions. A key example of this is the use of Urban Consolidation Centres (UCCs), which can be effective at reducing freight traffic and emissions in urban areas. Local authorities would benefit from more guidance and advice on UCCs, with a particular focus on demonstrating the benefits of existing successful schemes, to ensure that they are considered as part of local freight transport strategies and land use policies.

Given the challenging nature of some of these barriers, we have developed our own set scenarios using the outputs of this study with slightly lower uptake of key measures. In particular, we assume lower levels of UCC use and no use of longer heavier vehicles. We also assume lower levels of uptake of vehicle-level interventions as smaller freight operators are likely to find it challenging to implement such a comprehensive package of measures.

Source: CfSRF (2015) *An assessment of the potential for demand-side fuel savings in the HGV sector.*

Rail electrification

Currently around 40% of the rail network is electrified and around 60% of rail passenger journeys are on electric trains. Further rail electrification could reduce emissions through displacement of diesel trains, particularly as the carbon intensity of the grid reduces over time. Emissions can also be reduced through the technologies and improvements that can be applied with electrification such as optimising speed and use of energy storage. The Government has identified a number of cost-effective opportunities to further reduce emissions from rail[110]:

- Currently committed schemes will increase electrification to 51% of track mileage, while additional schemes with a reasonable business case (benefit-cost-ratio greater than 1.5) would raise this to 56%.
- Roll-out of battery technology would help to electrify trains on stretches of the track not suitable for overhead cables. New battery powered trains could be applied to 0-15% of diesel mileage, with a central scenario of 5%.
- Further diesel energy efficiency improvements are likely to be made through improvements in transmission systems, engine modifications, on-board energy storage and Driver Advisory Systems. Energy efficiency savings could be 5-20%, with a central scenario of 10%.

Electrification requires significant upfront investment in infrastructure such as masts, overhead lines and associated power and control equipment. For example, a major route like the Great Western Main Line will cost more than £1 billion to electrify. The business case for electrification is driven mainly by reductions in operating costs as well as improvements in capacity and reductions in journey time. Reductions in carbon emissions do not have a significant impact on the business case and electrification tends to make most sense on busier lines where the operational savings and performance benefits offset the capital costs. Therefore it is unlikely to be cost-effective to electrify the entire rail network.

b) Options for decarbonising aviation and shipping

Aviation emissions scenarios

The key drivers of future aviation emissions are demand for air travel and the carbon intensity of flying:

- **Demand for air travel**. The key drivers of demand will include future GDP growth, and fuel and carbon prices which feed through to ticket prices. Demand for air travel is particularly sensitive to changes in income rather than ticket prices, and will also be affected by the availability of alternatives to air travel (e.g. rail and potentially video conferencing).
- **Carbon intensity of flying**. There are a range of options available to reduce the carbon intensity of aviation. These include improving the fuel efficiency of aircraft through engine and airframe developments, through efficiency improvements in air traffic management and in airlines' operational practices, and through use of sustainable biofuels.

In the absence of measures, aviation emissions are likely to continue to increase. In our previous reports[111], we set out analysis of the path for aviation emissions to 2050. This concluded that appropriate long-term assumptions for Government planning are for aviation emissions to be

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[110] Unpublished DfT analysis shared with CCC.

[111] For example, see CCC (2009) *Meeting the UK aviation target – options for reducing emissions to 2050* and CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*

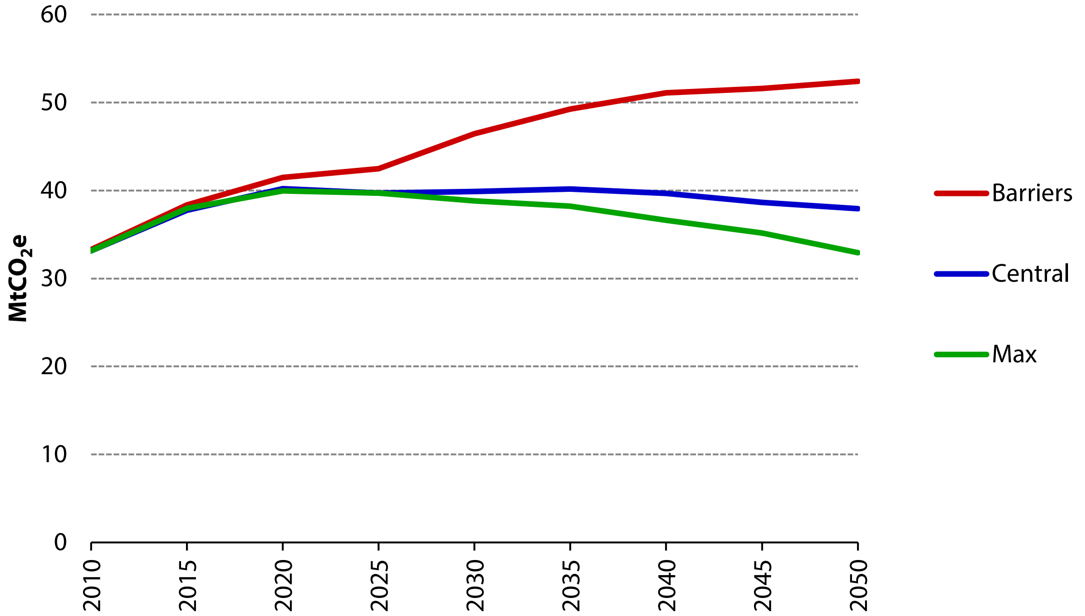
around 2005 levels in 2050 (i.e. 37.5 $MtCO_2$). Under our 'Likely' scenario this was achieved through a 0.8% annual improvement in fuel efficiency, 10% take-up of biofuels, and by constraining demand growth to around 60% above 2005 levels in 2050.

For this report we commissioned DfT to model a number of emission scenarios to 2050 to test the achievability of our planning assumption. Our scenarios cover different uptake rates of abatement options:

- **Central emissions scenario**. Emissions are capped at 37.5 $MtCO_2$ in 2050, in line with our planning assumption.
- **High emissions 'Barriers' scenario**. Emissions are not capped and only low abatement options are available.
- **Low emissions 'Max' scenario**. High abatement options are delivered.

In 2050, the Central scenario meets our planning assumption of 37.5 $MtCO_2$, of which international aviation emissions are 36.2 $MtCO_2$. In the Barriers scenario emissions are higher, at 51.9 $MtCO_2$, and in the Max scenario emissions are lower at 32.6 $MtCO_2$ (Figure 5.5).

Figure 5.5: UK aviation emission scenarios (2010-2050)



Source: DfT projections for CCC (2015).

Under our central scenario, which is designed to meet the 2050 planning assumption, emissions would be unaffected by the assumed level of runway capacity. To the extent that additional runway capacity was provided in future, there would need to be less growth in demand and hence emissions at other airports in order to stay within the overall planning assumption (or higher abatement options would have to be delivered).

The key conclusion from our analysis is that our original planning assumption remains appropriate and feasible. In order to achieve this, additional policies will be needed. For example, the International Civil Aviation Organisation (ICAO) is currently developing a market based measure to reduce international aviation emissions and aiming to agree this in autumn 2016. We will monitor the outcome of these talks closely to assess consistency with our planning assumption and provide further advice if necessary.

Inclusion of international aviation emissions in carbon budgets

In principle, emissions from international aviation should be included in carbon budgets unless there are strong practical considerations which prevent this. Where they cannot be included, budgets must be set such that the 2050 target in the Act can be met including these emissions – that has been the approach to date and is continued in this report.

Currently, inclusion of international aviation remains impractical, given the design of the EU ETS for aviation and ongoing uncertainty about how this will be treated in future:

- Given that aviation is included in the EU ETS, accounting rules for carbon budgets suggest that if international aviation is to be included in carbon budgets then it should be on the basis of UK allowances rather than on a gross basis (e.g. bunker fuels). However, the current design of the EU ETS for aviation means that only emissions from flights within Europe are covered. Inclusion on this basis would be unfavourable: it would leave a proportion of emissions outside carbon budgets, and the exact amount of UK emissions to add to carbon budgets and report annually would be unclear given the EU ETS is administered on an airline, rather than Member State, basis.
- ICAO negotiations about a global market-based measure for international aviation emissions are expected to conclude in autumn 2016. At that point the implications for carbon budgets should be assessed, including whether it is practical to include international aviation emissions in carbon budgets or more sensible to continue with formal exclusion, whilst making allowance for the emissions in the way the budget is set.

This approach to international aviation emissions does not affect the level of effort implied by our recommended fifth carbon budget. Whether or not it is included in budgets, our proposals are on a path to meeting the 2050 target with international aviation included.

Shipping emissions scenarios

The key drivers of future shipping emissions are shipping demand and carbon intensity of ships. For our 2012 advice on inclusion of international aviation and shipping[112] we developed scenarios for both UK demand and carbon intensity to 2050 which we have updated for the fifth carbon budget:

- **UK shipping demand**. The key drivers of shipping demand include GDP growth, fossil fuel and carbon prices, and UK consumption of fossil fuels and bioenergy. We have updated these assumptions to be consistent with our economy-wide analysis. In particular, our scenarios are fully consistent with the demand for fossil fuels under our economy-wide emission scenarios, and take into account that these reflect a reduction in demand for fossil fuels. Overall, under our central demand scenario tonne-miles increase by 0.4% per year from 2010 to 2050 if a carbon price is introduced, and otherwise by 0.6% per year.

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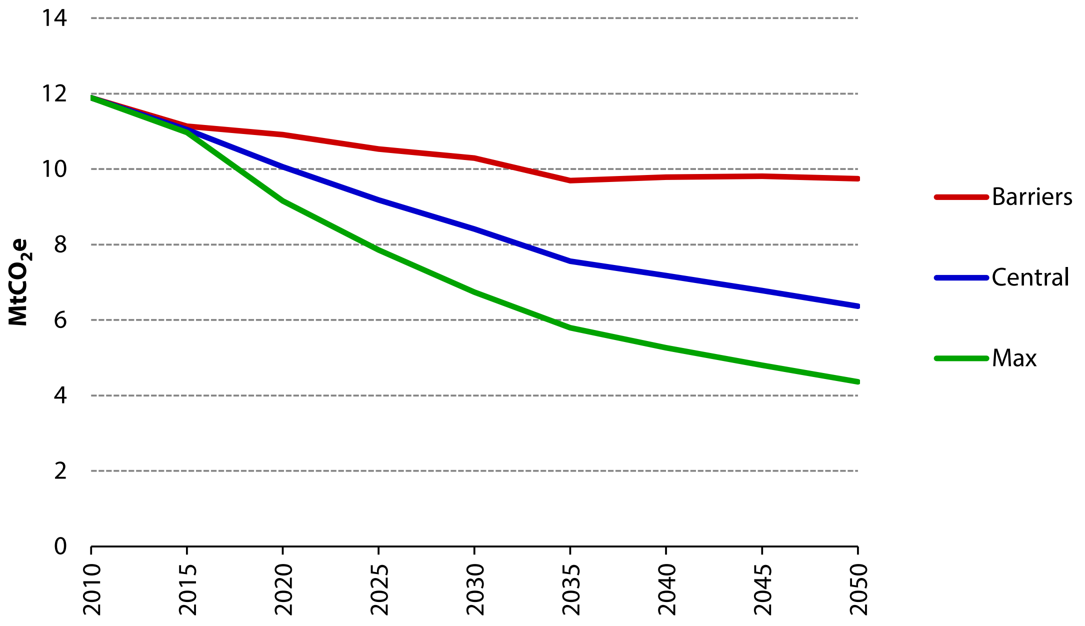
[112] CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*

- **Carbon intensity of shipping**. The key options identified in our Shipping Review[113] for reducing carbon intensity of ships are use of larger ships, technology and operational innovation to improve fuel efficiency, and the use of alternative fuels as a substitute for fossil fuels. Taking these together suggests scope for reducing average carbon intensity of ships by up to 65% by 2050.

Our emissions scenarios model the impact of different policies on uptake of abatement measures overlaid on our central demand scenario:

- **High emissions 'Barriers' scenario**. This reflects the International Maritime Organisation (IMO) Energy Efficiency Design Index (EEDI) which is the currently agreed international policy (i.e. 30% improvement in new ship fuel efficiency by 2025), but limited further abatement.
- **Central emissions scenario**. This assumes that take-up of abatement measures goes beyond that required to meet the EEDI. It includes speed reductions and increases in the average size of unitised container ships, as well as some limited penetration of biofuels and LNG.
- **Low emissions 'Max' scenario**. This assumes strong policy action to incentivise full take-up of abatement potential from technological and operational measures. It assumes more increases in ship size and further, but still limited, penetration of biofuels and LNG.

Figure 5.6: UK shipping emission scenarios (2010-2050)



Source: CCC analysis.

Overall, the range for UK shipping emissions in 2050 across these scenarios is 4.4-9.7 $MtCO_2e$ (Figure 5.6). Under our Central scenario 2050 international shipping emissions are 5.1 $MtCO_2e$ and domestic shipping emissions are 1.3 $MtCO_2e$. Over the fifth budget period emissions from

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[113] CCC (2011) *Review of UK Shipping Emissions*

domestic shipping are 7-10 $MtCO_2e$ and from international shipping are 30-40 $MtCO_2e$. These projections are on a bunker fuels basis, consistent with the UK's national emissions inventory.

Inclusion of international shipping emissions in carbon budgets

International shipping emissions are not currently formally included in carbon budgets. The first four legislated carbon budgets have been set, however, so that that they reflect international shipping emissions on the path to a 2050 target that includes them.

In principle, international shipping emissions should be included in carbon budgets, unless there are strong practical considerations which prevent this. Formal inclusion in carbon budgets was not initially practical given the level of uncertainty around the level of UK international shipping emissions under alternative methodologies.

Since then we have provided detailed analysis of these alternative methodologies, of possible future UK shipping emissions and the EEDI has been introduced.

In our 2012 statutory advice on inclusion of international aviation and shipping in carbon budgets[114] we concluded that while the basis for reporting international shipping emissions in the UK's national emission inventory (i.e. bunker fuels) was imperfect, the difference as against other methodologies was unlikely to be material. We therefore recommended that international shipping emissions should be included in carbon budgets on this basis.

This approach remains appropriate. International shipping emissions should therefore be included within the fifth carbon budget at a level of 40 $MtCO_2e$, reflecting projected emissions over the period under currently agreed international policy (consistent with the 'High' scenario above). Uncertainties around the level of international shipping emissions are likely to be small relative to factors already accepted in legislated carbon budgets. There are no additional costs of inclusion beyond those already committed to, and no competitiveness risks:

- **Methodologies for inclusion of international shipping emissions**. In our 2012 advice we recommended that international shipping emissions be included in carbon budgets on the basis of bunker fuel sales. This is the convention used for reporting emissions to the UNFCCC and is used in the UK's greenhouse gas inventory. Alternative methods for measuring shipping emissions have been proposed (e.g. based on shipping activity) but have not yet been fully developed or agreed for annual reporting. Therefore inclusion should be initially on the basis of bunker fuels, moving to inclusion on an alternative approach once this is sufficiently developed and agreed internationally.
- **Projected shipping emissions**. The appropriate scenario for initial inclusion in carbon budgets is one based on a central assumption for demand coupled with carbon intensity projected under currently agreed policies (i.e. the EEDI adopted by the IMO). This does not assume unilateral UK policy action.

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[114] CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*

- **Uncertainty in international shipping emissions**. A potential concern is that changes in the agreed accounting methodology, or year-to-year fluctuations in reported bunker fuel sales, could imply unintended changes to the effort required from other sectors covered by carbon budgets. Our analysis suggests the impact of alternative methodologies and the uncertainty in bunker fuel estimates (both historical and projected) are relatively small, particularly relative to factors already included in carbon budgets[115]. As a result, any consequences for carbon budget management would also be small and manageable under provisions set out in the Climate Change Act.
- **Costs and competitiveness**. Our projection for international shipping emissions reflects the currently agreed international policy for reducing shipping emissions (i.e. the EEDI), which the UK Government has agreed to through the IMO. It does not assume any unilateral UK policy action. There are therefore no additional costs beyond those already committed to, nor the competitiveness risks that could result from a unilateral UK approach.

There is therefore no reason to continue to exclude international shipping emissions from carbon budgets, and they should be added to the fifth carbon budget at a level of 40 $MtCO_2e$.

3. Existing ambition and projected emissions without further policy

In section 1 we showed that surface transport CO_2 emissions[116] are expected to increase from 109 $MtCO_2$ in 2013 to 126 $MtCO_2$ in 2030 without further effort to mitigate climate change. In developing our new abatement scenarios we first consider measures that the Government has in place or is aiming to deliver to 2030. In surface transport these include:

- An EU target to reduce test-cycle emissions from new cars to 95 gCO_2/km and new vans to 147 gCO_2/km by 2021.
- The EU Renewable Energy Directive, which is expected to increase biofuel use to 8% of liquid fuel by energy by 2020.
- Support for EVs to 2020.
- Policies to improve the efficiency of buses and HGVs.
- Planned rail electrification schemes.

DfT and DECC modelling suggests that these policies could result in surface transport emissions falling to 84-105 $MtCO_2$, with a central estimate of 94 $MtCO_2$ by 2030. With rising demand and no new policy measures, emissions are then expected to increase (Figure 5.7).

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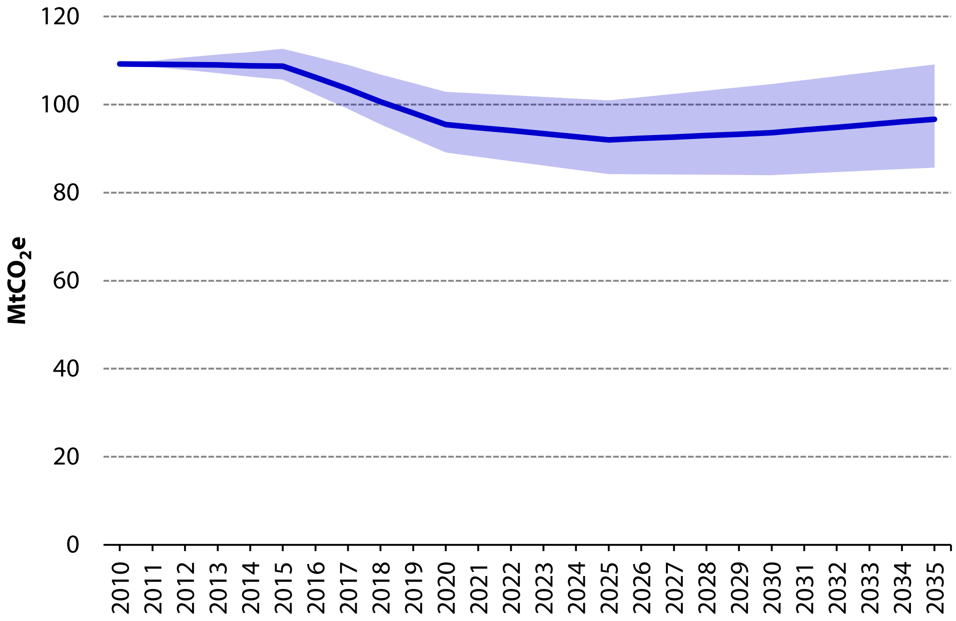
[115] See Figure 2.5 in CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*

[116] Domestic aviation and shipping and non-CO_2 are considered separately.

Figure 5.7: UK surface transport CO_2, projections under current and planned policies (2010-2035)



Source: DfT projections for CCC (2015); DECC interim projections (October 2015); CCC analysis.
Notes: Road and rail emissions projections were provided by DfT in October 2015. Other surface transport emissions come from DECC interim projections provided in October 2015. The range is estimated by CCC by scaling the uncertainty in emissions due to GDP and fuel prices taken from DfT's Road Traffic Forecasts 2015. This does not include uncertainty over the extent to which policies are successful.

4. Abatement scenarios

a) Scenarios to 2030

Surface transport CO_2

Our scenarios look beyond measures already planned or in place. Our Central scenario to 2030 includes measures that are likely to be cost-effective compared to the Government's projected carbon values, measures required by regulation and measures that are required on the path to meet the UK's legislated 2050 target:

- Real-world conventional vehicle efficiency improves by 37% on average for new cars, 33% for new vans and by 24% for new HGVs relative to 2010. As these efficiency improvements reduce the cost of driving, we assume that they result in a slight increase in demand for transport[117].
- Electric vehicles reach around 60% of new sales for cars and vans (around 35% PHEV and 25% BEV). Combined with conventional vehicle efficiency improvements, this implies a fleet-average, test-cycle CO_2 intensity of around 50 gCO_2/km for new cars and 60 gCO_2/km for new vans in 2030.

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[117] We use DfT's estimated fuel cost elasticities, which are 0.2 for cars and vans and 0.05 for HGVs in 2030. Using cars and vans as an example, this means that for every 1% fuel cost saving there is a 0.2% increase in demand.

  - We have updated our modelling of how this level of uptake could be achieved given capital and fuel cost projections, non-financial barriers and potential future incentives for EVs (Box 5.9).
  - This scenario will require a significant roll-out of EV recharging infrastructure and a need to ensure that increasing electricity demand from the growing number of EVs can be met by the UK's electricity supply (Box 5.10).
  - Whilst our projection is ambitious, it is within the range of others in the literature. A 2013 study by Cambridge Econometrics for the European Climate Foundation, informed by a review of existing projections, found that European EV uptake could be between 37% and 80% by 2030[118].
- Electric small rigid HGVs reach 40% of sales (30% PHEV and 10% BEV). Electric buses reach 25% of sales.
- Hydrogen fuel cell buses make up 25% of new bus sales. Fuel cell vehicles may also have niche applications for other modes by 2030 but this is not explicitly included in the scenario.
- Biofuels displace around 3 billion litres of petrol and diesel, equating to around 11% of liquid fuel by energy in 2030.
- We also include further emissions reductions from behaviour change in passenger transport and improvements to freight operations.
  - For cars we assume a 5% reduction in car-km relative to our baseline scenario, a 2% fuel saving from the use of eco-driving technology and a further 2% fuel saving from the enforcement of speed limits.
  - For HGVs we assume improved logistics provides a 10% reduction in HGV-km relative to our baseline scenario and further use of driver training and other fuel saving technologies by 80% of the fleet.
  - Taking account of the reductions in vehicle-km alongside the increase in travel due to the reduced cost of driving, we estimate that total vehicle-km increases by 22% between 2010 and 2030, compared to an increase of 23% before measures.
- Rail emissions fall by 25% compared to 2010 levels, through electrification, use of battery powered trains and improvements to the efficiency of diesel trains.

Overall we expect these measures to reduce surface transport emissions from 126 $MtCO_2$ in our baseline scenario to 62 $MtCO_2$ in our Central scenario by 2030 (Figure 5.8). The abatement is primarily due to conventional vehicle efficiency (22 $MtCO_2$) and uptake of ULEVs (26 $MtCO_2$), with smaller reductions from biofuels (7 $MtCO_2$), behaviour change in passenger transport (4 $MtCO_2$), improvements to freight operations (4 $MtCO_2$) and rail electrification (1 $MtCO_2$).

Figure 5.9 shows how the key factors driving this reduction change over time; test-cycle CO_2 intensity for new conventional cars, biofuel usage and EV uptake.

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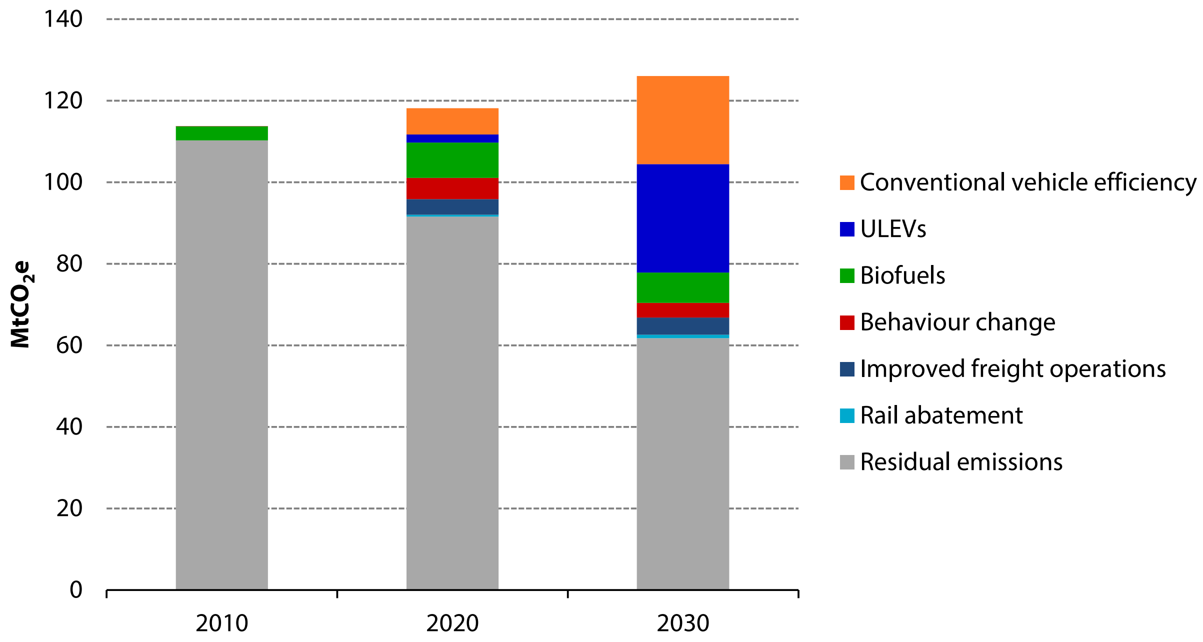
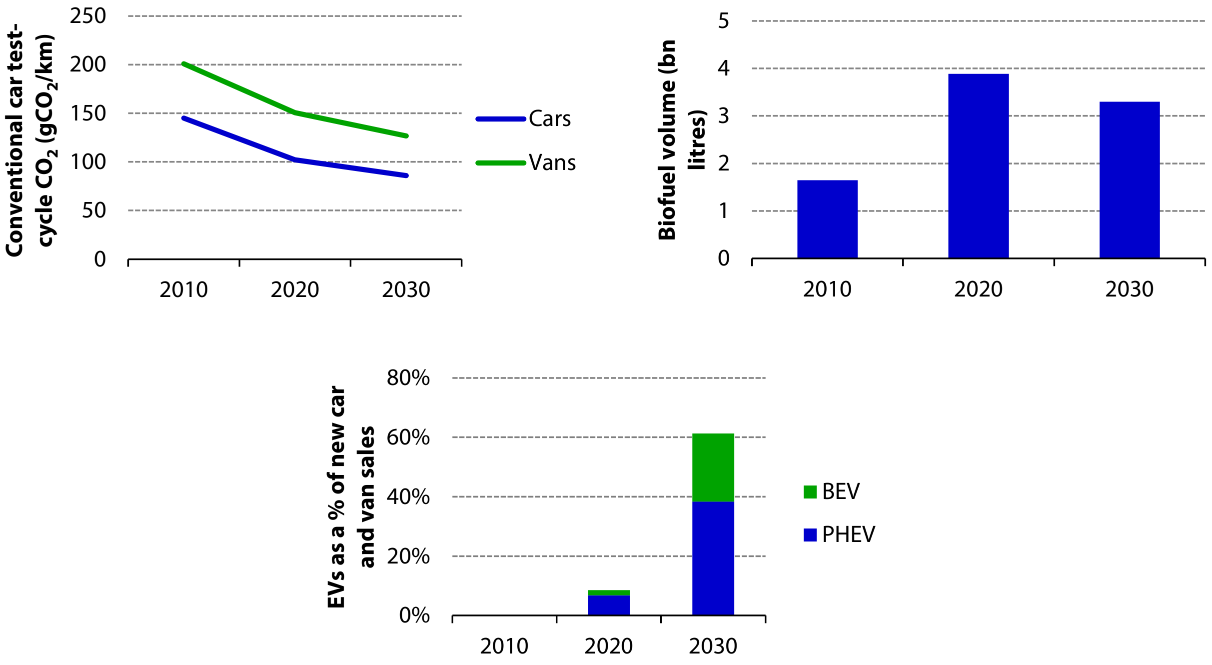
[118] Cambridge Econometrics (2013) *Fuelling Europe's Future.*

Figure 5.8: UK surface transport abatement under our Central scenario (2010-2030)



Source: CCC analysis.
Notes: Abatement relative to baseline emissions projection.

Figure 5.9: Key transport indicators under our Central scenario (2010-2030)



Source: CCC analysis.
Notes: Test-cycle CO_2 intensity is on a WLTP basis.

Box 5.9: Modelling uptake of electric cars and vans

We model uptake of EVs using a methodology developed by Element Energy for the Committee in 2013. This analysis takes account of the financial and non-financial barriers to EV uptake and splits vehicle buyers into different market segments. These include private buyers with different attitudes towards EV ownership and fleet buyers who are more likely to consider the total cost of ownership and vehicle capabilities in an economically rational way. The key factors considered in the analysis are:

- **Upfront and running costs**, such as capital costs, fuel costs (including fuel duty for petroleum and the additional costs of low-carbon power generation for electricity), maintenance and insurance.
- **Perceived costs** associated with limited range, recharging time, access to recharging infrastructure and the supply of plug-in vehicle models.
- **Incentives**, which covers a range of potential measures that could be used to incentivise EV uptake. These include upfront grants, favourable Vehicle Excise Duty or Company Car Tax and provision of free access to low emissions zones or parking spaces. As these measures all have an intrinsic value, a package of incentives does not necessarily have to include an upfront grant, particularly in the longer term as EV capital cost premiums fall.

Taking these considerations together, we estimate that plug-in vehicles could make up around 60% of new sales by 2030 if provided with a national network of rapid charging infrastructure and incentives of around £1,000 per vehicle in 2030 (this would not have to be an upfront grant, but a package of incentives that vehicle buyers value at this level). This is lower than estimated in previous work, reflecting the reduction in projected cost differential between conventional vehicles and EVs under our central assumptions.

Alternatively, vehicle leasing could make BEVs and PHEVs look more attractive as their high upfront costs are spread over a longer period. We have also modelled a scenario where vehicle buyers are able to spread out the capital cost over a four year period with an interest rate of 7.5%, which achieves 60% uptake in 2030 even if incentives were reduced to around £500.

There are uncertainties over future EV battery costs (Box 5.4), with recent evidence suggesting these are falling more rapidly than assumed in our central case. Based on a scenario in which average battery pack costs fall to around $200/kWh in 2025, rather than in 2030 as under our central assumptions, the incentives required to deliver our central scenario of 60% of new sales could fall to zero by 2030.

Source: Element Energy et al (2013) *Pathways to high penetration of electric vehicles*; CCC analysis.

There are some key differences between this scenario and that set out in our fourth carbon budget review:

- Road transport demand is projected to be higher in 2030 largely due to lower fuel price projections, with total vehicle-km in 2030 6% above our 2013 projection.
- The real-world CO_2 intensity of conventional cars and vans is higher than previously estimated, due largely to a more significant gap between real-world and test-cycle emissions.
- Plug-in electric small HGVs were not included in our previous scenario but new evidence suggests these could be a feasible and cost-effective measure.
- There are more significant opportunities to reduce HGV-km than previously identified, with a 10% reduction in 2030 compared to our previous estimate of 6.5%. There are also greater efficiency improvements in the HGV fleet due to driver training and fitting existing vehicles with fuel saving technologies.

- We include abatement from additional rail electrification not included in our fourth carbon budget review analysis.

Overall, these changes offset one another and the combined effect is that our new Central scenario for surface transport CO_2 emissions of 62 $MtCO_2$ in 2030 (a 44% reduction on 2013) is broadly similar to the 61 $MtCO_2$ we estimated in our fourth carbon budget review.

Box 5.10: Electric vehicle infrastructure and electricity demand

A high uptake of plug-in vehicles will require roll-out of supporting infrastructure, which is likely to be delivered in various forms depending on how the vehicles are used:

- **Home charge points**. Around 70% of vehicle buyers have access to off-street parking and will be able to recharge their vehicle overnight at home. Our projections suggest that the costs of a home charger will fall to around £170 in 2030, which we include in our estimates of vehicle capital cost.
- **Rapid charge points**. In order to alleviate range anxiety and allow EV drivers to make longer trips, our analysis assumes the deployment of a national network of rapid charge points along major roads. This is equivalent to approximately 16,000 rapid chargers over 2,000 sites by 2030.
- **Distribution network upgrades**. If large numbers of plug-in vehicles need to recharge in the same place at the same time, such as commercial fleets recharging in a single depot, it may be necessary to upgrade the local power distribution network. The extent to which this will be necessary is currently uncertain and will depend on the extent to which smart recharging technology can be developed. This technology, which would allow plug-in vehicle recharging to respond to electricity prices and to peaks in local power demand, could reduce the costs of infrastructure upgrades and provide a valuable demand-smoothing service. Plug-in vehicles could perform an additional service by allowing electricity to be transferred from their battery to satisfy local power demand during a peak period, thereby reducing the need for additional power generating capacity. Such systems are currently in development[119].
- **Electricity demand**. In our Central scenario, demand for electricity from EVs will increase to around 20TWh in 2030 (6% of UK electricity demand in 2030). This increase in demand is fully accounted for in our power sector scenarios (Chapter 2).

Source: CCC analysis.

Devolved Administrations (DAs)

Whilst our scenarios cover all UK transport emissions, it is important to consider whether differences in national circumstances in Scotland, Wales and Northern Ireland could give rise to differences in abatement opportunities. Our projections of road transport demand come from the National Transport Model, which includes differences in geography and traffic flows and can be disaggregated by nation[120]. However, we assume that uptake of abatement measures in the DAs is proportional to distance travelled (by mode), as in the UK as a whole, as there is currently little evidence of any significant differences in uptake or abatement opportunities. We will continue to monitor the roll-out of policies in the DAs and account for any differences in uptake.

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[119] Cenex (2015) *Does the case for vehicle-to-grid stack up?*

[120] Northern Ireland is not included in the National Transport Model. We estimate future transport emissions in Northern Ireland by assuming they are proportional to future GB transport emissions.

Sensitivity analysis

Our Central scenario is calculated on the basis of our central demand and fuel price projections but we have also considered key uncertainties and how different assumptions can affect these results:

- **Demand for travel**. To reflect uncertainty in underlying travel behaviour, DfT now models two additional scenarios in its road traffic forecasts (in addition to its GDP and fuel price sensitivities). These new scenarios have lower demand than DfT's central projection, which we use in our Central scenario[121]. As a sensitivity, we have used one of these demand projections, in which recent trends in trip rates[122] are extrapolated forward in time. In this scenario total vehicle-km increase by 9% between 2010 and 2030, compared to 23% in our Central scenario. Under this demand projection road transport emissions would be 6 $MtCO_2$ (10%) lower in 2030.
- **Lower fossil fuel prices**. Lower fossil fuel prices could act to increase emissions, both by reducing the costs of driving and by making conventional cars and vans look relatively more attractive compared to EVs. Using the Government's low fossil fuel price projections[123], we estimate that emissions would be 1.7 $MtCO_2$ (3%) higher in 2030 than our Central scenario. Around 1.2 $MtCO_2$ of this is due to increased demand for travel and 0.5 $MtCO_2$ is due to some EVs being replaced by conventional cars.
- **Balance of petrol and diesel**. Diesel cars typically emit less CO_2 than equivalent petrol cars, but recent controversy over emissions of nitrogen oxides (NOx) from diesel cars[124] has thrown some doubt over the extent to which diesel cars will remain a popular choice for consumers. We have considered the potential impacts on road transport emissions of switching away from diesel towards petrol cars[125]. In order to investigate the maximum scale of the impact we have modelled an extreme case in which 100% of new conventional and PHEV car sales are petrol fuelled by 2020. This results in the average conventional car in the fleet emitting 6% more CO_2 than in our Central scenario. Overall, road transport emissions are 1$MtCO_2$ (2%) higher than in our Central scenario. This relatively small impact reflects:
  - In our Central scenario, only 70% of the car fleet will be a conventional car by 2030, with the remaining 30% being a PHEV or BEV.
  - Cars make up only around 55% of total road transport emissions in 2030.

  This analysis suggests that even a large shift away from diesel cars would not have a significant impact on CO_2 emissions provided it is coupled with a longer term shift to EVs.

Risks and further opportunities

We recognise there are risks in delivering this Central scenario, both in terms of underlying cost and demand projections and in the development of markets and infrastructure. In order to test these risks, we have developed scenarios in which these assumptions are more or less favourable in delivering emissions reduction over the fifth budget period.

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[121] DfT (2015) *Road Traffic Forecast 2015.*

[122] Trips per person per year.

[123] Including a lower gas price projection, which reduces the price of electricity for EVs.

[124] ICCT (2015) *FAQ: In-use NOx emissions from diesel passenger cars.*

[125] We assume that conventional vans, HGVs and buses are still fuelled by diesel as petrol fuelled versions are not widely available.

We have developed a "Barriers" scenario in which the UK maintains an ambition to reduce emissions from transport but a series of barriers lead to lower overall abatement. This scenario includes:

- Electric cars and vans making up only around 40% of new sales in 2030 (30% PHEV and 10% BEV):
  - EV-enthusiast consumer segments are assumed to have the same characteristics as mass-market consumers, who have some resistance to EV ownership.
  - Range anxiety is assumed to be more severe across all consumer segments.
  - Incentives are withdrawn before 2030.
  - Commercial vehicle buyers require a shorter payback period to make an investment.
- Biofuel uptake is reduced to 1.8 billion litres, approximately equal to the volume of biofuel currently used in the UK, equating to around 5% of liquid fuel by energy in 2030.
- Demand-side measures targeting car driver and freight operator behaviour are less successful. For cars we assume a 3% reduction in car-km relative to our baseline scenario, eco-driving technologies are not used and there is no further enforcement of speed limits. For HGVs, we assume improved logistics provide an 8% reduction in HGV-km relative to our baseline scenario and further use of driver training and other fuel saving technologies by only 50% of the fleet.

Taken together, these measures reduce surface transport emissions to 75 $MtCO_2$ in 2030, 14 $MtCO_2$ higher than our Central scenario.

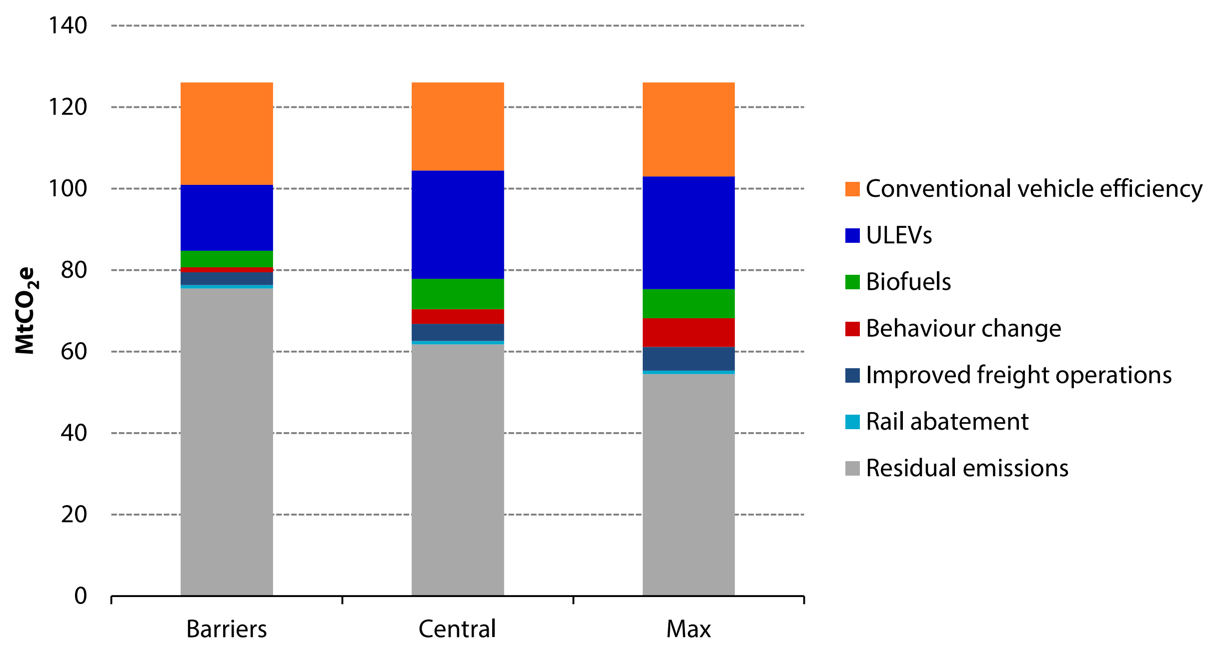
Whilst our Central scenario is challenging, there are further technically feasible opportunities for emissions reduction in the transport sector. We have developed a "Max" scenario to reflect the level of emissions that could be achieved if ambition were sufficiently high or conditions were more favourable than in our Central case. The following measures are included in this scenario in 2030:

- Improved testing of cars and vans could help to achieve further real-world conventional new vehicle efficiency improvements. In this scenario, conventional efficiency improves by 44% for new cars and 40% for new vans between 2010 and 2030.
- If battery costs fall more rapidly, there is potential for a slightly higher sales share of 65% for electric cars and vans (35% PHEV and 30% BEV).
- Efforts to reduce emissions using demand-side measures lead to greater shifts in behaviour. For passenger cars this scenario has a 10% reduction in vehicle-km relative to our baseline scenario and the speed limit is reduced to 60mph on motorways and dual carriageways. Improved freight logistics provide an 18% reduction in HGV-km relative to our baseline scenario and further use of driver training and other fuel saving technologies by 100% of the fleet.

These measures provide an additional 7 $MtCO_2$ of abatement compared to our central scenario, resulting in surface transport emissions of 54 $MtCO_2$ in 2030.

Figure 5.10 sets out the different abatement by measure and residual emissions under the Barriers, Central and Max scenarios in 2030.

Figure 5.10: UK surface transport abatement in 2030 under our Barriers, Central and Max scenarios



Source: CCC analysis.
Notes: Abatement relative to baseline emissions projection.

Domestic aviation and shipping

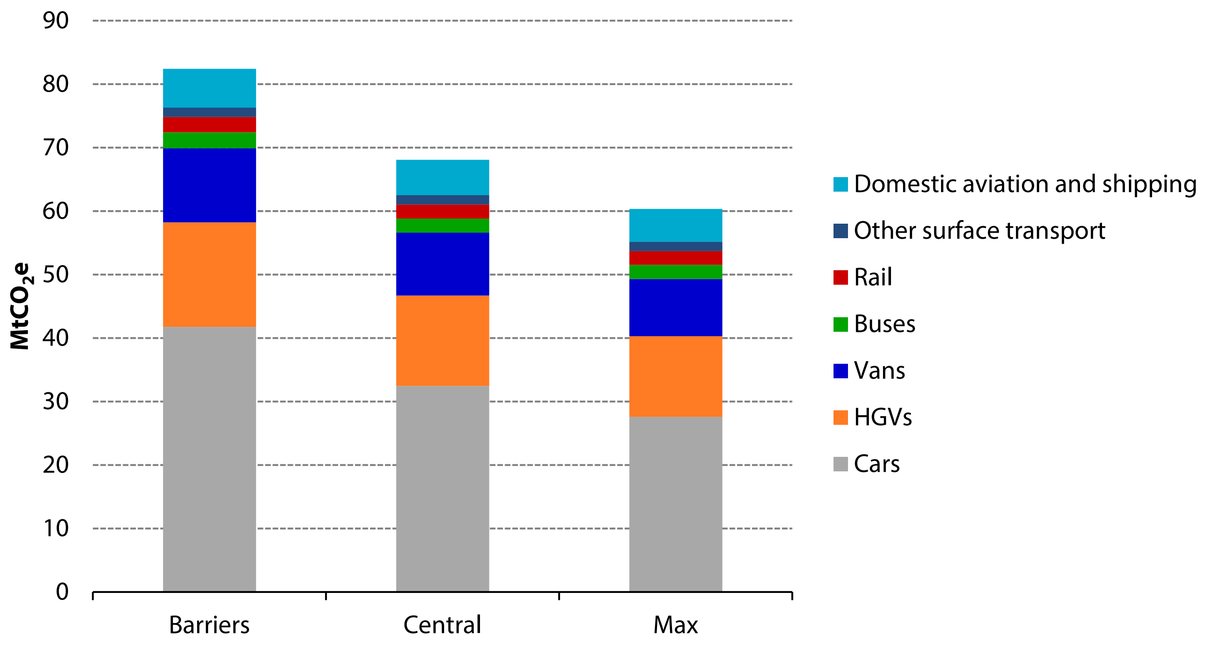
Further emissions reductions are available from domestic aviation and shipping. Our scenarios are modelled as absolute emissions trajectories, rather than abatement against a baseline scenario as with surface transport:

- Domestic shipping emissions could fall to 1.3-1.9 $MtCO_2e$ by 2030, a decrease of 13-41% on 2013 levels. This is largely due to improved fuel efficiency of ships. The low end of the range reflects the impact of the EEDI, and the higher end of the range assumes additional uptake of technological and operational measures.
- Domestic aviation emissions could be in the range 1.6-1.8 $MtCO_2e$ in 2030, up to a 14% fall 2013 levels, largely reflecting improvements in the fuel efficiency of aircraft.

Domestic transport emissions

Adding together projected emissions for all modes, domestic transport CO_2 emissions reach 67 $MtCO_2$ in 2030 under our Central scenario. Under our Barriers and Max scenarios, emissions reach 82 $MtCO_2$ and 60 $MtCO_2$. Non-CO_2 emissions contribute a further 0.7 $MtCO_2e$ (Figure 5.11).

Figure 5.11: UK domestic transport emissions in 2030 under our Barriers, Central and Max scenarios



Source: CCC analysis.
Notes: Domestic aviation and shipping includes military aircraft and shipping. Other surface transport includes motorcycles, aircraft support vehicles, various other non-road modes and non-CO_2 transport emissions.

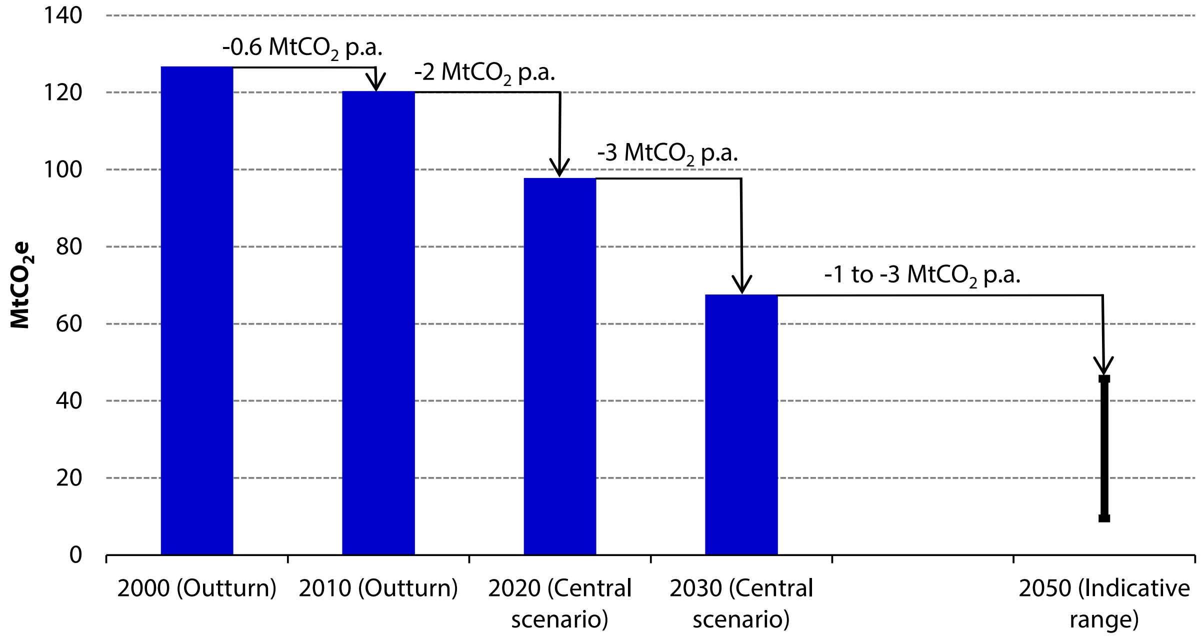
b) Scenarios to 2050

Following our Central scenario to 2030 would keep open a range of options for the transport sector's contribution to meeting the 2050 target. Given that our projections suggest zero-emission vehicles will be increasingly cost-effective beyond 2030, there is potential to virtually decarbonise the fleet by 2050, but there are uncertainties:

- As their electric range increases and they become more widely accepted by consumers, there is potential for EVs to be rolled-out across virtually the whole car and van fleet. With sufficient investment in research and development, there is also the possibility that hydrogen fuel cell HGVs could begin to enter the fleet starting in the early 2030s. Taken together, with sufficient effort there is the potential for most road transport vehicles to be zero-emission by 2050.
- Even with a high uptake of EVs by 2030, there is a risk that decarbonisation could slow to 2050. Vehicles that need to travel long distances or carry heavy loads may continue to prove difficult to switch to zero-emission options. If that were the case, plug-in hybrid vehicles could still be widely used in 2050, with zero-emission vehicles restricted to short-distance, urban applications. Given uncertainties around future travel behaviour; there is also a risk that policies to change behaviour fail to achieve the desired effect.
- Taking these uncertainties into account, we estimate that domestic transport emissions could fall to 10-46 $MtCO_2$ by 2050. This would mean an emissions reduction rate of 1-3 $MtCO_2$ per year from 2030-2050, following a decrease in emissions of 3 $MtCO_2$ per year in our Central scenario between 2020 and 2030 (Figure 5.12).

Reaching the level of abatement in the Central scenario by 2030 would leave open the option of reaching maximum abatement by 2050, which could be required if other sectors of the economy underperform. However, slowing abatement to 2030 would make it challenging and costly for the transport sector to ramp-up effort and achieve this maximum abatement by 2050.

Figure 5.12: UK transport abatement and rate of emissions reduction (2000-2050)



Source: CCC analysis.

Alternative scenarios

While the Central scenario represents our current assessment of the cost-effective path, it is possible that technology costs turn out differently to those in our current projections and/or unforeseen technical or non-financial barriers make the chosen options infeasible. Given this uncertainty, we have considered three alternative scenarios which provide a similar level of abatement to the Central scenario in 2030, and the potential to reach our 2050 abatement range, using a different mix of measures.

- **Alternative 1 - Hydrogen economy**. More widespread use of hydrogen (e.g. in power and buildings) would mean that hydrogen refuelling infrastructure was more widely available and fuel cells could be used across all vehicle types[126]. The availability of long-range, zero-emission cars and vans would mean that the fleet could be decarbonised slightly more quickly, which might mean less effort from other measures. For example, biofuels could be phased out more rapidly due to high costs and sustainability concerns, with biofuel use reduced back to 2010 levels by 2030.

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[126] E4tech et al (2015) *Scenarios for deployment of hydrogen in contributing to meeting carbon budgets and the 2050 target*

- **Alternative 2 - EV success / No hydrogen**. In the absence of hydrogen technology, it is possible that natural gas will be used to fuel HGVs[127], which offers only a modest emission saving. To get to overall abatement in 2050 within our indicative range, full take-up of electric cars and vans would be required, resulting in a near-zero emission fleet by 2050. Some HGV emissions could be saved in 2050 by increasing efforts to improve logistics but the impact of this would be limited, meaning that the majority of road transport emissions in 2050 would be from HGVs. There is a risk to this scenario, in that it relies on the success of electric cars and vans, with no room to go further on HGVs, and no option of achieving maximum abatement in transport if it is needed.
- **Alternative 3 - EV delay / Maximum demand reduction**. If barriers to EV adoption cause a delay in uptake, then a similar level of abatement in 2030 could be achieved by further reductions in demand for car travel. In this scenario, EV sales make up around 50% of new sales in 2030, compared to 60% in our Central scenario. This could be offset by doubling the car-km reduction from 5% in the Central scenario (representing 24% of trips) to 10% (representing 36% of trips). Whilst this level of demand reduction is feasible, avoiding or mode shifting 36% of car trips would present a very significant policy challenge. In addition, delaying EV uptake to 2030 would mean a faster ramp up in production to achieve a near-zero emission fleet by 2050, which could be both challenging and costly (Box 5.11).

5. Costs and impacts

The measures in our Central scenario are either lower cost than the Government's projected carbon values, required by regulation or required to prepare for 2050 (Table 5.3). A delay in their deployment would therefore increase costs. We have quantified the cost for such a delay as well as the overall resource cost of our scenarios:

- On average, the improvements in conventional vehicle efficiency in our Central scenario save money even before carbon savings are included.
- While EVs are not projected to become cost-effective until the mid-2020s, there is a case for supporting an early market now to reach a high level of uptake in 2030 and keep open the option of a near zero-emission fleet by 2050. Our analysis suggests that this pathway could be more cost-effective than delaying mass-market EV deployment until later, which would mean conventional vehicles would have to be scrapped early to sufficiently reduce emissions from the fleet by 2050 (Box 5.11).
- We have modelled a delayed action scenario in which abatement is held at constant levels during the 2020s then resumed from 2031. We estimate that there would be a small cost saving in the 2020s to delayed action, with a net present value of around £2 billion over the period to 2030. However, costs would then be significantly higher in the period 2030-2050, such that delayed action fails to realise cost savings of around £20 billion, mainly due to the delayed uptake of EVs, which are cost-effective by 2030. Furthermore, this delay would result in higher GHG emissions over the period 2030-2050. At the Government's carbon values, these GHG emissions would impose an additional cost of around £50 billion. Overall, we estimate the total cost of delayed action in the 2020s would be around £70 billion.

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[127] Assuming the majority of the available bioenergy resource is used in power and buildings, with very limited supply available for transport.

- Overall, our updated scenario costs £1.3 billion relative to our baseline scenario in 2030. To the extent that technology costs or fossil fuel prices are different to our central assumptions, costs could increase to £4.7 billion or could save -£3.1 billion overall (Table 5.4).

In addition the scenario has a series of co-benefits, such as improved air quality and opportunities for UK auto manufacturing (Box 5.12).

It is therefore appropriate to aim to deliver significant abatement in the transport sector, as set out in our Central scenario. This will require policies to be strengthened and extended into the 2020s to ensure that incentives for investment are in place and that barriers to deployment are addressed. The key policy implications of our scenarios are covered in the next section.

Box 5.11: Rationale for supporting a high uptake of EVs in 2030

EVs are expected to begin to be cost-competitive with conventional cars in the 2020s. Nevertheless, achieving 60% market share by 2030 will require the Government to implement policies to help overcome financial and non-financial barriers. There are a number of important reasons for supporting the early adoption of EVs during the 2020s, rather than delaying increased uptake.

- Building an early market and supporting infrastructure for EVs during the 2020s will help raise the awareness among mass-market consumer segments required for high levels of uptake in 2030.
- Given the high levels of uncertainty in future emissions reductions across the economy, it is important to keep open the option of going further in transport to offset difficulties in another sector. To get to a near-zero emission fleet by 2050 EVs would need to make up close to 100% of sales by 2035, given fleet turnover cycles of around 15 years. Getting to this level of uptake in 2035 would be extremely challenging if EV market share were much less than 60% in 2030.
- It is likely that a delay in this pathway would require transport emissions to be reduced more rapidly during the 2040s to help meet the 2050 target. In order to do this, older conventional cars would have to be scrapped early and replaced with EVs. We estimate that a carbon value of around £1,200/tCO_2 would be required to bring about this scrappage, compared to a projected carbon value of £150/tCO_2 in 2040.
- Early adoption of EVs is also being driven by the need to improve air quality in urban areas, which has become an urgent issue in recent years. For example, as part of a package of measures to improve air quality in London it is planned that all new taxis is Central London will be a PHEV by 2018. Benefits from improving air quality are not included explicitly in our calculations but could contribute to early uptake.

Source: CCC analysis.

Table 5.3: Costs of measures in our Central scenario

Measure	Mode	Average £/tCO_2 in 2030	Justification for inclusion in scenario
Conventional vehicle efficiency	**Cars**	-1	Conventional vehicle efficiency improvements found to be cost-saving on average.
	Vans	-30	
	HGVs	-15	
Electric vehicles	**Cars**	90	New ULEVs found to be cost-effective by 2030. Need to build an early market in the 2020s to reach significant deployment required in 2030 to allow near zero-emission fleet by 2050.
	Vans	-33	
	Small HGVs	-39	
	Buses	103	
Hydrogen fuel cell vehicles	**Buses**	188	
Biofuels	**All**	107	Increased biofuel use to 2020 required by regulation. Maintained at a constant level during the 2020s.
Behaviour-change measures	**All**	0	Likely to be cost-effective when wider benefits are considered.

Source: CCC analysis.
Notes: The average abatement cost includes vehicles that we deployed before 2030 and are still in operation. These costs are generally higher than those of a new vehicle in 2030.

Table 5.4: Costs of Central scenario under different fossil fuel price and technology cost assumptions

	Central	High fossil fuel prices	Low fossil fuel prices	Low technology costs	High technology costs
Cost of Central scenario in 2030 (£bn)	1.3	-3.1	4.7	-1.7	4.3

Source: CCC analysis.

Box 5.12: Co-benefits of the central scenario to 2030

Air quality

Poor air quality remains an urgent problem in some areas of the UK. Several cities and regions in the UK, including London, Birmingham and Glasgow have been in breach of European air quality directives designed to protect public health. In response, the UK Government published updated plans to reduce emissions of nitrogen oxides (NOx) in September 2015[128]. The report emphasised the electrification of the vehicle fleet as the most significant measure to benefit both air quality and efforts to reduce CO_2. Other measures covered in this chapter, such as improved public transport services and reducing congestion, were also highlighted as important to improving air quality.

UK manufacturing

There is an opportunity for the UK automotive manufacturing sector to become a world leader in the development and production of ULEVs as demand increases both domestically and globally.

- There has been at least £18 billion in low carbon investment in the UK automotive manufacturing sector between 2003 and 2013, according to a 2014 report prepared for the Low Carbon Vehicle Partnership[129]. The report sets out the results of a survey of UK automotive manufacturers, citing advantages in UK research and development capability and the longstanding and stable policy environment provided by EU legislation and the Climate Change Act as reasons for sustained investment in ULEV development in the UK.
- The Nissan Leaf became the first UK manufactured ULEV in 2013 and made up around 30% of all UK PHEV and BEV sales in 2014[130]. Jaguar Land Rover revealed three ULEV demonstration vehicles in September 2015, suggesting that other UK manufacturers could soon begin production of ULEVs[131].

Source: CCC analysis.

6. Delivering the scenarios

To deliver the abatement set out in our Central scenario, action is needed in the near term. The key policy implications of our scenarios are set out below.

- **Provide motor industry with greater certainty to 2030**. There is a need for clear, stretching EU targets for new car and van CO_2 beyond 2020. Targets should be set using realistic testing procedures and take account of the need to increase uptake of ULEVs. EU standards for new HGV CO_2 should also be introduced as soon as is practical.
- **Tackle barriers to EV uptake**. Support for the upfront costs of EVs should be maintained while it is required to incentivise their uptake. Measures to help overcome non-financial barriers to EV uptake should be continued, including the roll-out of a national network of charge points and the provision of local incentives such as access to parking.

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[128] Defra (2015) *Draft plans to improve air quality in the UK. Tackling nitrogen dioxide in our towns and cities.*
[129] LowCVP (2014) *Investing in the low carbon journey.*
[130] SMMT (2015)
[131] http://www.imeche.org/news/engineering/innovative-engineering-from-jlr-reduces-vehicle-emissions-10091505

- **Ensure the tax regime keeps pace with technological change**. Vehicle taxation should be aligned to ongoing improvements in new vehicle CO_2 to incentivise uptake of the lowest emitting vehicles. There should also be sufficient differentiation between rates for high and low emission vehicles to incentivise uptake of ULEVs. We will address the Vehicle Excise Duty reforms announced in the summer 2015 Budget in our 2016 Progress Report.
- **Extend successful emissions-reduction schemes for freight operations**. Existing schemes to help freight operators reduce their fuel costs and emissions have been successful, but coverage has been limited to mainly larger freight operators. Similar schemes should be rolled out across the industry, including small operators, to ensure that opportunities to reduce freight emissions are realised.
- **Ensure lessons from schemes to reduce travel demand are applied**. Sustainable travel schemes can offer a wide range of benefits, including reduced CO_2 emissions, improved air quality and reduced congestion. Such schemes should be properly evaluated and extended if they provide cost-effective emissions reductions.
- **Push for successful negotiations to reduce emissions from international aviation and shipping**. This should ensure the agreement for international aviation delivers a policy framework consistent with the longer term climate objective, and that cost-effective abatement is incentivised in shipping, such that these sectors contribute to global emissions reduction.

Chapter 6: Agriculture and land use, land use change and forestry

Introduction and key messages

Agriculture accounted for 9.5% of greenhouse gas (GHG) emissions in the UK in 2013. In this chapter we present new evidence of options to reduce emissions and the sector's contribution to the cost-effective path to the UK's 2050 target. We estimate agriculture emissions on this path could fall by 14% from 2013 to 46 $MtCO_2e$ by 2030 (30% on 1990).

The land use, land use change and forestry sector (LULUCF) was a net carbon sink of 5.2 $MtCO_2e$ in 2013, which is equivalent to abating 1% of UK GHG emissions. There is scope for this sector to make a contribution towards the fifth carbon budget through increasing woodland cover and the integration of agro-forestry practices into existing arable and livestock systems.

Our key messages are:

- We estimate that agriculture could contribute 8.5 $MtCO_2e$ of emissions savings in 2030:
  - Measures already being implemented by farmers, or being delivered through the industry-led GHG Action Plan could deliver 2.6 $MtCO_2e$ in 2030.
  - Measures aimed at mitigating nitrous oxide (N_2O) emissions from crops and soils such as improved nitrogen use efficient plants, manure planning, and addressing soil compaction could deliver 2.7 $MtCO_2e$ in 2030.
  - Around 2 $MtCO_2e$ could be saved in the livestock sector through changes in diet, improvements in animal health and breeding. Other options aimed at manure management, energy efficiency and on-farm anaerobic digestion could deliver an additional 1.3 $MtCO_2e$ in 2030.
- About 80% of these measures are cost saving from a social perspective and could provide opportunities to save costs for farmers. The remaining 20% are cost-effective compared to the Government's projected central carbon values.
- This central scenario for emissions reduction is feasible but challenging. It would need to be underpinned by a strong policy framework that goes beyond information and advice, and includes financial incentives, and tackling non-financial barriers. With agriculture a devolved matter, the four countries of the UK will need to ensure that policies are in place to deliver these savings.
- Our central estimate of emissions savings of 8.5 $MtCO_2e$ is within a range of scenarios with lower and higher abatement of 5.5 $MtCO_2e$ and 9.5 $MtCO_2e$. Residual agricultural emissions would then be between 46-50 $MtCO_2e$ by 2030, accounting for a larger share of UK emissions (e.g. 14-16%) than today. There are, however, large uncertainties currently associated with measuring non-CO_2 emissions, and a risk that emissions could be significantly higher than assumed by our scenarios.
- With regard to LULUCF, we estimate that increased afforestation and wider deployment of agro-forestry practices could reduce emissions by 2.4 $MtCO_2e$ by 2030 in our central scenario.
- Beyond the reduction of emissions, these measures deliver additional benefits which include synergies with efforts to adapt to a changing climate. For example, more efficient use of inorganic fertiliser can improve soil and water quality, while tree planting can enhance biodiversity.

We set out the analysis that underpins these conclusions in the following sections:

1. Overview of emissions from the agriculture sector
2. Options for reducing emissions
3. Existing ambition and projected emissions without further policy
4. Abatement scenarios
5. Costs and impacts
6. Decarbonising the land use, land use change and forestry sector
7. Delivering the scenarios

1. Overview of emissions from the agriculture sector

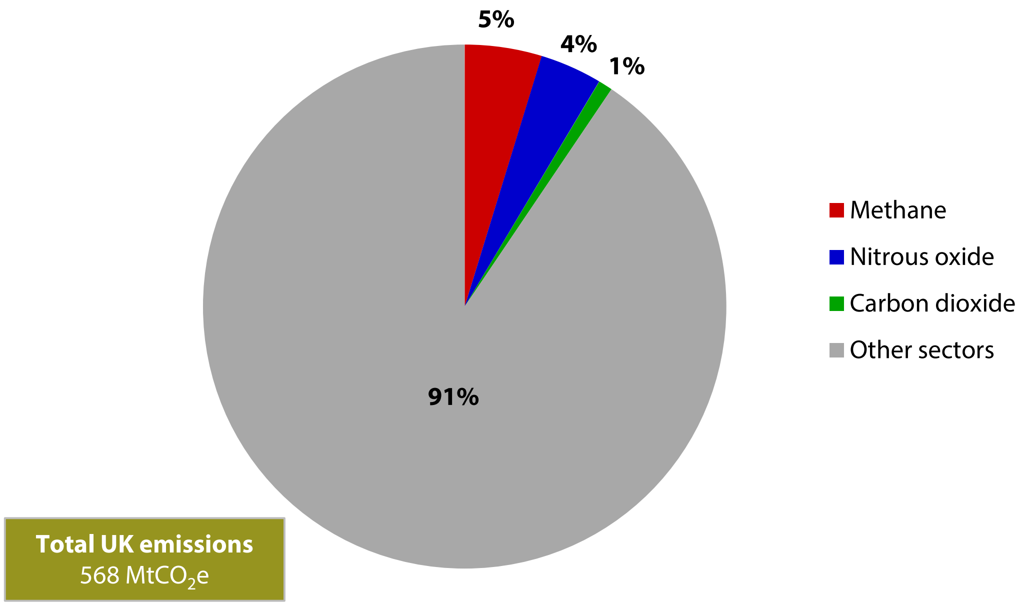
Agricultural emissions were 54 $MtCO_2e$ in 2013, accounting for around 9.5% of total UK GHG emissions (Figure 6.1). This share is higher for the devolved administrations (e.g. 29% for Northern Ireland and 16% for Scotland) and reflects the importance of agriculture to their economies compared to the UK as a whole.

Emissions in this sector are dominated by non-CO_2 GHGs, so we are only able to report on 2013 emissions due to the lag in reporting non-CO_2 data.

Agriculture emissions comprise:

- **Methane (CH_4):** 50% of emissions (27 $MtCO_2e$), sourced mainly from enteric fermentation, which occurs in the digestive system of ruminant animals (e.g. cattle and sheep) and waste and manure management.
- **Nitrous oxide (N_2O):** 41% of emissions (22 $MtCO_2e$), and largely arise from the application of nitrogen fertiliser (organic and chemical) to arable and grassland, returns from animal grazing and crop residues incorporated into soils.
- **Carbon dioxide (CO_2):** 9% of emissions (5 $MtCO_2e$) come from the use of fossil fuels to power stationary and mobile machinery (e.g. heating systems and tractors).

Figure 6.1: GHG emissions from agriculture in the context of total UK emissions (2013)



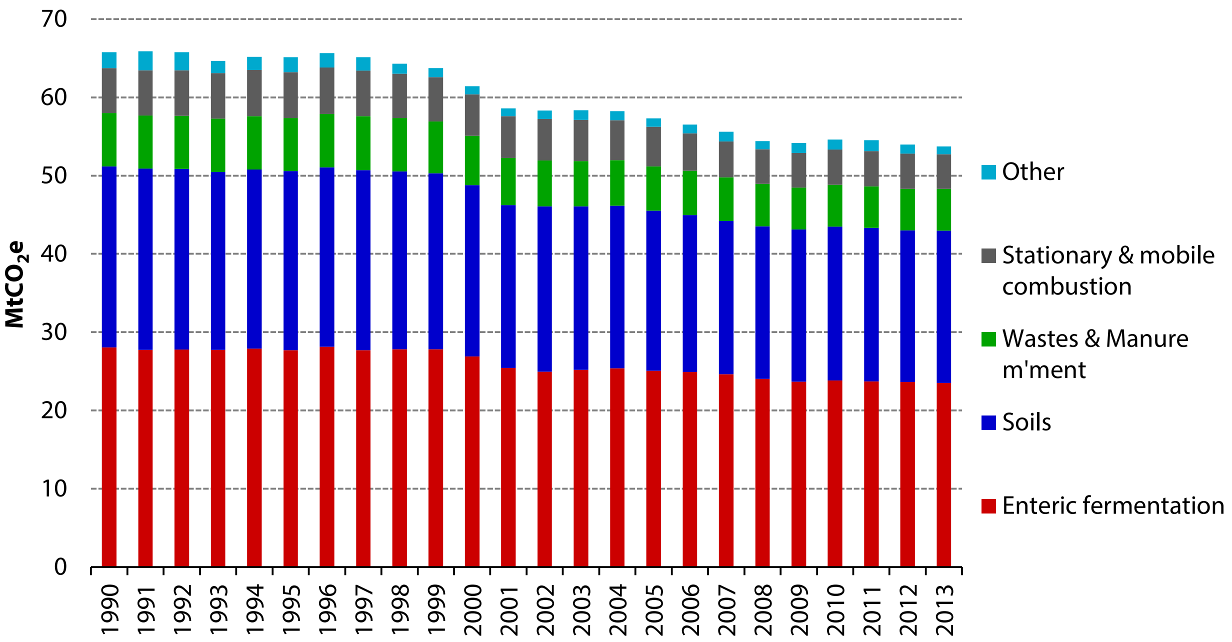
Source: National Atmospheric Emissions Inventory (NAEI) (2015).
Notes: Emissions from other sectors excludes international aviation and shipping sectors.

Agricultural emissions declined from 1990 to 2009, but have remained largely flat in recent years:

- Since 1990, emissions have fallen 19%, due primarily to the reduction in livestock numbers following reform of the Common Agricultural Policy in 2000 (which decoupled farming support payments from animal numbers). This not only impacted methane, but also nitrous oxide emissions as fertiliser use on grasslands declined. In addition, the introduction of legislation to address non-GHG pollutants (e.g. the Nitrates Directive) has helped deliver reduction in emissions (Figure 6.2).
- Between 2009 and 2013, emissions declined by less than one percent.

There are large uncertainties attached to measuring non-CO$_2$ emissions, due to the way the current agricultural inventory is calculated. There are uncertainties that arise from the methodology due to the use of generic emissions factors which are unlikely to reflect specific UK conditions (e.g. on soil and climate), and from the inventory itself which does not fully reflect changes in farming practices that could be delivering abatement. Work undertaken by Defra to better understand and measure the impact of biological systems and different farming practices should reduce these uncertainties with the launch of a new Smart Inventory in 2017.

Figure 6.2: Agricultural emissions by source (1990-2013)



Source: NAEI (2015).

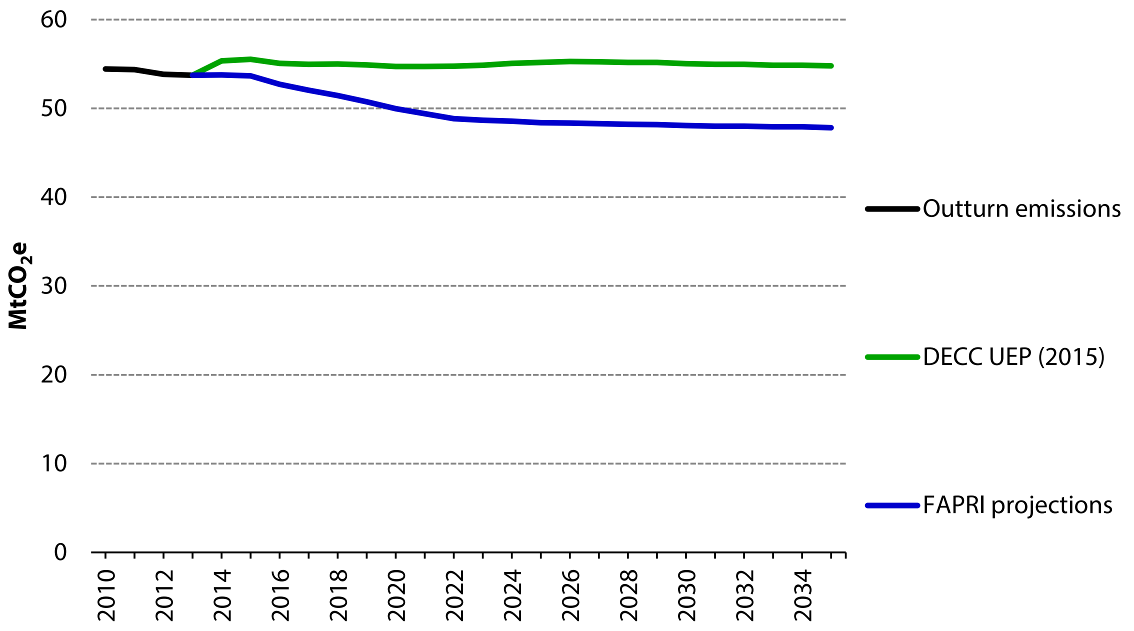
Expectations for emissions without abatement action

The starting point for developing an emissions reduction trajectory is a projection of baseline emissions (without policy actions) based on DECC's Updated Energy and Emissions Projections (UEP) (November 2015):

- DECC's projections are derived by applying Defra emissions factors to livestock and crop activity data from the Food and Agriculture Policy Research Institute (FAPRI) model. The FAPRI model projects farm related activity (e.g. livestock numbers, crop production, fertiliser use) to 2030 based on assumptions around key drivers for this sector such as population, GDP growth, exchange rates, yields, commodity and input prices. These factors are important determinants of the returns to farmers and hence total agricultural production.
- Despite recent difficulties regarding low milk prices for UK dairy farmers, expert review in Defra has indicated that FAPRI had been overly pessimistic on future growth in the dairy sector in the face of increasing global demand for dairy products, the removal of milk quotas in the EU and the UK dairy sector being one of the most efficient in the EU. An alternative range of projections has therefore been established where the lower estimate is based on the FAPRI model outputs, and the higher one based on more optimistic assumptions about dairy sector growth.
- In line with DECC, we have used a central projection between these two. In the absence of policy, this projects agricultural non-CO_2 emissions increasing by 6% to 51 $MtCO_2e$ between 2013 and 2030. This largely reflects an increase in livestock numbers, as the amount of land area under cultivation is expected to be largely unchanged.

With the inclusion of CO_2 emissions, total agricultural emissions are projected to rise by 2% to 55 $MtCO_2e$ by 2030 (Figure 6.3). Disaggregating emissions by gas: N_2O emissions are projected to rise by 2% to 22 $MtCO_2e$; methane emissions are projected to increase by 9% to 29 $MtCO_2e$; and CO_2 emissions are projected to fall by 29% to 3.6 $MtCO_2$.

Figure 6.3: Projections of agricultural baseline emissions to 2035



Source: NAEI (2015), DECC UEP (November 2015) and Defra.
Note: DECC central projection is mid-way between FAPRI and Dairy Growth plan.

2. Options for reducing emissions

Opportunities for reducing agricultural emissions are focused on-farm through the deployment of best practice and technology. In order to assess options over the fifth carbon budget period, we commissioned Scotland's Rural College (SRUC) and Ricardo Energy and the Environment to estimate the abatement potential and costs of a number of options. We also assessed other measures based on academic literature and existing Defra analysis[132].

The SRUC project also considered options which could be available over the longer-term, on the path to the 2050 target. Our qualitative assessment of these is set out in section 4.

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[132] For example, the *Agricultural UK GHG Platform*, and *Farmscoper (the Farm Scale Optimisation of Pollutant Emission Reduction)* decision support tool evaluates the impacts of specific mitigation methods on a wide variety of environmental pollutants.

On-farm abatement options for the fifth carbon budget

There is a large range of options that could potentially deliver emission savings over the fifth carbon budget period. It was not possible to quantitatively assess the abatement potential and costs of all of these. We therefore focused on a limited number of measures that were developed from a longer list and prioritised on the basis that they:

- Have the potential to deliver a high or medium level of abatement.
- Provide certainty of practical feasibility given current evidence and/or timelines required to test and deploy options.
- Are not deemed to be high-risk or have negative co-effects (e.g. on animal welfare).

The mitigation measures are grouped into broad categories, aimed at saving emissions from:

- Soils
- Crops
- Livestock
- Waste and manure management
- Mobile and stationary machinery

The analysis of these measures allow us to understand the level of abatement that is feasible from this sector, as well as costs, other impacts (e.g. on soils and wider sustainability issues), uncertainties, risks, and interactions between mitigation options. In section 4 we set out our central scenario drawing on the cost-effective set of measures available, taking account of deliverability and other considerations. We recognise this may not be the only way to deliver this path, and alternative measures will continue to evolve in the future as evidence (e.g. on technology and costs) develops.

A brief description of the measures assessed in our research, together with the maximum feasible potential and cost effectiveness estimates are set out below. Further details can be found in the SRUC/ Ricardo Energy and the Environment (2015) report[133].

Measures to reduce emissions from soils

Our analysis covered several measures to reduce N_2O from soils (Table 6.1):

- **Improved synthetic fertiliser** use through actions such as carrying out soil analysis, application of lime, using a nitrogen planning tool and not applying fertiliser in very wet or waterlogged conditions. While the number of farmers using a fertiliser recommendation system has increased over recent years, around 20% of applicable land area does not manage its nitrogen use in England. Costs of soil sampling, provision of advice and using a management tool can be offset by reduced fertiliser use.

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[133] Scotland's Rural Collage (SRUC) & Ricardo Energy & Environment (2015) *'Review and update the UK agriculture MACC to assess the abatement potential for the fifth carbon budget period and to 2050'.*

- **Improved manure management practices** aim to improve the application of organic manures in order to reduce nitrogen losses from leaching and run-off and improve the proportion of nitrogen used by crops. Three measures were considered:
  - Using a manure planning tool
  - Switching to a low-emission manure spreading technologies e.g. trailing shoe and open slot injectors
  - Shifting from autumn to spring manure application

  The measures are assumed to apply to the 24% of tillage area and 46% of grassland that receives manure. While EU regulation has created Nitrate Vulnerable Zones (NVZs), which restrict the use of fertilisers and manures in areas of high risk of ground and surface water pollution, there is still a sizeable land area in the UK where there is scope for improvement in these practices. There are equipment costs (e.g. low-emission spreaders), and lower costs associated with preparing manure management plans. A shift to spring manure application is assumed to incur no additional costs on average, though in some cases additional manure storage capacity may be needed. Savings are in terms of reduced synthetic fertiliser costs.
- **Loosening compacted soils.** Soil compaction increases N_2O emissions and reduces the soil's ability to be a methane net sink. As well as reducing GHG emissions this measure provides other benefits such as improving soil function and increasing yield. Measures to address soil compaction include loosening through aeration or ploughing, adding top-soil or sub-soiling and re-seeding. Based on a range of evidence it is assumed that around 20% of arable and grassland area in the UK is compacted. Costs depend on the specific technique used to address compaction, with cultivation of moderately compacted soils less costly than sub-soiling deeply compacted soils. The benefits of this measure are from reduced fuel use in mobile machinery and increased crop yields.

Table 6.1: Soil mitigation measures (2030)

Measure	**Maximum technical potential ($MtCO_2e$)**	**Cost effectiveness (£/tCO_2e)**
Improved synthetic fertiliser use	0.1 to 0.2	35 to 175
Improved manure management practices:		
• Manure planning	0 to 0.1	-25 to -100
• Manure spreaders	0.2	110 to 125
• Switch from autumn to spring application	0.1	-155
Loosening compacted soils	0.4	0

Notes: Range reflects estimate with and without interactions with other measures based on maximum technical potential scenario. Estimates of abatement potential rounded to nearest $0.1MtCO_2e$, cost effectiveness to nearest £5/tCO_2e.

Measures to reduce emissions from crops

These measures aim to improve the efficiency of nitrogen use through planting specialised crop varieties, targeted timing of fertiliser uptake, or the use of technology to more accurately match soil and climate conditions to crop nutrition requirements (Table 6.2). They cover the following:

- **Catch/cover crops** are sown after the harvest of cereals, oil seed rape and other summer-harvested crops. The benefits depend on the type of plant chosen and include: reduced risk of nitrate leaching over winter; reduced risk of soil erosion, and a source of nitrogen to subsequent crops. Our analysis assumes these crops are applicable to 34% of sandy or silty soils in the UK. The main costs relate to seed, cultivation and termination costs.
- **Legumes** such as white clover take nitrogen from the atmosphere and fix it in soils. On arable land they are used in crop rotations and on grasslands are planted in a mixture of legume and grasses. In both cases the benefits reflect reduced need for other fertiliser application. Applicability depends on the type of legume being used, soil type and other factors such as disease risk. For arable applications, the main costs are related to the difference in gross margins between the grain legume and the substituted crop (e.g. winter wheat). On temporary grassland, the cost consists of additional seed costs, while on permanent grasslands there is also a drilling cost.
- **Crops with improved nitrogen use efficiency** require planting new crop varieties that provide either higher yields or less fertiliser or both. This measure requires the development of breeding programmes which could have significant lead times, and our scenarios assume that this measure could start in 2025 at the earliest. Costs are uncertain but we assume new crop varieties are available at the same price as current crops. The savings are from reduced fertiliser requirements.
- **Triticale** is a hybrid cereal grain crop which requires less fertiliser and crop protection to establish than wheat. While the crop has a lower market value it is cheaper to grow and is generally higher yielding since it is less affected by disease than a second wheat. This option assumes 50% of land currently planted with second wheat use triticale instead. Estimates are taken from ADAS (2010)[134].
- **Nitrogen inhibitors (NIs) and Controlled release fertilisers (CRFs)** aim to delay the production of nitrate until the time of greatest crop need. In the case of NIs these act by inhibiting the activity of the bacteria that oxidise ammonia ions to nitrate, whilst CRFs are fertilisers coated with a material that breaks down slowly to delay the release of nitrogen. These measures are applicable anywhere synthetic fertiliser is used. The main impact is to reduce the proportion of nitrogen converted to N_2O, with the rates varying across studies. The measures would not be applied together and cost-effectiveness will depend on the average emission reduction factor used and costs of application. While NIs were not found to be cost-effective by SRUC, in practice different results could hold according to variability in effectiveness, costs and other impacts such as yields and reduced fertiliser requirements. In our scenarios we assume the application of CRFs only.

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[3] ADAS (2010) *'Scoping the potential to reduce GHG emissions associated with nitrogen fertiliser applied to arable crops'*

- **Precision farming (PF)** covers a wide range of technologies used to obtain precise information on soil and crop quality in order to precisely apply management practices (e.g. fertiliser, pesticides). Measures can be applied to arable land and temporary grasslands, but in practice are unlikely to be adopted by small farms. Our analysis focuses on a 'medium' PF system, covering GPS, yield monitoring and mapping and variable rate application. Costs include equipment, monitoring, training and maintenance, while benefits are reduced fertiliser requirement and/or improved yields.

Table 6.2: Crop mitigation measures (2030)

Measure	**Maximum technical potential ($MtCO_2e$)**	**Cost effectiveness (£/tCO_2e)**
Catch/cover crops	<0.1	1230 to 6270
Legumes:		
• Arable land	0.6 to 0.7	280 to 360
• Grassland	0.2 to 0.4	-20 to -45
Crops with improved nitrogen use efficiency*	1.1	-110
Triticale*	0.7	-160
Nitrogen inhibitors	0.1 to 1.5	95 to 710
Controlled release fertilisers	0.2 to 1.1	35 to 135
Precision crop farming	0.4	-95 to -105

Notes: Range reflects estimate with and without interactions with other measures. Estimates of abatement potential rounded to nearest 0.1$MtCO_2e$, cost effectiveness to nearest £5/tCO_2e.
* Estimates based on Defra R&D project AC0221.

Measures to reduce emissions from livestock

Our analysis centred around three types of measures to reduce livestock emissions (Table 6.3):

- **Livestock diet.** We considered four animal dietary measures:
  - **Improved nutrition** aims to improve the digestibility of beef and sheep diets to increase yield and reduce enteric emissions. It involves nutritional advice from an animal specialist, forage analysis and improved grazing management. While a high proportion of dairy farms use nutritional advice, 58% of grazing farms rarely or never do, suggesting there is scope for improved practice in this area.

  - **Probiotics** are microbials (e.g. yeast) fed directly to ruminant livestock which can reduce methane and increase productivity. They are applicable on farms where animals are fed daily. The main cost is the probiotic.
  - **Nitrate additives** involves mixing nitrate into ruminant diets (concentrates or mixed feeds), to partially replace non-protein nitrogen sources or high protein sources (e.g. soya). If used by farms that already have feed mixers and additional storage facilities, the cost is that of the nitrate itself, and would be partially offset by reducing other additives (e.g. urea).
  - **High fat diet** involves using unsaturated fatty acids to reduce methane and can be blended with concentrates. The Farm Practice Survey suggests this is being used by 20% of farms, so there is considerable scope for further uptake. The costs consist of the oilseeds and are partially offset by the reduced concentrates.
- **Health measures.** Improved animal health can reduce emissions intensity by improving feed conversion rates and fertility and reducing mortality. We focus on sheep and cattle. While there are many individual measures that can be applied (e.g. Defra considered 28 measures[135]) there is likely to be a high degree of interaction between them, given the extensive links between diseases. Consequently, we followed the approach of ADAS[136] and developed scenarios to quantify the effects of a 20% and 50% improvement in cattle health.
- **Selection for balanced beef breeding goals.** Genetic improvement through the uptake of selective breeding in beef cattle can contribute to emissions savings as well as increasing profitability. This measure aims to improve breeding traits of the entire population of beef cattle by using real industry data. However, this would require a step change in behaviour among commercial beef farmers, in terms of better understanding of the measure and application of the breeding goals. Costs include the premium for buying semen from the breeding herd and monitoring herds for efficiency improvements.

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[135] Defra (2013), '*Life cycle analysis of endemic diseases on GHG emissions intensity - AC0120*'

[136] ADAS UK Ltd (2014), *' Study to Model the Impact of Controlling Endemic Cattle Diseases and Conditions on National Cattle Productivity, Agricultural Performance and Greenhouse Gas Emissions'.*

Table 6.3: Livestock mitigation measures (2030)

Measure	Maximum technical potential ($MtCO_2e$)	Cost effectiveness (£/tCO_2e)
Livestock diet:		
• Improved nutrition	0.1	-25 to -30
• Probiotics	0.1	-230
• Nitrate additives	0.7 to 0.9	60 to 80
• High-fat diet	0.4 to 0.5	170 to 220
Health measures		
• Cattle health	0.8	-40
• Sheep health	0.4	30
Balanced beef breeding goals	0.1	-50

Notes: Range reflects estimate with and without interactions with other measures. Estimates of abatement potential rounded to nearest 0.1$MtCO_2e$, cost effectiveness to nearest £5/tCO_2e.

Other measures

These fall into two groups, waste and manure management and energy efficiency (Table 6.4):

- **Waste and manure management**:
  - **Slurry acidification.** Methane from slurry can be reduced by 40-87% by adding strong acids (e.g. sulphuric acid or hydrogen chloride). This measure is applicable to all slurry stored in tanks, irrespective of livestock type. The resulting slurry has a higher nitrogen content which reduces the need for additional synthetic fertiliser. The main cost of this measure is the acid.
  - **Anaerobic digestion (AD).** Our assessment is based on three representative small-scale AD plants. In each case the manure and biomass is assumed to be transported to a nearby digester from surrounding farms:
    - Cattle manure and maize silage (250 kW capacity) supplied annually with substrate from 1,800 dairy cattle, 360 beef cattle and 5,000 fresh tonnes of maize silage.
    - Pig and poultry manure and maize silage (500 kW capacity) supplied with substrate from 2,000 sows, 100,000 layers and 300,000 broilers with 10,000 fresh tonnes of maize silage.
    - Maize silage (1000 kW capacity) supplied annually with 40,000 fresh tonnes of maize silage.

    Costs reflect capital and operating costs, transportation, and feedstock costs. The amount of abatement takes account of reduced emissions from storage (including pre-digestion losses and emissions from the AD plant) and the production of renewable energy.

- **Energy efficiency measures:**
  - **Buildings and stationary machinery.** Our assessment of the scope for abatement from energy efficiency measures is based on a Defra (2010) review.[137]. This looked at the scope for reducing CO_2 emissions from on-farm energy use from buildings and stationary machinery by farm types. Examples of measures covered include: glazing greenhouses; heat recovery in horticulture and dairy; insulation upgrades in farm buildings; temperature control in pig housing and grain stores[138].
  - **Mobile machinery.** SRUC also looked at fuel efficiency for mobile machinery (e.g. tractors), which involve measures to improve driving style and regular maintenance. However, savings were not found to be cost-effective and we have therefore excluded it from our abatement scenarios in section 4.

Table 6.4: Other mitigation measures (2030)

Measure	Maximum technical potential ($MtCO_2e$)	Cost effectiveness (£/tCO_2e)
Slurry acidification	0.3 to 0.5	45 to 95
Anaerobic digestion		
• Cattle & maize	0.2 to 0.3	125 to 170
• Pig & poultry and maize	0.2	-20
• Maize silage only	0.1	-40
Energy efficiency		
• Buildings & stationary machinery	1.1	-260 to 35
• Mobile machinery	<0.1	90

Notes: Range reflects estimate with and without interactions with other measures. Estimates of abatement potential rounded to nearest 0.1$MtCO_2e$, cost effectiveness to nearest £5/tCO_2e.

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[137] Defra (2010), *'Energy Marginal Abatement Cost Curve for English Agricultural Sector.'*

[138] Our analysis excluded biomass which is covered in the buildings sector and covers direct emissions savings only, as electricity savings are counted in the power sector.

3. Existing ambition and projected emissions without further policy

Our scenarios for the fifth carbon budget start from a top-down projection of baseline emissions without policies in place (Section 1). From this we deduct emissions savings based on a bottom-up assessment by SRUC of a limited set of mitigation measures based on future uptake.

Farmers however, are already implementing measures that reduce emissions, which may not necessarily be accounted for in the emissions baseline projections. Therefore, the continuation of these current trends needs to be included in our abatement estimates in addition to further uptake of measures. We have used several sources to understand what action is already taking place:

- Baseline abatement from measures considered by SRUC but excluded from their analysis.
- Abatement from measures not considered by SRUC, but being delivered through the industry-led GHG Action Plan.

Based on these considerations and drawing on evidence from the Defra (2012) review[139] and the SRUC work, we estimate the level of cost-effective abatement in the 'policy baseline' to be 2.6 $MtCO_2e$ in 2030 in the UK. This is lower than the 4.5 $MtCO_2e$ (3 $MtCO_2e$ for England and 1.5 $MtCO_2e$ for the DAs) we previously assumed to be delivered through the industry-led action plan. This could be due to a combination of factors such as latest evidence of abatement potential and/or costs having changed, or that we have better accounted for interaction between measures.

Beyond the GHG Action Plan post-2022, we assume no further baseline abatement after this point.

The next section sets out how we use the evidence on abatement options set out in section 2 to develop scenarios for the fifth carbon budget period.

4. Abatement scenarios

In this section, we set out our scenarios for cost-effective abatement to 2030. We also provide a qualitative assessment of what further measures could be deployed beyond 2030 in order help meet our longer-term climate objective. As noted above, these scenarios are not intended to be prescriptive of what needs to be done, but are a way to understand the level of abatement that might be appropriate balancing a range of factors.

Abatement scenarios to 2030

Our scenarios for agriculture reflect a range of cost-effective and feasible abatement potential over the fifth carbon budget period. As set out above, we start from a 'policy baseline' which delivers savings of 2.6 $MtCO_2e$ in 2030, and assume this level of savings will be delivered across all scenarios.

Beyond this, we set out three scenarios. These are based on delivering varying amounts of abatement from the cost-effective measures set out in section 2. All three scenarios assume a move away from the current voluntary approach based on the provision of advice and information. The different levels of abatement reflect, in broad terms, the strength of government policy that could be used to drive uptake:

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[139] Defra (2012) *'2012 review of progress in reducing greenhouse gas emissions in English agriculture'*

- **Central scenario** assumes there is a strong policy framework in place based on incentives (e.g. new grants or incentive mechanisms) and more far reaching policies that could also deliver non-GHG benefits (e.g. Nitrate Vulnerable Zones).
- **Barriers scenario** reflects a lower level of abatement and is based on a weaker policy approach, but still includes incentives for measures that require some up-front investment to encourage up-take.
- **Maximum scenario** is based on achieving the maximum technical potential from the options in section 2. While this scenario involves the maximum abatement potential of the sub-set of options we have considered in depth, in practice the same level of abatement could be achieved with slightly lower abatement from a wider mix of measures.

Central scenario

Our central scenario identifies emissions abatement potential of 8.5 $MtCO_2e$ by 2030 (Table 6.5). The vast majority, 90% of savings, are attributed to reductions in non-CO_2 emissions, with the remainder from CO_2 emissions. In terms of emissions savings by main source:

- Baseline abatement delivers around 30% of savings;
- Crops and soils measures account for about 32% of the savings;
- Livestock measures targeting diets, health, and breeding account for just over 22% of savings.
- The remainder comes from waste and manure management (5%) and improvements in fuel efficiency (11%).

Around 80% of the abatement has negative costs from a social cost perspective (i.e. over the lifetime of the measure and using a 3.5% discount rate). The remaining 20% have a positive cost, but are less than the Government's central carbon values by 2030. Private costs to farmers could be different to social costs, as they are likely to have higher discount rates and shorter pay-back periods. Our analysis suggests that at a 7% discount rate (but leaving pay-back periods unchanged), would still result in around 80% of abatement being cost-saving.

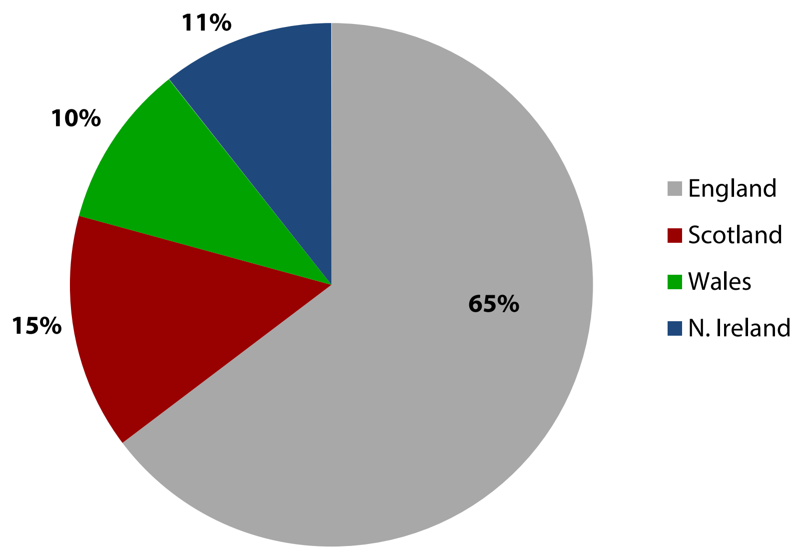
Table 6.5: Central scenario abatement in 2030

Category	Measure	Direct abatement ($MtCO_2e$)
Crops and soil management	Precision farming for crops	0.3
	Manure planning and application	0.1
	Grass clover crops	0.2
	Controlled-release fertilisers	0.2
	GM crops with enhanced nitrogen use efficiency	1.0
	Triticale	0.6
	Loosening compacted soils	0.3
Livestock health measures	Improvements to cattle health	0.7
	Improvements to sheep health	0.3
Livestock diets	Improved nutrition	0.1
	Probiotics	0.1
	Nitrate additives	0.7
Livestock breeding	Use of balanced breeding goals	0.1
Waste and manure management	Anaerobic digestion	0.2
	Slurry acidification	0.2
Fuel efficiency	Improved housing, drying, glazing, irrigation etc.	0.9
Baseline	Measures already being taken-up or promoted through the GHG Action Plan	2.6
Total		**8.5**

Notes: Estimates takes account of interactions. Total rounded to nearest 0.5 $MtCO_2e$.

Agriculture is a devolved policy matter. Policies will need to be developed in each nation in order to deliver the necessary reduction in emissions consistent with the fifth carbon budget. The potential to reduce emissions will differ across the countries because the structure of farming varies. A disaggregation of the UK savings by country is shown in Figure 6.4 and more detail is given in Chapter 5 of the Advice Report.

Figure 6.4: Central scenario abatement savings by country in 2030



Source: SRUC (2015), Defra & CCC calculations.

Risks and further opportunities

Barriers scenario

We have considered a barriers scenario in which emissions savings are reduced due to a series of hurdles to the uptake of measures. A weaker policy framework is assumed to be in place and emissions savings are reduced to 5.5 $MtCO_2e$ (Table 6.6). Key barriers to higher up-take include:

- Behavioural: lack of knowledge and information on measures and outcomes.
- Time and effort required to change current farming practices.
- Other drivers of behaviour are more important than reducing emissions e.g. crop prices and weather.
- Lack of finance for up-front investment e.g. anaerobic digestion and precision farming.
- Lack of funding for R&D e.g. for crops with nitrogen use efficiency.
- Uncertainty and scepticism over outcomes e.g. on improved yields and reduced need for fertiliser.

This scenario is illustrative of the level of abatement that could be delivered if barriers exist across the range of measures. In practice it may be the case that some measures have very difficult barriers while others are easier to overcome, or that policy focuses on delivering higher abatement from a more limited set of measures.

Max scenario

While our central scenario is ambitious, there are further opportunities in this sector that are technically feasible by 2030. We have modelled a 'max' scenario that reflects up-take reaching the maximum technical potential of the measures in the central scenario. This achieves emissions reduction of 9.5 $MtCO_2e$ by 2030 (Table 6.6).

This scenario is illustrative of the types of measures that could produce higher savings. In practice, we have considered a limited subset of options in our analysis, and the max scenario might be delivered by other measures we have not considered in detail. These could involve, for example measures to improve the fuel efficiency of mobile machinery and low-emissions manure spreaders if costs fall further than expected.

Table 6.6: UK direct abatement under scenarios in 2030 ($MtCO_2e$)

Category of measure	**Central**	**Barriers**	**Max**
Crop and soil management	2.7	1.4	3.1
Livestock measures	1.9	0.7	2.2
Waste & manure management	0.4	0.2	0.5
Fuel efficiency	0.9	0.5	1.1
Baseline uptake (GHG Action Plan)	2.6	2.6	2.6
Total	**8.5**	**5.5**	**9.5**
Residual UK emissions	**46.5**	**49.5**	**45.5**

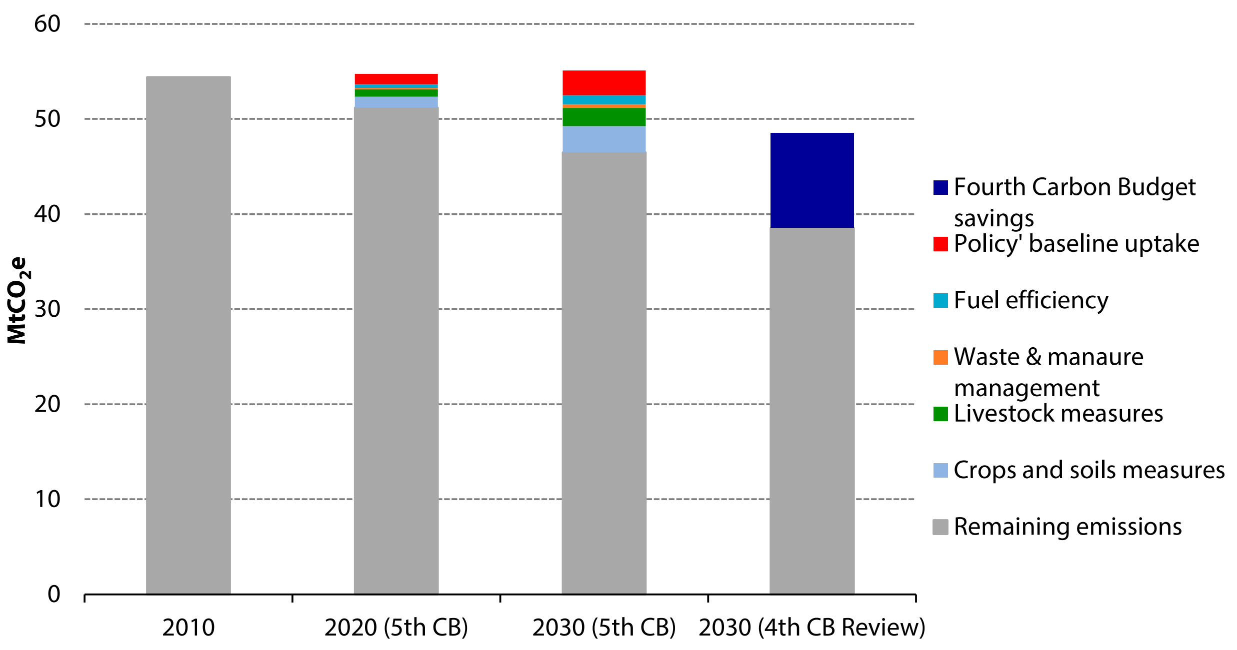
Note: Total abatement and residual emissions rounded to the nearest 0.5 $MtCO_2e$.

Total abatement and rate of change

Our central scenario savings of 8.5 $MtCO_2e$ by 2030 compares to 10 $MtCO_2e$ in our Fourth Carbon Budget review. Combined with the latest projections from DECC, which has higher baseline emissions by 2030, this implies higher residual emissions of 46.5 $MtCO_2e$ by 2030, compared to 38.5 $MtCO_2e$ in our 2013 advice (Figure 6.5).

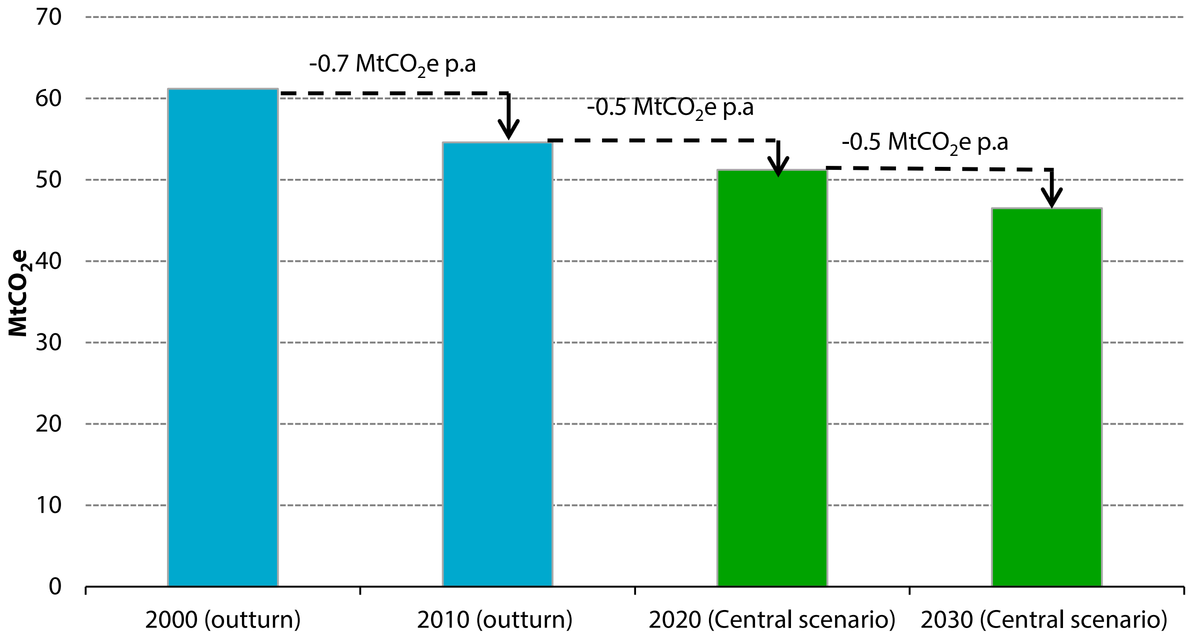
Our revised central scenario implies a 15% reduction in GHG emissions compared to 2010 or a saving of 0.5 $MtCO_2e$ per year. This is equivalent to a 0.6% annual reduction between 2010 and 2020 and 1% per year between 2020 and 2030 (Figure 6.6).

Figure 6.5: Direct abatement under our central scenario, and compared to Fourth Carbon Budget Review



Source: SRUC (2015), DECC *UEP* (November 2015) & CCC calculations.

Figure 6.6: Agricultural abatement and rate of emissions reduction in central scenario (2000-2030)



Source: DECC UEP (2015) and CCC analysis.

Potential longer-term measures to 2050

Beyond 2030, the agriculture sector is likely to represent an increasing share of total emissions as other sectors decarbonise more quickly. However, for UK emissions to decline by at least 80% by 2050, agriculture will need to deliver deeper reductions in emissions in order to contribute to our longer-term cost-effective path. This will require the development of future options and innovative solutions that go beyond those set out above.

We have undertaken a qualitative assessment of some further measures that could contribute to longer-term abatement beyond the fifth carbon budget period. This is not comprehensive, but illustrative of the types of measures possible. In addition to measures that are deployed on-farm, we also include two demand-side measures that could influence upstream agricultural emissions:

- **On-farm measures:** With the exception of precision livestock farming, these measures would not be feasible for immediate implementation based on an assessment by SRUC. Further work is required in order to assess costs and abatement potential to determine if they could become feasible in the future:
  - **Novel crops:** This involves introducing new crop varieties not previously grown to any large scale in the UK or modifying existing types through breeding, both of which could require less nitrogen use. This could include perennial wheat crops which have deeper and denser root systems, and are therefore better able to fix nitrogen, while sequestering carbon in the soil.
  - **Precision livestock farming:** As with precision farming on arable farms, this involves the use of technology and information to target inputs better (e.g. feed and medical treatment). The uptake of precision farming by livestock farmers lags behind that of the arable sector. The barriers include a lack of awareness and training, and financial support for product development and for the uptake of measures by farmers. The new Countryside productivity scheme launched in England earlier this year is providing grants for the investment of technology to improve livestock productivity (e.g. LED lighting for housing). It provides one potential step to overcome some of these barriers.
  - **Genetically modified (GM) livestock:** This measure involves altering the genetic material of animals in order to change the characteristics so that for example, it is better able to resist diseases and improve growth. Current research so far has focused on improvement in emissions intensity rather the direct reduction in emissions emitted from livestock. Genetically modifying animals for food production is currently banned in the EU. In addition, concerns for animal welfare and the unknown wider impact on ecosystems means that current applicability is very limited. Addressing these concerns, changing the regulatory framework and further research and development however, could make this a viable option in the future.

All these measures would require consideration well before 2030 in order to prepare for their implementation. As such they should be considered alongside the specific measures required to meet the fifth carbon budget.

- **Demand-side change:** There are significant opportunities to reduce emissions through changed consumer behaviour:
  - **Diet change:** A rebalancing of diets away from more carbon-intensive products such as red meat and dairy products can potentially deliver emissions savings, while providing health benefits.[140]. Further research would be required to understand the links between diet and emissions, and to understand how changes in the domestic diet alone influence UK agricultural emissions. UK farmers may respond by increasing exports, rather than changing to less carbon-intensive production.
  - **Food waste reduction:** According to Waste and Resources Action Programme (WRAP),[141] around 4.2 million tonnes of avoidable food waste was thrown away by UK households in 2012. By weight, fresh vegetables and salad was the largest food group (19%), while standard bread was the single largest food type. WRAP estimates GHG emissions of 17 $MtCO_2e$ associated with this avoidable waste, which include pre and post-farm gate emissions (e.g. on-farm, transportation and landfill). Although levels have fallen by 21% since 2007, there are opportunities to reduce this further through simple measures such as information provision for households (e.g. the differences between use-by and sell-by dates, and how best to store food).

5. Costs and impacts

The take-up of measures included in our central scenario would save 8.5 $MtCO_2e$ in 2030:

- Around 80% of the abatement has a negative resource cost and will save money through resource efficiency as well as reduce emissions.
- The remaining 20% of the savings incurs a positive cost of up to £78/tCO_2e by 2030[142]. These measures include loosening soil compaction, improving sheep health and slurry acidification.

Uptake in our central scenario is based on the cost-effective level of abatement using the Treasury's Green Book social discount rate of 3.5%, which is appropriate for identifying options in the least cost pathway as part of a national strategy to reduce emissions. Delaying action therefore implies higher costs overall, providing barriers to uptake can be addressed without significant costs.

In addition to reducing emissions, many of the measures also deliver positive co-benefits for adapting to a changing climate and wider Government objectives such as improving air quality. For example, increasing nitrogen use efficiency can improve water and soil quality important for adaptation purposes, while also reducing ammonia emissions, which is important for air quality.

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[140] Biesbroek S et al (2014) *'Reducing our environmental footprint and improving our health: greenhouse-gas emissions and land use of usual diet and mortality in EPIC-NL: a prospective cohort study'.*

[141] WRAP (2013) *'Household food and drink waste in the UK 2012'*

[142] Or are marginally higher than this, contribute significant emissions savings and are needed for the longer term.

6. Decarbonising the land use, land use change and forestry (LULUCF) sector

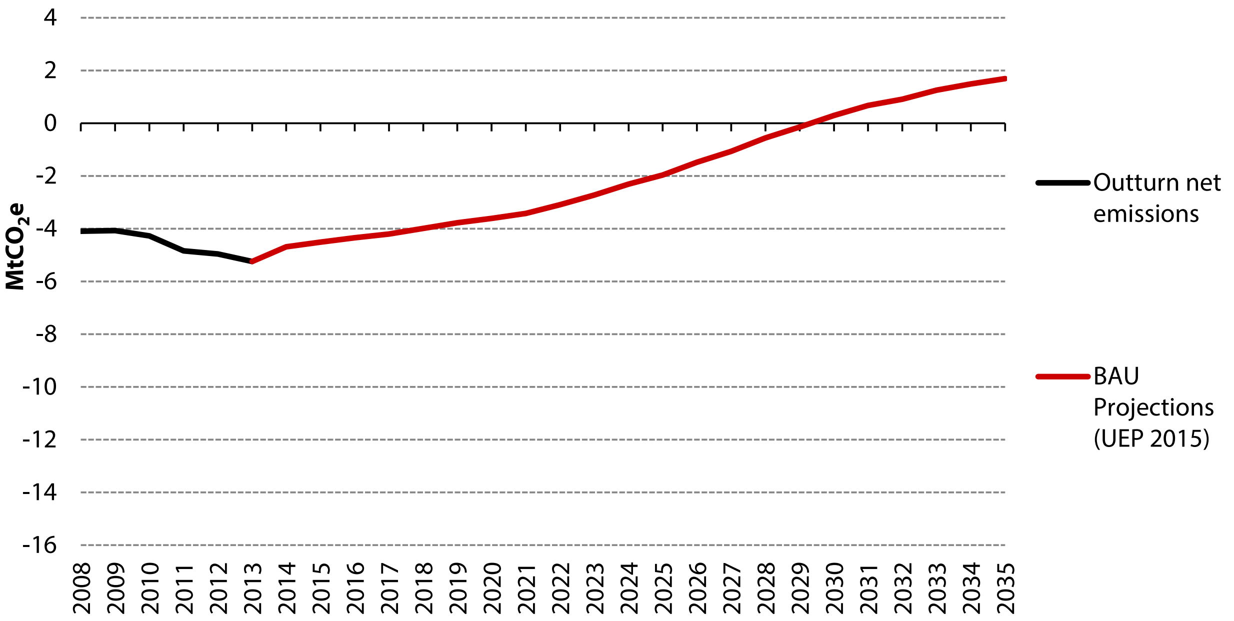
Carbon is sequestered by forestry and grassland, while carbon losses occur on existing cropland and natural land (e.g. grassland) that is converted to cropland or settlement. This section considers the abatement savings that the land use, land use change, and forestry sector (LULUCF) can contribute to the fifth carbon budget.

Overview of emissions

The LULUCF sector has been a net sequester of emissions since 2001, reaching 5.2 $MtCO_2e$ in 2013 which is equivalent to reducing UK GHG emissions by about 1%. The size of the net carbon sink has increased 23% since 2010.

Based on the 2015 DECC business as usual projections[143] however, the sector is set to become a net source of emissions in the late 2020s, reaching 0.3 $MtCO_2e$ by 2030 (Figure 6.7). This assumes no new policy is introduced after 2010, which means no planting of trees across the UK. While emissions from peat are currently excluded from the LULUCF inventory, their expected inclusion in the next few years will increase net emissions in this sector.

Figure 6.7: LULUCF business as usual emissions projections (2014-2035)



Source: DECC UEP (2015).

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[143] DECC (2015) *'Updated Energy & Emissions Projections'* https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2015

Options for reducing emissions

There is a range of options that could be implemented to increase the sink by slowing the release of emissions and increasing carbon sequestration:

- **Afforestation:** Only around 13% of the UK is covered by woodland compared to a European average of 44%. However, England and the DAs all have plans to increase woodland cover. For example, England's ambition is to increase cover to 12% by 2060 from 10% in 2015 (equivalent to an average rate of 5,000 ha per year). To date progress amongst all the countries has been short of the ambition.
- **Agro-forestry:** The integration of trees and shrubs within arable and livestock systems can deliver GHG savings, such as increased soil carbon stocks and reduced fertiliser use. In addition, it can provide a range of non-GHG benefits (e.g. improvements in water quality and soil fertility). Benefits have been recognised at the EU level, and farmers in some member states (e.g. Scotland but not England) are now able to receive funding under Pillar II of the Common Agricultural Policy (CAP) while still being able to receive Pillar I payments (Box 6.1).
- **Peatland restoration:** This involves the re-wetting of degraded peatland. The emissions savings of this practice is unknown at present, although current UK and International studies should improve our understanding.
- **Land management practices:** The way agricultural land (arable and grassland) is managed can impact soil carbon stocks. Work is on-going at the UK and EU level to assess the abatement potential ahead of its inclusion in the LULUCF inventory by 2021.

Box 6.1: Agro-forestry in the UK

Agro-forestry is the term given to the integration of trees or shrubs into a sustainable production system, on both arable land and grasslands. Agro-forestry is classified as either silvoarable (trees and crops) or silvopastoral (trees and animals).

In addition to offering another source of income from the trees (e.g. fruit, biomass and timber), there are a range of environmental benefits that an agro-forestry system can deliver compared to a monoculture system:

- **GHG benefits:** This includes carbon sequestration in the trees and soil carbon improvements if grown on arable land. One study[144] indicated that the fine root carbon in soil under a UK silvoarable system can be up to 79% greater than an arable control. In addition, nutrient recycling from leaf fall and the rooting system can displace some fertiliser use on the arable crop.
- **Other benefits:** There are non-GHG benefits attached to growing trees, some of which relate to adapting to a changing climate. These include water quality improvement from reduced nitrate leaching into water courses, improvements in soil structure and fertility, and enhanced biodiversity. For example, establishing rows of trees between alleys of arable crops can provide wildlife corridors. From an animal welfare perspective, trees can also provide shade from the sun and shelter from the wind for grazing livestock.

Take-up to date in the UK has been extremely low, and no official estimates exist on the amount of land applying agro-forestry practices. A close proxy would be the use of trees and hedges for buffer strips alongside water courses, fruit production in shrubs and shelter belts. It is estimated that these account for around 1% of UK agricultural land.

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[144] Upson, M.A. & Burgess, P.J (2013), *'Soil organic carbon and root distribution in a temperate arable agroforestry system', Plant and Soil, 373, 43–58, 2013*

Box 6.1: Agro-forestry in the UK

Wider adoption of agro-forestry requires overcoming several barriers related to finance, lack of policy support, land tenure (tenanted farmers are less likely to adopt this system given the timescales involved in establishing trees as crops) and farmer awareness. The Scottish Government is now providing financial and policy support by granting Rural Development Programme funding of £3,600/hectare for the planting of up 400 trees/hectare on sheep grazing land, without farmers losing their Pillar I payments under the CAP.

Abatement scenarios to 2030

To date, our scenarios for carbon budgets have only included abatement from increasing afforestation rates. In this section, we re-evaluate the abatement saving from this particular measure, and consider additional savings from the inclusion of agro-forestry.

Central scenario

Our central scenario includes cost-effective abatement totalling 2.4 $MtCO_2e$ by 2030:

- **Afforestation:** Increasing the rate of tree-planting (above baseline rates of zero planting) by around 15,600 hectares a year could deliver 1.8 $MtCO_2$ savings in 2030 in the UK. Given that carbon sequestration increases rapidly over time as trees grow, savings are estimated to double to 3.6 $MtCO_2e$ by 2035.This level of afforestation is consistent with meeting the policy aspiration set out by England and the DAs, although we note that progress to date has been short of the ambition with tree planting reaching 10,300 hectares in the year to end March 2015. It is essential therefore, that plans are put in place to deliver the targets.
- **Agro-forestry:** Our central scenario assumes savings of 0.6 $MtCO_2$ can be delivered by 2030. This is focused on CO_2 from carbon sequestration in trees and soil, and excludes other GHG savings (e.g. N_2O savings from reduced fertiliser use). This is based on increasing agro-forestry systems by an additional 0.6% of UK agricultural land area on top of the 1% of land that is currently used for hedgerows and shelter belts. This uptake assumes a high level of policy support, including finance to support farmers, with CAP being one possible mechanism, as is the case in Scotland. However, barriers due to lack of knowledge and awareness that currently exist among farmers about the potential benefits of agro-forestry systems are considerable and would also have to be addressed.

Barriers scenario

In this scenario, we assume barriers exist that restrain the level of additional tree planting both in terms of woodland creation and agro-forestry, resulting in emissions savings of 0.5 $MtCO_2$ by 2030:

- **Afforestation:** a reduced level of additional annual afforestation to around 285 hectares would deliver savings of 0.3 $MtCO_2$ by 2030. This assumes that forestry payments under the Rural Development Programme (2015-2020) are not continued after 2020, when the current CAP ends.
- **Agro-forestry:** this scenario assumes the level of support and interest continues to remain very low, with savings of only 0.2 $MtCO_2$ by 2030 based on using 0.2% of additional agricultural land.

Maximum scenario

This scenario looks at what can be achieved with more ambitious levels of woodland creation and agro-forestry, while still remaining cost-effective. Under this scenario, potential savings increase to 4.8 $MtCO_2$ by 2030:

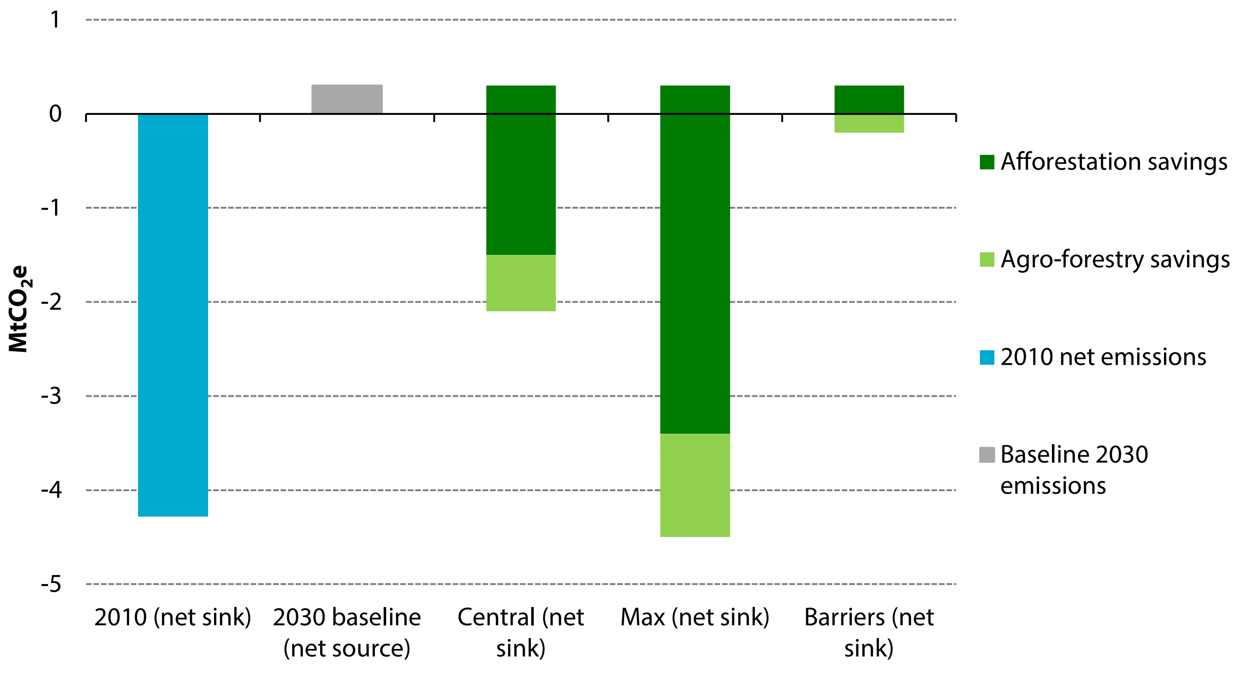
- **Afforestation:** an additional 15,000 hectares above the central scenario would deliver 3.7 $MtCO_2$ of savings by 2030. This assumes policy aspiration is increased beyond the current ambition of England and the DAs.
- **Agro-forestry:** this assumes policy support is increased both in terms of finance and awareness, so that wider adoption of land delivers savings of 1.1 $MtCO_2$ by 2030, based on an additional 1.3% of agricultural land developing agro-forestry systems.

Our range of abatement would imply that the LULUCF sector is a net carbon sink of between 0.2 $MtCO_2e$ and 4.5 $MtCO_2e$ by 2030 (Figure 6.8).

Beyond the fifth carbon budget period, the rate of sequestration from trees planted by 2030 will increase rapidly as they start to reach maturity, thus offering higher abatement savings. Assuming annual planting rates in the central scenario are maintained above 12,000 hectares annually, savings from afforestation could reach 7 $MtCO_2$ by 2050.

There is also scope to achieve savings from other measures not included in our scenarios. Peatland restoration could be the most significant of these in terms of abatement potential. However, this will require Government to address gaps in the LULUCF inventory, which currently excludes emissions from upland peat and the savings potential from the restoration of degraded peat.

Figure 6.8: Abatement in the LULUCF sector by CCC scenario to 2030



Source: SRUC(2015), DECC UEP (2015) and CCC analysis.

7. Delivering the scenarios

Our central abatement scenario over the fifth carbon budget period from agriculture and LULUCF sets out a contribution to the cost-effective path that is both feasible and challenging. In order for this to be delivered a number of actions will need to take place. These include:

- Government should set out a clear and strong ambition, providing a credible signal to farmers, landowners, investors and the wider agriculture industry for the future path for these sectors.
- The central scenario for agriculture goes beyond the current industry-led voluntary approach and needs to be underpinned by a strong policy framework, including financial incentives, tackling non-financial barriers as well as more far reaching policies (e.g. as in the Nitrate Vulnerable Zones).
- Many of these measures are cost-saving from a social perspective and could also save farmers money, improve productivity and increase resource efficiency. There is an opportunity to use this to engage industry bodies in a partnership to develop effective ways to deliver the scenario.
- More needs to be done to address non-financial barriers preventing the industry from moving towards low-carbon practices (e.g. lack of awareness of options, uncertainty and scepticism over outcomes).
- Government needs to co-ordinate effort across DAs to ensure all nations play a part in delivering the UK ambition.
- In order to meet afforestation rates, England and the DAs will need to put in place plans to meet existing targets. For agro-forestry, wider adoption requires addressing the financial and non-financial barriers (e.g. lack of information and awareness) that exist among farmers and policy makers.

Chapter 7: Waste and F-gases

Introduction and key messages

Waste and F-gas emissions account for 7% of total UK greenhouse gas (GHG) emissions. Waste emissions are predominantly methane emissions which arise due to the decomposition of biodegradable waste in landfill sites in the absence of oxygen. F-gases are used in various applications, mainly as coolants in air conditioning and refrigeration, and are typically released through leakage.

Waste emissions

- Waste emissions have fallen 67% since 1990, due to a reduction in biodegradable waste going to landfill, investment in methane capture technology and improved management at landfill sites. DECC projects that waste emissions will continue to fall, with emissions in 2030 80% lower than in 1990.
- The ability to reduce waste emissions beyond 80% from 1990 will ease the burden of meeting the 2050 target if abatement in other sectors proves difficult or expensive. We have identified further cost-effective abatement potential by reducing waste throughout the supply chain, preventing biological waste going to landfill, ensuring that this can be diverted to be used in productive ways (e.g. anaerobic digestion units).
- Our Central scenario suggests that waste emissions could reduce from 23 $MtCO_2e$ in 2013 to 10 $MtCO_2e$ by 2030 and 8 $MtCO_2e$ in 2050.
- Compared to a scenario with delayed action in the 2020s, this scenario would save around £4 billion in present value terms under central fossil fuel and carbon value assumptions.
- Currently the GHG inventory estimates emissions from waste water treatment are 4 $MtCO_2e$. This is based on high default values due to limited available data on waste water emissions and could be an overestimate. There is need for accurate data for waste water emissions and the identification of further abatement potential.

F-gas emissions

- F-gas emissions have increased since 2000 due to their use in refrigeration and air conditioning.
- The 2015 EU F-gas regulation introduced a series of measures, including a quota system, series of bans and further leakage checks, which are expected to bring emissions down significantly by the early 2030s.
- Going forward, the Government needs to ensure the UK fulfils its duties under the EU 2015 F-gas regulation, monitor its effectiveness and find opportunities to exceed regulatory minimums.

We will return to policy challenges in our 2016 Progress Report.

We set out the analysis that underpins these conclusions in the following sections:

1. Overview of emissions from the UK waste and F-gas sectors
2. Options for reducing emissions
3. Existing ambition and projected emissions without further policy
4. Abatement scenarios
5. Costs and impacts
6. Delivering the scenarios

1. Overview of emissions from the UK waste and F-gas sectors

Waste emissions

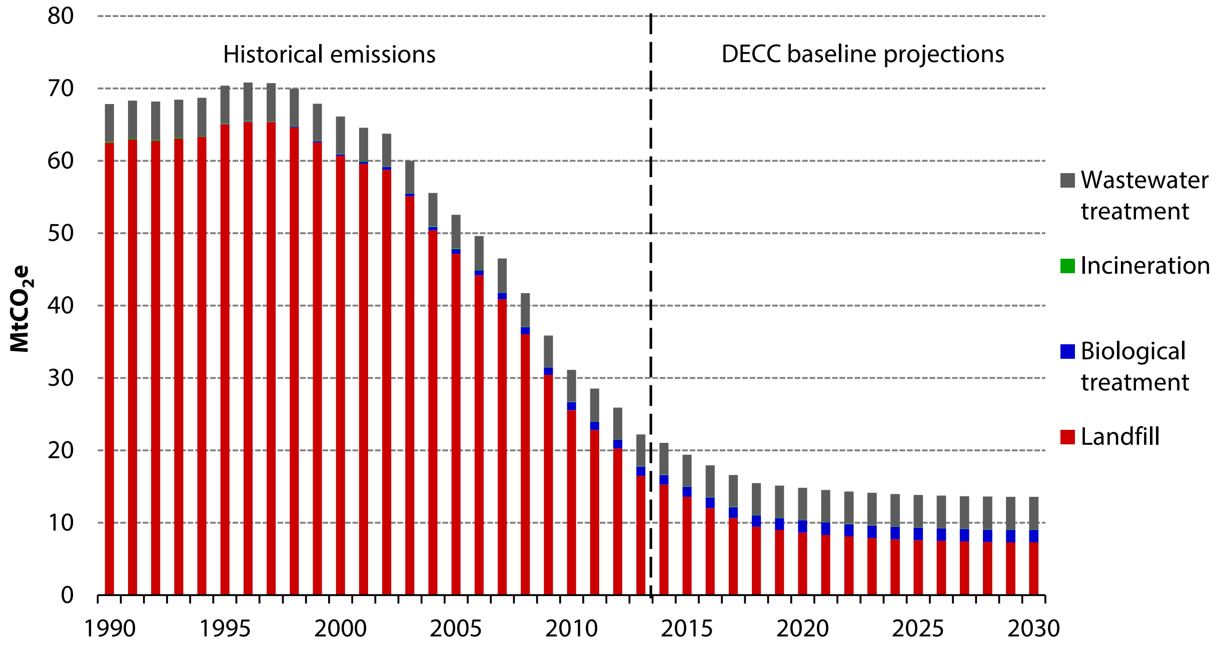
Waste emissions were 23 $MtCO_2e$ in 2013 and accounted for almost 4% of total UK greenhouse gas (GHG) emissions. Waste emissions are predominantly methane emissions which arise due to the decomposition of biodegradable waste in landfill sites in the absence of oxygen:

- **Landfill emissions**. Entirely methane, landfill emissions were 17 $MtCO_2e$ in 2013. Landfill emissions have fallen by 74% since 1990 (Figure 7.1). Half of this reduction has been due to reductions in biodegradable waste going to landfill; the other half has been due to investment in methane capture technology and improved management at landfill sites.
- **Wastewater treatment emissions**. Mainly methane with some nitrous oxide (N_2O), wastewater treatment emissions were 4 $MtCO_2e$ in 2013.
- **Biological treatment emissions**. A mixture of methane and nitrous oxide from composting and anaerobic digestion, biological treatment emissions were 1 $MtCO_2e$ in 2013.
- **Incineration (without energy recovery) emissions**. 1% of waste emissions and are mainly CO_2.

DECC project that waste emissions will continue to fall to 14 $MtCO_2e$ by 2030, 80% lower than in 1990. This continued reduction will be caused by less waste going to landfill and some improvement in methane capture from landfill sites.

Given their dominance, we focus on further abatement opportunities to reduce methane emissions from landfill.

Figure 7.1: DECC projection of waste emissions (1990-2030)



Source: DECC (2015) *Non-CO_2 greenhouse gas emissions projections.*
Notes: 1990-2013 are historical emissions; 2014-2030 are projected emissions.

F-gas emissions

Current emissions

Fluorinated gas (F-gas) emissions were around 17 $MtCO_2e$ in 2013 and accounted for 3% of total UK GHG emissions. The majority of emissions (77%) were the result of gas leakage of hydrofluorocarbons (HFCs) used in refrigeration and air conditioning as a substitute for ozone-depleting substances. Other F-gases (23%) were from diverse sources, such as the use of metered dose inhalers, aerosols and fire-fighting equipment.

The four reported F-gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and newly measured nitrogen trifluoride (NF_3). While they are released in small amounts they have very high global warming potentials (between 140 and 23,900 times that of CO_2) and long atmospheric lifetimes (Box 7.1):

- **HFCs** (95% of total emissions) are released mainly from refrigeration and air conditioning appliances, aerosols and foams, metered dose inhalers (MDIs) or fire extinguishers. They are released during the manufacture, lifetime and disposal of these products.
- **PFCs** result mainly from the manufacture of electronics and sporting goods, as well as fugitive emissions from halocarbons production used for various purposes (e.g. refrigerants, pesticides or solvents).
- **SF_6** emissions come mainly from the use of electrical insulation, magnesium casting and military applications.

- **NF_3** emissions are presently a result of semiconductor manufacture and are very small. These are not currently covered by carbon budgets, but we have recommended the UK government should include them as soon as practically possible.

Box 7.1: Climate change impact of methane and F-gases

Different greenhouse gases vary in their impact on the climate system, which is typically measured by global warming potential (GWP).

- While CO_2 has a GWP of 1 and a mean lifetime around 30-95 years, methane from waste has a lifespan of around 12 years only.[1]
- For F-gases, lifetime can range from 5 years to 50,000 years.[2] The choice of timespan determines the level of GWP since short-lived gases may initially have a large impact that decreases over a longer time period. For instance, methane has a GWP of 34 over 100 years, but 86 over 20 years.[3] Currently, GHG inventories typically report on emissions using GWP values over the 100 years horizon.

This means that, if reported on a shorter time span, methane or F-gases used in refrigeration would represent a higher proportion of total emissions.

Source: [1] Jacobson, MZ (2005) Correction to Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming, *Journal of Geophysical Research*, Volume 107, Issue D19, ACH 16-1–ACH 16-22.
[2] DECC (2014) *Review of data and methodologies used in the calculation of UK emissions from F-Gases*
[3] Myhre, G., et al (2013) Anthropogenic and Natural Radiative Forcing, *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Emission trends

F-gas emissions peaked at 25 $MtCO_2e$ in 1997 when 78% of total emissions were the result of industrial production of halocarbons. Between 1997 and 2001, F-gas emissions fell substantially as a result of fitting abatement technologies at halocarbon production facilities. Since then, emissions have been on a rising trend with an annual average 2% increase between 2001-2013. Higher use in refrigeration and air conditioning was the main factor behind this growth with the 2006 EU F-gas regulation aiming at mitigating this:

- **Refrigeration emissions.** The main source of F-gases showed an annual average 4% rise over the period 2009-2013 due to increasing demand for refrigeration products. This growth in emissions has been lower than in previous years (12% average annual growth between 2001-2009), likely to be a result of the goal in the EU 2006 F-gas regulation to replace high GWP F-gases with lower GWP refrigerants and reduce leakage.
- **Mobile air conditioning (MAC) emissions.** These emissions grew an average 2% a year over the period 2009-2013, following annual average 7% growth between 2001-2009. The EU 2006 MAC directive is the main reason behind the reduction as it restricts F-gases use in new cars.
- **Stationary air conditioning emissions.** Rose by annual average 9% over the period 2009-2013 because of increasing use of relevant products as compared to 14% average yearly growth over 2001-2009. The EU 2006 F-gas regulation is likely to be behind the deceleration in the growth.

Altogether, while some main sources of F-gases increased over the period 2009-2013 other emissions fell or grew at a lower pace so that total F-gas emissions showed an annual average 1.6% growth.

2. Options for reducing emissions

Waste - Landfill

There are three established approaches to reducing emissions from waste, which focus on reducing methane emissions arising from landfill sites: waste prevention, waste diversion, and methane capture.

Waste prevention

Waste emissions can be reduced through waste prevention, which offers substantial upstream environmental and economic gains associated with resource efficiency beyond the benefits of reducing methane from landfill.

There are benefits to households, businesses and local authorities for preventing waste arising. Currently:

- UK householders spend £12.5 billion every year on food that ends up being thrown away[145], while food and packaging waste is estimated to cost the UK food industry £6.7 billion per year,[146]
- £140 million worth of used clothing goes to landfill each year[147] and almost a quarter of used electrical products taken to household waste recycling centres each year could be reused, with a gross value of £200 million,[148]
- The waste that we produce costs UK businesses £885 million[149] and local authorities £3.2 billion to manage, [150]

Preventing waste by acknowledging the true value of materials all the way through the supply chain represents a move towards a circular economy - where resources are kept in the economy for as long as possible, we extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life (Box 7.2).

Opportunities for waste prevention occur throughout a product life-cycle. Actions could include:

- Minimising waste through process design, reducing material offcuts or optimising packaging,
- Improved design to expand the lifespan of products and to enable more repair, remanufacture, reuse and recycling,
- Use of different business models such as take-back schemes, leasing and producer responsibility.

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[145] WRAP (2012) *Household Food and Drink Waste in the United Kingdom 2012*, www.wrap.org.uk/sites/files/wrap/hhfdw-2012-main.pdf.pdf

[146] WRAP (2012) *Estimates of waste in the food and drink supply chain*, http://www.wrap.org.uk/sites/files/wrap/Estimates%20of%20waste%20in%20the%20food%20and%20drink%20supply%20chain_0.pdf

[147] WRAP (2012) *Valuing our clothes*, http://www.wrap.org.uk/content/valuing-our-clothes

[148] WRAP (2011) *Realising the Reuse Value of Household WEEE*, www.wrap.org.uk/sites/files/wrap/WRAP%20WEEE%20HWRC%20summary%20report.pdf

[149] Defra (2013) *Environmental Protection Expenditure (EPE) Survey 2011*, www.gov.uk/government/publications/environmental-protection-expenditure-epe-survey-2011. Includes operational and capital costs

[150] LGA (2013) *Wealth from waste: The LGA local waste review*, www.local.gov.uk/c/document_library/get_file?uuid=a9ae477e-e0cf-4665-862e-ed01caa810f6&groupId=10180

Transition towards a circular economy requires action from everyone in the supply chain, from those extracting raw materials to the designers, manufacturers, distributors, retailers, and consumers.

Waste diversion

Where waste cannot be prevented, there is potential to go further in diverting biodegradable waste away from landfill to other treatment options. Diverting waste away from landfill would also take the UK a step closer to a circular economy through recovering and regenerating materials at the end of each service life:

- **Recycling**. The processing of various waste streams (e.g. plastics, glass and paper/card) into new products can reduce the use of raw materials and energy within manufacturing, as well as reduce environmental impacts from waste processing (e.g. incineration). In particular, the recycling of biodegradable waste streams such as paper/card and wood will avoid landfill methane emissions.
- **Composting**. Composting can be used to treat food and green waste. If properly managed, organic waste in a compost pile will decompose in the presence of oxygen (i.e. aerobically rather than anaerobically) and will produce (biogenic) CO_2 instead of methane. The compost can be applied to land, reducing the need for fertiliser and the associated emissions. Composting requires that food and green wastes are collected separately from other wastes.
- **Anaerobic Digestion (AD)**. AD can be used to treat sorted food and green waste. The biogas produced can be used, for example, for generating heat and/or power or as a vehicle fuel (if it is cleaned of impurities). The digestate that remains after biogas has been generated can be applied to land, displacing the need for fertiliser.
- **Mechanical Biological Treatment (MBT)**. MBT involves breaking mixed waste down (e.g. by shredding) and removing any recyclable material. The waste is then either composted or digested, producing biogas. There are two possible outputs: a low-quality soil or a solid recovered fuel (SRF) for burning in a dedicated combustion facility. The emissions impact of MBT with SRF varies according to the type of thermal process. For example, if it is used to offset coal use in cement kilns, the emissions savings are favourable but if used for mass-burn incineration the savings are less favourable relative to landfilling.
- **Incineration** with energy recovery. Waste collected can either be fed directly into a furnace or boiler without any prior separation or sorting, or it can be passed through an MBT process first and the refuse-derived fuel fed into the incinerator.

In 2012 WRAP commissioned Eunomia to produce updated analysis on the costs and benefits of landfill bans.[151] The study concluded that diverting biodegradable wastes from landfill could yield strong climate change benefits and resource efficiency gains, particularly coupled with policies to support waste sorting. With sorting, the waste could be diverted to recycling, biological treatment or incineration with energy recovery. Based on this research, the devolved administrations have already started, or are planning, to divert specific waste streams from landfill (Section 3).

The research by Eunomia and current devolved administration waste policy suggest that far more can be done to in reduce waste emissions through diversion away from landfill. To be

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[151] WRAP (2012) *Updated report on the feasibility of landfill bans*, http://www.wrap.org.uk/content/updated-report-feasibility-landfill-bans

successful this will require 5-10 year lead-in times with complementary policies to aid waste prevention, separate collection and the alternative treatment of waste.

Our scenarios consider the impacts of waste prevention policy in the UK, further waste diversion from landfill within the devolved administrations, and additional emission abatement potential through prevention or diversion of biodegradable waste going to landfill.

Methane capture

Even if biodegradable waste sent to landfill could be eliminated overnight, there would still be legacy emissions from waste. This highlights the importance of methane capture from landfill sites.

The average methane capture rate in the UK is estimated to be 61%, the second highest in the EU. Methane capture at modern landfill sites is over 80% and can reach as high as 90%. In practice the capture rate is site specific, depending on the age of landfill site, technology implemented, the point at which the technology becomes active based on the amount of methane generated, and its day-to-day operation.

The DECC landfill waste emission projections assume that the UK average capture rate rises from 61% to 65% and is maintained at this level. There is further potential to increase average capture rates as highlighted in the recent ACUMEN study (Box 7.3). However maintaining this capture rate will be challenging as waste sent to landfill and methane generated from this waste continue to fall. Due to this level of challenge and the uncertainty over what impact reducing waste going to landfill will have on average capture rates our scenarios have not assumed any further increase in the methane capture rate than that in the DECC projections.

Overall, where waste can be prevented this has been proven to be economically beneficial and should be the first option. However, where waste cannot be prevented then there are options to increase diversion away from landfill. In addition, the reduction, reuse and recycling of waste (rather than disposal) is associated with further emissions savings upstream (e.g. those arising from agricultural, energy, and industrial production), although the precise level of savings is often difficult to quantify.

Box 7.2: The circular economy

Traditionally, economies have relied on cheap, accessible energy and materials to function effectively. The decoupling of economic progress from resource constraints is one of the greatest challenges of the 21st century.

A 2012 report from the Ellen MacArthur Foundation, with analysis by McKinsey, has placed a material cost saving opportunity of adopting this approach in Europe of between $340bn and $630bn per annum by 2025.

The circular economy is a generic term for an industrial economy that, by design or intention, is restorative and eliminates waste throughout the supply chain. It seeks to provide a model to decouple economic progress from resource constraints in a way that inspires innovation throughout the whole value chain, rather than relying solely on the waste recycling end of the market. The circular economy is restorative, with materials designed to circulate at high quality with their economic value preserved or enhanced.

Most of the value in the circular economy comes much further up the chain (or loop); recycling is the last resort. It is the componentisation, remanufacture, refurbishing and reselling of goods that is of most value to the economy and, in doing so, creates the most high value jobs.

Moves towards a circular economy may reveal opportunities to reduce emissions in other sectors. For instance, well planned recycling of glass as an input in producing new glass products is essential to achieve cost-effective abatement from industry, as set out in Chapter 4.

Source: Ellen MacArthur Foundation (2012) *Towards the Circular Economy: Economic and business rationale for an accelerated transition*, http://www.ellenmacarthurfoundation.org/publications

Box 7.3: Project ACUMEN

Assessing, Capturing and Utilising Methane from Expired and Non-operational landfills (ACUMEN) was a partnership project funded by the EU, Defra and other participating organisations, and staffed by the Environment Agency, local councils and technology companies. ACUMEN aimed to demonstrate new techniques and technologies to improve the capture and use of methane from closed and historic landfills.

The project installed and operated a range of new techniques at demonstration landfills. The aim was to show technologies that can work on the full range of closed landfills. This includes innovative monitoring systems with an assessment of the costs and benefits of each demonstration project to see which options best suit certain categories of closed landfill.

The techniques demonstrated include small scale gas engines (8 - 150 kilowatts), a novel low-calorific gas flare and an active biological oxidation technique. The six demonstration sites ranged from 5 to 40 hectares in size, and between 20 and 50 years in age.

The project finished in late 2015 and provides a range of techniques to landfill owners to help them assess the options for managing methane at their sites and technical guidance in order to replicate the demonstrations at their own landfills.

Source: Project ACUMEN, https://www.gov.uk/government/groups/acumen-assessing-capturing-and-utilising-methane-from-expired-and-non-operational-landfills

F-gases

Available evidence suggests that, in many refrigeration and air conditioning sectors and all foam uses, a combination of low GWP alternatives to HFCs could reach 100% market penetration in or before 2030 (Table 7.1).

Most of the abatement options are estimated to be cost-effective. Specifically, for different policy options, the average abatement cost in 2030 was calculated to be in the range of £15 to £42/tCO_2e which is well below central UK carbon values by 2030 (£78/tCO_2e).

There may be scope to reduce F-gas emissions further through low GWP alternatives for metered dose inhalers (MDIs: devices used to deliver a given amount of medication to the lungs). Available evidence suggests that dry powder inhalers are an alternative that do not use a gas and have been used for over 20 years in many countries.[152] However, these are generally more expensive than MDIs, with a high abatement cost around £174/tCO_2e in 2015, and are not considered suitable for users with breathing difficulties.

Table 7.1: Abatement options for certain F-gases in 2030 at EU level

Sector	Current F-gases	Key lower GWP alternatives	Abatement cost (£/tCO_2e, 2014 prices)
Refrigeration	HFCs	Domestic and commercial: R600a Industrial: NH_3 Transport: R290, CO_2, HFC-1234yf	Domestic: £1 Commercial: -£1 to £22 Industrial: -£20 to -£1
Stationary air conditioning (including heat pumps)	HFCs	R290 direct, CO_2, HFC-1234yf, NH_3	From £5 to £17 £119 for heat pumps
Mobile air conditioning	HFCs	HFC-1234yf, R744	Trucks: £39, Buses: £44 Ships: £15-£32, Rail: £507
Foams	HFCs	HC, unsaturated HFC	-£1 to -£56
Aerosols and fire protection	HFCs	Unsaturated HFCs and FK 5-1-12	£9 and £3-£20
Electric switchgear and magnesium die casting	SF_6	Solid insulation and HFC-134a, SO_2	£317 and £0

Source: Adopted from European Commission Impact Assessment (2012), http://ec.europa.eu/clima/policies/f-gas/legislation/documentation_en.htm
Notes: Original abatement costs (€, 2010 prices) were converted to pounds sterling (2014 prices) using annual average exchange rates and GDP deflator values.

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[152] AEA (2010) *HFC consumption and emissions forecasting. Containing an update to the June 2008 HFC projections.*

3. Existing ambition and projected emissions without further policy

Waste

Government policy to reduce landfill emissions has focused on reducing waste, diverting waste from landfill and capturing the methane from landfill sites. Waste emission reduction has occurred through a combination of information and voluntary programmes to prevent waste, a landfill tax to divert waste from landfill and investment in methane capture technology. Action is being taken at EU, national, devolved administration and local authority levels. We briefly summarise each below.

EU Directive

The 1999 EU Landfill Directive requires a 65% reduction in biodegradable municipal waste (BMW) landfilled in the UK by 2020 relative to 1995 levels of BMW production. Estimates for 2012 suggest that BMW sent to landfill has fallen by 71% against the baseline, and so is currently outperforming the targets set.

The EU Commission intends to present a new, more ambitious circular economy package late in 2015 which will aim at transforming Europe into a more competitive resource-efficient economy, addressing a range of economic sectors, including waste. We will monitor developments and report on the package in our 2016 Progress Report.

National waste emission policies

Waste management is a devolved issue, with England and each of the devolved administrations developing waste strategies and legislating waste measures. We first consider progress in policies affecting the whole of the UK, then progress for the individual nations against the devolved targets.

UK-wide policy

In order to achieve current targets under the EU Directive, the UK introduced the Landfill Tax in 1996. This imposes a charge on landfill operators for each tonne of waste landfilled, creating an incentive to reduce the waste sent to landfill either through waste prevention or diverting waste to other treatments (recycling, composting, recovery, and reuse). The tax has been increased from its initial rate of £7 per tonne in 1996 to £82.60/t in 2015/16. As of April 2015, Scotland has acquired responsibility for setting its own landfill tax and Wales will follow in 2018.

There are a number of voluntary programmes aimed at reducing packaging and food waste managed by WRAP, which has set a number of targets to reduce waste both in food production, groceries and household use.

Capture of methane at landfill sites has increased from an average rate of 1% in 1990 to 61% in 2013. This reflects investment driven by a combination of permit conditions and financial incentives for capturing methane from landfill and anaerobic digestion (e.g. under the Renewables Obligation, Feed-in-Tariffs, and Renewable Heat Incentive).

England

In our 2014 Progress Report, we reported the launch of the 'Waste Prevention Programme' (WPP) for England to drive waste further up the waste hierarchy by helping businesses and households realise cost savings through waste prevention and resource efficiency.

While the WPP sets in place useful policies to support waste prevention and plans for indicators, there are, unlike the devolved administrations, no targets or milestones in England to evaluate progress other than those from WRAP or EU Directives. There are no further increases planned for the landfill tax in real terms which may slow down progress on reducing landfill emissions.

The Government's 2011 'Anaerobic Digestion (AD) Strategy and Action Plan for England' includes a £10 million loan fund to support new AD capacity, and an innovation fund to bring down costs of AD, identify potential sources of waste feedstock, and develop markets for digestate (an AD by-product). Since its launch in June 2011, the number of AD plants has increased from 54 to over 185 plants by April 2015, with a further 500 plants currently under development.[153]

Scotland

In the 'Zero Waste Plan', Scotland has set a plan to reduce the environmental impact of waste and move towards a circular economy. Scotland is planning to roll out separate food waste collections from 2016 and implement a ban on biodegradable municipal waste going to landfill by 2021.

Wales

In Wales, the reduction in waste emissions follows the introduction of a number of levers encompassing regulatory mechanisms, waste prevention and improvements at landfill. In June 2010, Wales published 'Towards Zero Waste', an overarching waste strategy, and set statutory targets for waste going to landfill and recycling targets for municipal waste. The Welsh Government is aiming for a circular economy approach to waste, with the aim that by 2050 nothing that could be recycled or re-used is sent to landfill.

Northern Ireland

The 'Northern Ireland Waste Management Strategy' was published in December 2013 and set various additional targets alongside Waste Regulations (Northern Ireland) 2011. In February 2015, a regulation came in force banning landfilling of food waste once collected. The regulations provide for the separate collection and subsequent treatment of food waste and require district councils to provide food waste bins for households. It also places a duty on food businesses from not producing in excess of 5kg of food waste per week.

DECCs waste emissions projections take into account England's waste prevention policy. We have separately estimated the potential impact of the devolved administration's policies or aims in diverting waste from landfill for our abatement scenarios.

F-gases

Without further policy, i.e. with only pre-2008 measures, it is possible that F-gas emissions increase further (Figure 7.2). This is due to the fact that there is an increasing use of products and appliances using F-gases, such as in refrigeration and air conditioning equipment or foams used for energy efficiency measures.

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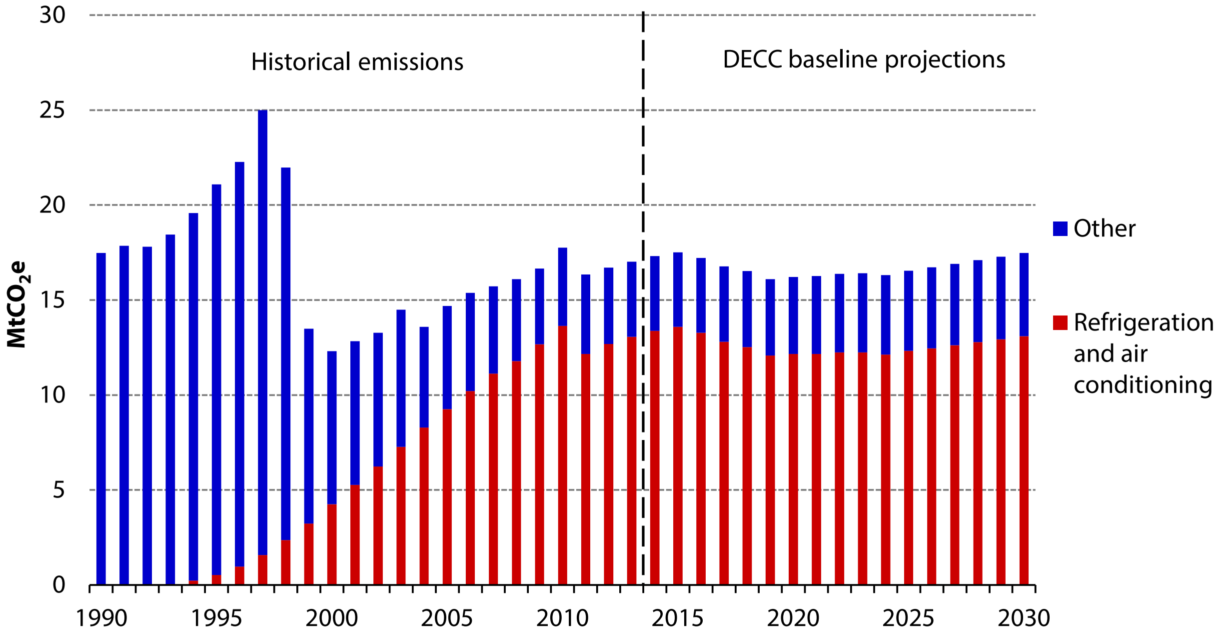
[153] NNFCC (2015) *Anaerobic Digestion deployment in the UK*, http://www.nnfcc.co.uk/bioenergy/ad-deployment-report

The 2006 EU F-gas regulation and 2006 MAC Directive introduced restrictions on various uses of F-gases but DECC's latest projections, without further policy, show that emissions would stay broadly flat between 2015-2030, at 7.5 $MtCO_2e$ by 2030, with emissions from refrigeration and air conditioning accounting for 75% of the total.

The 2015 EU F-gas regulation introduced a series of measures, including a quota system, a series of bans and further leakage checks, which are expected to bring emissions down significantly by the early 2030s (Box 7.4).

Figure 7.2: Projected baseline F-gas emissions (1990-2030)



Source: DECC (2015) *Non-CO_2 greenhouse gas emissions projections.*
Notes: 1990-2013 are historic emissions; 2014-2030 are projected emissions.

4. Abatement scenarios

Our approach to building scenarios is out in detail in Chapter 1.

Waste

As set out above, DECC's projection of landfill waste emissions assumes a continued fall in biodegradable waste going to landfill with some further improvement in methane capture. Overall DECC's landfill waste emissions fall from in 17 $MtCO_2e$ in 2013 to 7 $MtCO_2e$ in 2030.

We now detail emission abatement in our scenarios.

Central scenario

Our Central scenario includes our estimate of the impact of devolved administration polices to divert biodegradable waste streams from landfill. We then assume either prevention or diversion of five biodegradable waste streams (food, paper/card, wood, textiles and garden waste) from landfill, across the UK by 2025. This reduces 2030 emissions from landfill by 4 $MtCO_2e$.

There are challenges to achieve this abatement by 2030 to prevent waste occurring, create value of materials used all the way through the supply chain, and bring in complementary policies for separate waste collection and diversion to alternative waste treatment options (recycling, biological treatment and anaerobic digestion). However, there has been good progress to date to prevent food waste in households through information campaigns and voluntary agreements, with further progress expected from WRAPs Courtauld 2025 proposals[154]. Our scenario assumes a 10 year lead in to banning these waste streams going to landfill, a substantial period at the top end of requirements based on studies by Eunomia and experience so far from Scotland. This will give national and local authorities time to develop complementary policies to treat waste.

If achieved, this will reduce waste emissions to 10 $MtCO_2e$ in 2030, an 85% reduction from 1990 (Figure 7.3).

Barriers scenario

Our Barriers scenario includes devolved administration polices to divert biodegradable waste stream from landfill, and prevention or diversion of only food and paper/card from landfill in England by 2030. To 2030 this reduces emissions from landfill by 2 $MtCO_2e$.

If achieved, this will reduce waste emissions to 12 $MtCO_2e$ in 2030, an 80% reduction from 1990.

Outlook to 2050

By 2050, across the scenarios, landfill waste emissions are in the range 1-3 $MtCO_2e$ (Figure 7.3).

The other remaining emissions are 5 $MtCO_2e$ from wastewater treatment and 2 $MtCO_2e$ from biological treatment. The estimate of emissions from wastewater treatment is based on IPCC inventory default values given the lack of detailed data. This may be an overestimation; previous estimates of emissions were a little over 1 $MtCO_2e$.

There is a need to collect accurate data on wastewater treatment emissions so that realistic abatement potential can be identified.

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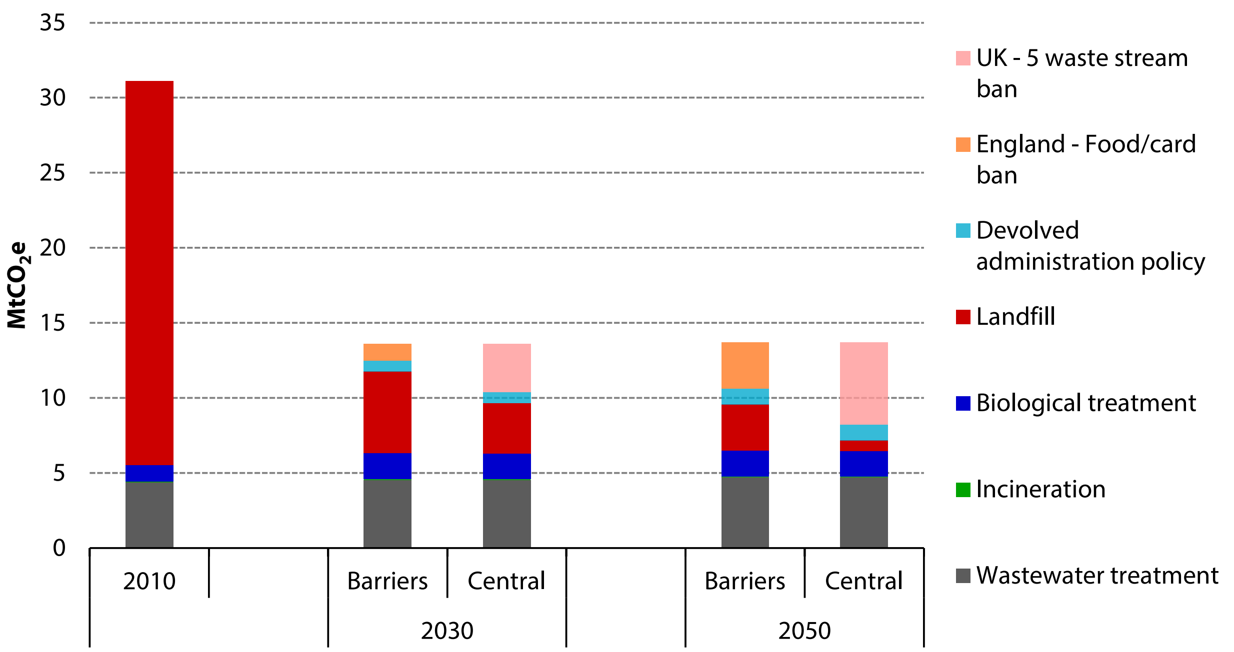
[154] A 10-year voluntary agreement that brings together a broad range of organisations involved in the food system to make food and drink production and consumption more sustainable. Courtauld 2025 will formally be launched in March 2016.

Figure 7.3: Fifth carbon budget scenarios for waste – Barriers & Central scenarios (2030, 2050)



Source: DECC (2015) *Non-CO$_2$ greenhouse gas emissions projections;* CCC analysis.

F-gases

Central

DECC's projection of non-CO$_2$ emissions takes account of EU 2015 regulations (Box 7.4), with total F-gases emissions falling to around 5 MtCO$_2$e by 2030 (see Figure 7.4), due to the following:

- **Refrigeration emissions**. Reduce from 7 MtCO$_2$e to around 1 MtCO$_2$e, an annual average 12% decrease over the period 2015-2030.
- **MAC Mobile air conditioning emissions**. Reduce from 3.3 MtCO$_2$e to 0.5 MtCO$_2$e, an annual average 12% decrease over the period 2015-2030.
- **Stationary air conditioning emissions**. Reduce from 3 MtCO$_2$e to 1 MtCO$_2$e, an annual average 7% decrease over the period 2015-2030.
- **Emissions from foams, firefighting and other uses**. Reduce from 2.6 MtCO$_2$e to around 1.2 MtCO$_2$e, an annual average 5% decrease over the period 2015-2030.

The projections expect emissions from metered dose inhalers and electrical insulation to increase in the period 2015-2030, reflecting that the 2015 EU regulation does not affect these emissions. In total, they are projected to rise by around 0.2 MtCO$_2$e to 1.5 MtCO$_2$e by 2030.

Current heat pumps use HFCs as a refrigerant and so are prone to leakages of gases with high GWP. The 2015 EU regulation applies to heat pumps, meaning that producers of refrigerants will need to shift to lower GWP gases. DECC's reference scenario takes into account their emissions, assuming around 1.5 million heat pumps by 2050 and applying insights from recent research.[155]

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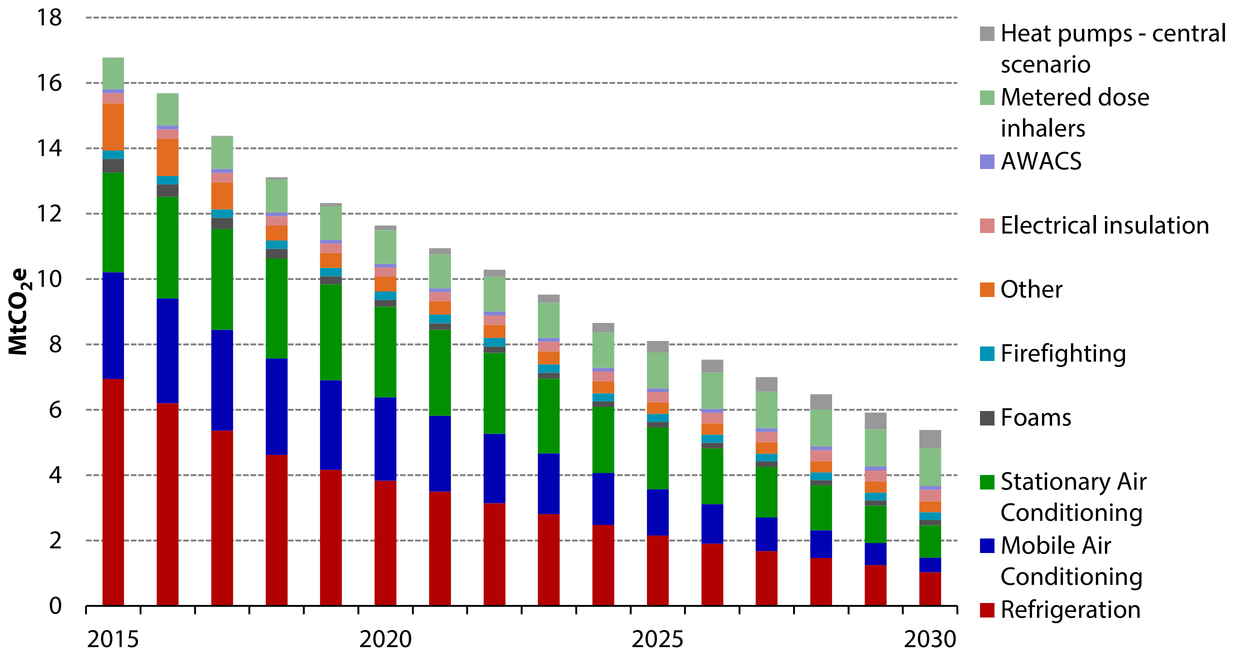
[155] DECC (2014) *Impacts of Leakage from Refrigerants in Heat Pumps,*

To be consistent with our Central scenario in buildings, we estimated F-gas emissions to reflect our heat pumps uptake, using DECC research and our 2013 analysis of heat pumps lifecycle emissions.[156] This adds around 0.6 $MtCO_2e$ emissions by 2030 (Figure 7.4).

Altogether, our Central scenario for F-gases expects emissions to fall to around 5.4 $MtCO_2e$ by 2030 which is a result of both the 2015 EU regulation and our central uptake of heat pumps. This translates to around a 68% reduction over the period of 2015-2030, or an annual average 7% decrease.

Figure 7.4: F-gas emissions under Central scenario (2015-2030)



Source: DECC (2015) *Non-CO_2 greenhouse gas emissions projections*; CCC analysis
Notes: Heat pump emissions are in line with our central uptake of heat pumps in buildings' sector. AWACS stands for Airborne Warning and Control System.

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https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/303689/Eunomia_-_DECC_Refrigerants_in_Heat_Pumps_Final_Report.pdf

[156] Ricardo AEA (2013) *Current and Future Lifecycle Emissions of Key 'Low Carbon' Technologies and Alternatives*, https://www.theccc.org.uk/publication/carbon-footprint-and-competitiveness/

Box 7.4: EU 2015 F-gas regulation

The EU 2015 F-gas regulation replaced 2006 EU regulation and is effective from 1 January 2015. It introduces a number of new measures together with strengthening of existing measures:

- It reduces the quantities of HFCs that producers and importers are allowed to place on the EU market. The reduction started with the initial cap in 2015 based on the annual average of the quantities in the market between 2009 and 2012. Producers then received maximum emission quotas based on their previous performance. The allowed emissions will be reduced sequentially, starting with a 7% cut in 2016 and reaching a 79% cut by 2030. Some HFC applications are exempted: use of HFCs in military equipment, the semiconductor manufacturing sector, metered dose inhalers and feedstock. These exemptions represented at least 5% of total UK HFCs emissions in 2013.
- For new equipment, the regulation introduced a series of bans on the use of F-gases covering cross-cutting areas. In addition to bans that were originally stated in 2006 regulation, new bans include:
    - Domestic refrigerators and freezers with GWP above 150 from 2015,
    - Refrigerators and freezers for commercial use with GWP above 2,500, from 2020, followed by a ban in 2022 for use of HFCs with GWP above 150,
    - Air conditioning systems containing less than 3kg of refrigerant with GWP above 750, from 2025.
- For existing equipment, there is a ban on using HFCs with a GWP above 2,500 for the maintenance and servicing of existing refrigeration equipment from 2020.
- There is some strengthening of existing obligations related to leak checking and repairs, F-gases recovery and technician training.

The EU 2015 regulation focuses mainly on reducing GHG emissions from the use of HFCs with some areas being exempted. The PFCs and SF_6 gases are not subject to the phase out but are likely to be affected by other parts of the regulation.

Barriers and Max scenario

Our Central scenario assumes UK F-gas emissions in line with DECC's reference projection, incorporating the impact of the 2015 regulations. There are not considered to be significant barriers to implementation of the 2015 regulations at the EU level, or UK-specific barriers that might result in the UK having a disproportionate share of the EU's F-gas emissions. Therefore, we do not have a separate Barriers scenario for F-gases.

While it may be possible for further reduction in F-gas emissions beyond DECC's reference projection by 2032, there is no solid evidence on the feasibility and cost-effectiveness of doing so, and we do not have a separate Max scenario for F-gases. However, though projections of F-gas emissions to 2035 are low, they will form a growing share of increasingly challenging carbon budgets, and it is important that Government fully evaluates the feasibility and cost-effectiveness of reducing F-gas emissions beyond the level required by EU legislation.

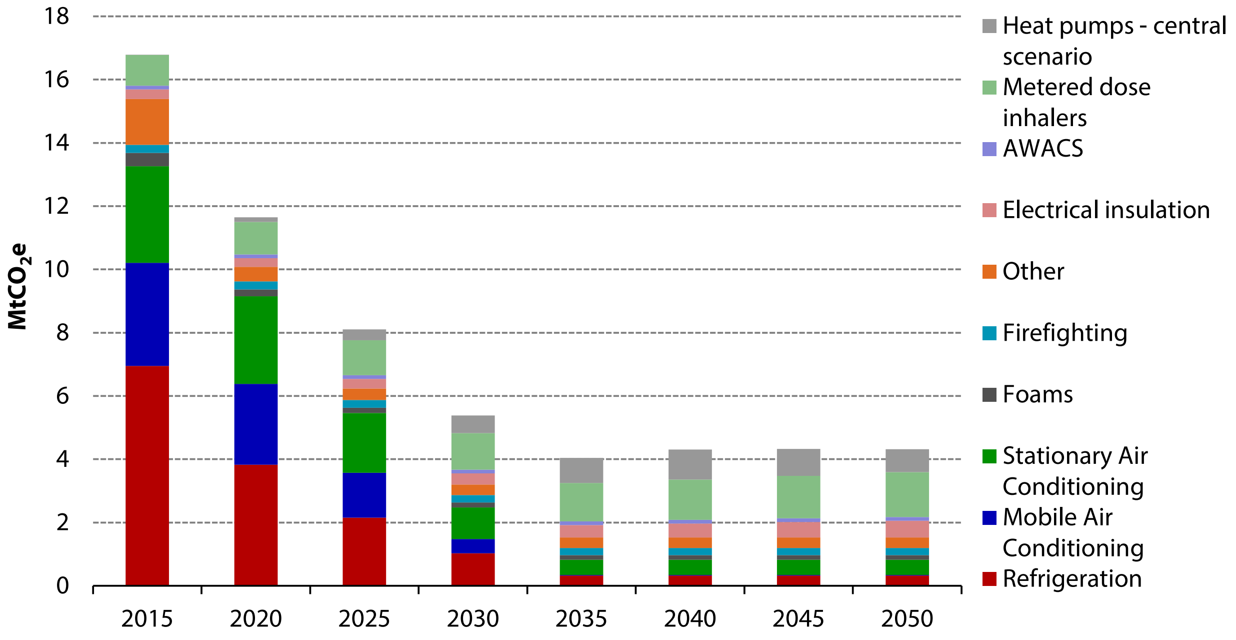
Outlook to 2050

When extending our Central scenario to 2050, we use DECC's reference projections up to 2035 in which total F-gas emissions fall to around 4 $MtCO_2e$. They then slightly increase to around 4.3 $MtCO_2e$ by 2050 reflecting:

- **Electrical insulation and MDI emissions** grow by around 1% per year based on the trend seen in the period of 2030-2035.
- **Heat pump emissions** reach a peak by 2040 and then fall to around 0.7 $MtCO_2e$ in 2050. This is based on our uptake of heat pumps in our Central scenario and its expected shift to lower GWP refrigerants by 2050.
- **Remaining emissions** (e.g. refrigeration and air conditioning or foams) stay flat as we do not assume any further impact of the 2015 EU regulation beyond 2035.

Overall, our Central scenario of F-gas emissions expects emissions to be around 4 $MtCO_2e$ by 2050 of which about 33% are from MDIs, 28% from stationary air conditioning and heat pumps, 12% from electrical insulation and 7% from refrigeration emissions (Figure 7.5).

Figure 7.5: F-gas emissions under Central scenario (2015-2050)



Source: DECC (2015) *Non-CO_2 greenhouse gas emissions projections*; Eunomia and the Centre for Air Conditioning and Refrigeration Research for DECC (2014) *Impacts of Leakage from Refrigerants in Heat Pumps*; CCC analysis.
Notes: Using CCC 2050 assumptions and Central scenario of heat pumps uptake in buildings. AWACS stands for Airborne Warning and Control System.

5. Costs and impacts

Waste

In waste, there would be a small cost saving to delayed action in 2020s. We estimate the net present value of this cost saving to be around £3 billion to 2050. However, the cost of the additional emissions in this scenario valued at the Government's carbon values would be nearly £7 billion. Avoiding delay is therefore the preferable path, with a total net present value of £4 billion.

F-gases

As shown above, the EC impact assessment of the 2015 regulation and underlying research present cost impacts of different policy scenarios and abatement measures across sectors. DECC's reference projections then provide information on the likely impact of the regulation on the UK F-gas emissions. However, the available evidence does not enable us to derive accurate cost estimates:

- The EC's published cost impacts are not disaggregated to a country level.
- DECC projections data do not match the split shown in the EC impact assessment.

Therefore, while we are not able to accurately estimate the UK abatement costs of EU 2015 F-gas regulation it is likely that, based on the evidence, the costs should be relatively low since most measures are cost-effective by 2030.

6. Delivering the scenarios

In order to overcome the barriers set out above and achieve the potential abatement outlined in Section 4, further action is needed to develop the required policies and measures:

- **For waste:**
  - Each nation should set out specific actions and clear milestones to further reduce biodegradable waste to landfill and increase methane capture rates.
- **For F-gases:**
  - Ensure that the UK fulfils its duties implied by the EU 2015 F-gas regulation and monitor its effectiveness.
  - Extend coverage of carbon budgets to include NF_3 emissions.
  - Find opportunities to exceed regulatory minimums on F-gas abatement: including clearly assessing and addressing barriers where evidence suggests cost-effective abatement above minimum standards.

We will return to policy issues in our 2016 Progress Report.

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