

Fourth Carbon Budget Review – technical report

Sectoral analysis of the cost-effective path to the 2050 target

Committee on Climate Change | December 2013



Preface

The Committee on Climate Change (the Committee) is an independent statutory body which was established under the Climate Change Act (2008) to advise UK and devolved administration governments on setting and meeting carbon budgets, and preparing for climate change.

Setting carbon budgets

In December 2008 we published our first report, 'Building a low-carbon economy – the UK's contribution to tackling climate change', containing our advice on the level of the first three carbon budgets and the 2050 target. This advice was accepted by the Government and legislated by Parliament in May 2009. In December 2010, we set out our advice on the fourth carbon budget, covering the period 2023-27, as required under Section 4 of the Climate Change Act. The fourth carbon budget was legislated in June 2011 at the level that we recommended.

In April 2013 we published advice on reducing the UK's carbon footprint and managing competitiveness risks. In November 2013 we published the first part of our review of the fourth carbon budget, covering climate science, international and EU circumstances.

Progress meeting carbon budgets

The Climate Change Act requires that we report annually to Parliament on progress meeting carbon budgets. We have published five progress reports in October 2009, June 2010, June 2011, June 2012 and June 2013. Our next annual report is due in July 2014 and will include a backward look at how the first carbon budget (2008-12) was met.

Advice requested by Government

We provide ad hoc advice in response to requests by the Government and the devolved administrations. Under a process set out in the Climate Change Act, we have advised on reducing UK aviation emissions, Scottish emissions reduction targets, UK support for low-carbon technology innovation, design of the Carbon Reduction Commitment, renewable energy ambition, bioenergy, and the role of local authorities. In September 2010, July 2011, July 2012 and July 2013 we published advice on adaptation, assessing how well prepared the UK is to deal with the impacts of climate change.

This report

This technical report sets out our updated sectoral analysis of the cost-effective path to the 2050 target as part of our review of the fourth carbon budget (2023-27). This supports our main advice, specifically Chapter 3 of our December 2013 report *Fourth carbon budget review – part 2: The cost-effective path to the 2050 target*.

Acknowledgements

The Committee would like to thank:

The team that prepared the analysis for the report: This was led by David Kennedy, Adrian Gault and Mike Thompson and included Andrew Beacom, Ute Collier, Hanane Hafraoui, Taro Hallworth, Jenny Hill, David Joffe, Ewa Kmietowicz, Sarah Leck, Eric Ling, Nina Meddings, Clare Pinder, Kavita Srinivasan and Indra Thillainathan.

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A wide range of stakeholders who attended our expert workshops and responded to our Call for Evidence, engaged with us, including through our public dialogue, or met with the Committee bilaterally.

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The Committee



The Rt. Hon John Gummer, Lord Deben, Chairman

The Rt. Hon John Gummer, Lord Deben established and chairs Sancroft, a Corporate Responsibility consultancy working with blue-chip companies around the world on environmental, social and ethical issues. He was the longest serving Secretary of State for the Environment the UK has ever had. His experience as an international negotiator has earned him worldwide respect both in the business community and among environmentalists. He has consistently championed an identity between environmental concerns and business sense.



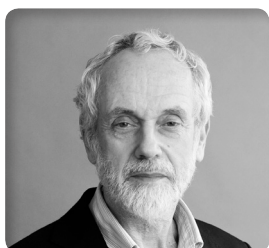
David Kennedy (Chief Executive)

David Kennedy is the Chief Executive of the Committee on Climate Change. Previously he worked on energy strategy and investment at the World Bank, and the design of infrastructure investment projects at the European Bank for Reconstruction and Development. He has a PhD in economics from the London School of Economics.



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



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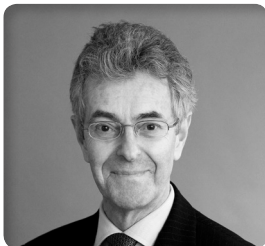
Paul Johnson

Paul is the director of the Institute for Fiscal Studies. He has worked on the economics of public policy throughout his career. Paul has been chief economist at the Department for Education and director of public spending in HM Treasury, where he had particular responsibility for environment (including climate change), transport and public sector pay and pensions. Between 2004 and 2007 Paul was deputy head of the Government Economic Service. He has also served on the council of the Economic and Social Research Council.



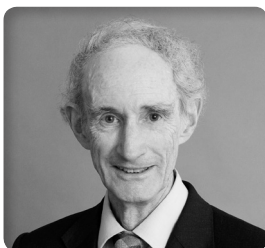
Professor Dame Julia King

Professor Dame Julia King DBE FREng Vice-Chancellor of Aston University. She led the 'King Review' for HM Treasury in 2007-8 on decarbonising road transport. She was formerly Director of Advanced Engineering for the Rolls-Royce industrial businesses, as well as holding senior posts in the marine and aerospace businesses. Julia is one of the UK's Business Ambassadors, supporting UK companies and inward investment in low-carbon technologies. She is an NED of the Green Investment Bank, and a member of the Airports Commission.



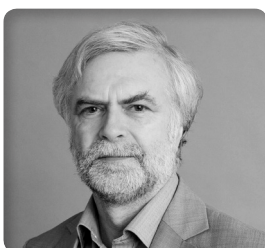
Lord John Krebs

Professor Lord Krebs Kt FRS, is currently Principal of Jesus College Oxford. 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 is chairman of the House of Lords Science & Technology Select Committee.



Lord Robert May

Professor Lord May of Oxford, OM AC FRS holds a Professorship jointly at Oxford University and Imperial College. 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 & Technology.



Professor Jim Skea

Professor Jim Skea, CBE, is Research Councils UK Energy Strategy Fellow and Professor of Sustainable Energy at Imperial College London. He was previously Research Director at the UK Energy Research Centre (UKERC) and Director of the Policy Studies Institute (PSI). He led the launch of the Low Carbon Vehicle Partnership and was Director of the Economic and Social Research Council's Global Environmental Change Programme.

Chapter 1: The cost-effective path to the 2050 target – summary and overview

Introduction and summary

The fourth carbon budget was designed to embody the cost-effective path to the 2050 target legislated in the Climate Change Act (i.e. to reduce emissions by at least 80% relative to 1990). It reflects measures that are cost-effective with respect to the projected carbon price, together with measures that may cost more than the projected carbon price, but that are necessary in order to manage costs and risks of meeting the 2050 target.

The currently legislated fourth carbon budget requires a 50% cut in emissions in 2025 relative to 1990. In our original advice we showed an illustrative scenario that would meet the budget through energy efficiency improvement in buildings, fuel efficiency improvement in vehicles, power sector decarbonisation, some electrification of surface transport and heat, and use of sustainable bioenergy.

This technical report supports our advice on reviewing the fourth carbon budget (summarised in Box 1.1) by setting out our detailed analysis of cost effectiveness on a sector-by-sector basis. In it we update the scenarios from our original advice on the fourth budget in light of new evidence on emissions projections and the costs and feasibility of abatement options.

Economy-wide, our analysis of the new evidence shows that the cost-effective path through the 2020s would result in a lower level of emissions than we previously expected and offers significant cost savings versus a scenario that delays action. Specifically, we conclude:

- **The cost-effective path.** Our updated assessment is that the cost-effective path entails lower emissions than in our original advice, even though we now make more prudent assumptions on the uptake and effectiveness of some low-carbon measures. This provides more confidence that the budget can be met.
 - Our original advice suggested that the budget could be met through deep decarbonisation of the power sector, energy efficiency improvement in buildings and in vehicles, some electrification of heat and transport and some efficiency measures in industry and agriculture.
 - Our updated assessment of abatement potential is more prudent than our original advice, reflecting barriers to uptake and factors which affect the economics of low-carbon measures. For example, we now assume lower numbers of heat pumps in the residential sector and lower emissions cuts from solid wall insulation.
 - New official projections suggest lower energy demand and emissions than previously expected, given slow economic growth since 2010 and improvements in projection methodologies to reflect current data and historic trends more robustly.

-
- Taken together these new assumptions imply a lower level of emissions in the 2020s than in our original advice, providing more confidence that the budget can be met.
 - **Cost savings relative to delayed action.** Following the cost-effective path for emissions reduction through the 2020s offers significant long-run savings relative to an alternative path where action to reduce emissions is delayed until the 2030s; this conclusion is robust across a wide range of plausible scenarios. It does not add to costs in the period prior to 2020.
 - Cutting emissions through the 2020s rather than delaying this to the 2030s offers cost savings of over £100 billion in present value terms under central case assumptions about fossil fuel and carbon prices, with much higher savings in a high fossil fuel or high carbon price world (e.g. up to £200 billion).
 - Only if there were a significant departure from the climate objective and fossil fuel prices were much lower than current levels would the budget entail significant costs over a delayed action path. A departure from the climate objective would be contrary to the agreed UN position and much lower fossil fuel prices would be counter to expectations.
 - In the near term, specifically in the period prior to 2020, cutting emissions in line with the cost-effective path implies no additional costs over and above those associated with policies to which the Government has already committed, and which are independent of the fourth carbon budget.

We set out our analysis in detail in five sectoral chapters following this summary, which has five sections:

1. Current emissions across the UK economy
2. Latest projections for emissions
3. Options for reducing emissions to 2030
4. Abatement scenarios for emissions in the 2020s
5. Costs and benefits of reducing emissions

Box 1.1: Conclusions of the Review of the fourth carbon budget

In our Review of the fourth carbon budget we concluded that there has been no significant change in the circumstances on which the budget was set and therefore no basis to change it:

- **Climate science.** If global emissions were to continue to increase throughout the century it is likely that global temperature would rise by 4°C or more. In order to limit risks of dangerous climate change and preserve close to a 50% chance of keeping temperature rise below 2°C, it is necessary that global emissions peak around 2020, with deep cuts through the 2020s and in the following decades. The currently legislated budget is a minimum UK contribution to this global emissions pathway.
- **International action.** The UK is not acting alone. While the UN process is moving slowly and there have been backward steps in some countries (e.g. Australia), many countries around the world have made commitments comparable to the UK and are acting to reduce emissions. These include the largest emitters (i.e. China, the US and the EU, accounting for 57% of global emissions). Required global emissions cuts consistent with limiting warming to 2°C are still feasible if very challenging, and remain an appropriate basis for UK policy.
- **EU developments.** The fourth carbon budget is at the low end of the range of ambition currently being discussed by the EU for emissions pathways through the 2020s. If the UK Government is successful in achieving its stated objectives in these EU discussions, the budget would have to be tightened significantly.
- **The cost-effective path to 2050.** Our updated assessment is that the cost-effective path entails lower emissions than in our original advice, even though we now make more prudent assumptions on the uptake and effectiveness of some low-carbon measures. This provides more confidence that the budget can be met. Following the cost-effective path for emissions reduction through the 2020s offers significant long-run savings relative to an alternative path where action to reduce emissions is delayed until the 2030s.
- **Impacts of the budget.** Our assessment of the budget's impacts on the circumstances specified in the Climate Change Act is broadly unchanged from our original advice. Impacts on energy affordability, fuel poverty, competitiveness and the public finances are important but manageable. For example, incremental affordability and fuel poverty impacts are small, with scope to offset these through energy efficiency improvement; competitiveness impacts can be addressed under current policies for energy-intensive industries, provided these are clarified and extended. In the long run (e.g. after 2030) the budget offers benefits in terms of lower electricity and energy prices than would ensue without early decarbonisation.

While our assessment that the cost-effective path implies a larger reduction in emissions in the 2020s than required by the budget might in principle imply that a tighter budget is appropriate, it would be premature to tighten the budget now. This reflects uncertainties over: the cost-effective path, EU emissions targets for the 2020s and the precise path for UK power sector decarbonisation under the Electricity Market Reform. Any change now would require a further change later, once these issues are resolved, and frequent budget changes would undermine the certainty that they are meant to provide.

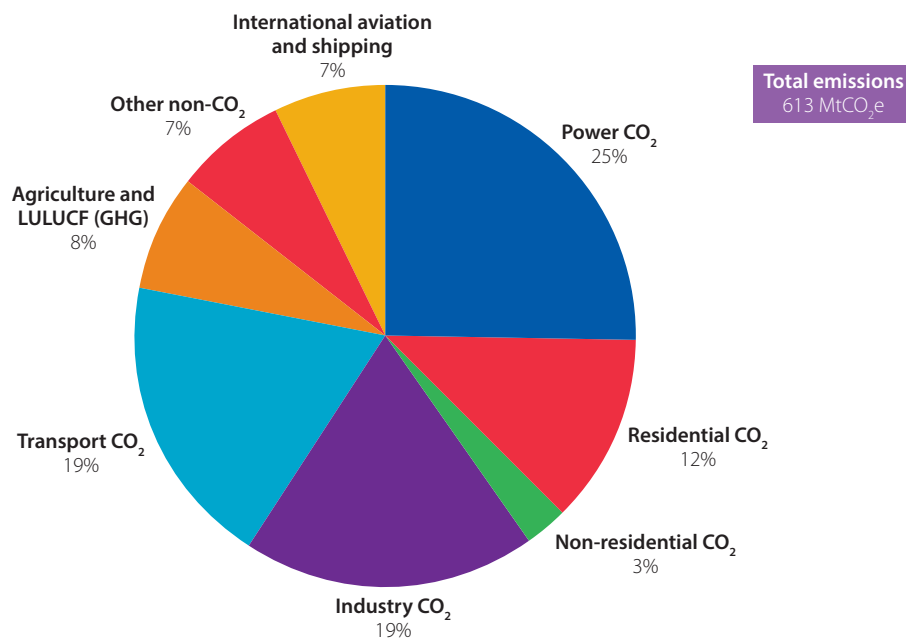
1. Current emissions across the UK economy

Economy-wide emissions of greenhouse gases (GHGs) that are covered by carbon budgets were 570 MtCO₂e in 2012 (Figure 1.1).

- CO₂ emissions were 479 MtCO₂, with the largest contributions from the power sector (156 MtCO₂, see Chapter 2), buildings (91 MtCO₂, see Chapter 3), industry (116 MtCO₂, see Chapter 4) and transport (116 MtCO₂, see Chapter 5).
- Non-CO₂ emissions were 91 MtCO₂e. The largest contributor was agriculture (47 MtCO₂e, see Chapter 6), with the remainder (Box 1.5) from landfill emissions in the waste sector, F-gases, leakage from gas pipes and coal mines, some industrial processes and catalytic converters in vehicles.
- The UK is also responsible for 43 MtCO₂e of emissions from international aviation (33 MtCO₂e in 2011) and international shipping (10 MtCO₂e in 2011), although these are not currently covered by carbon budgets.

Since 1990, economy-wide greenhouse gas emissions have fallen 26%, within which CO₂ emissions have fallen 19%, and non-CO₂ emissions have fallen 50%. Since 2009 (the latest year of data available when we advised on the fourth carbon budget), total CO₂ emissions have been broadly flat, whereas non-CO₂ emissions have fallen around 3% (Figure 1.2).

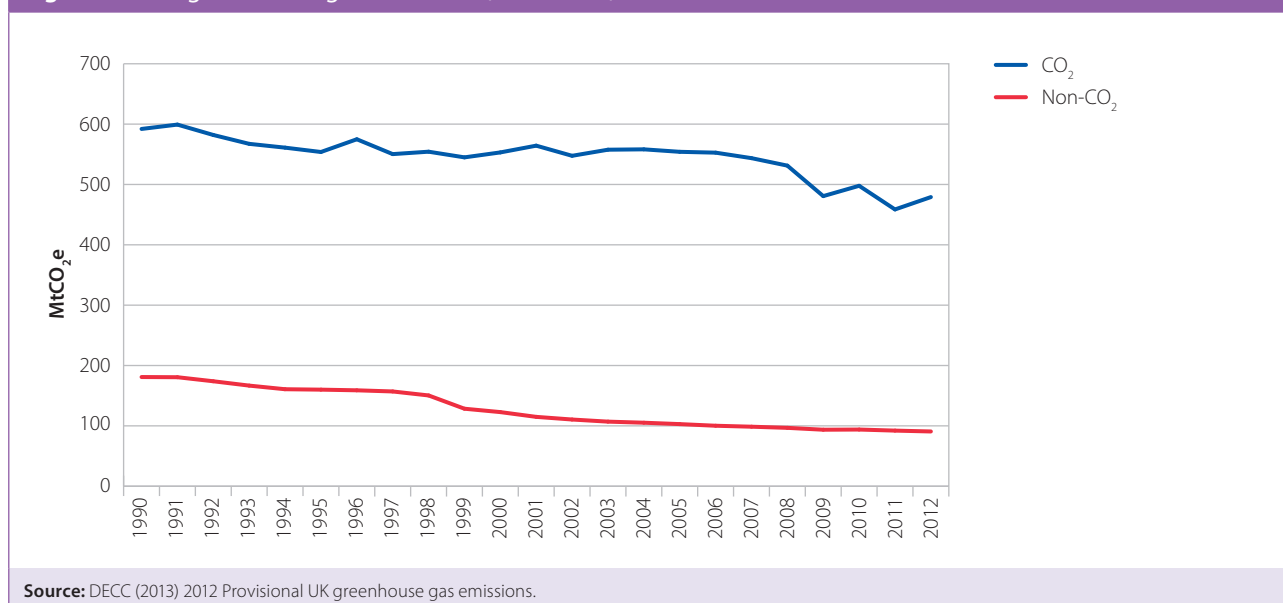
Figure 1.1: UK greenhouse gas emissions in 2012



Source: DECC (2013) Provisional emissions estimates; NAEI (2013) Final emissions estimates.

Notes: International aviation and shipping are currently not included in carbon budgets.

Figure 1.2: UK greenhouse gas emissions (1990-2012)



The legislated fourth carbon budget requires that emissions are reduced to 390 MtCO₂e in 2025. This implies a 50% cut relative to 1990, or a 32% cut relative to 2012.

The next three sections consider the feasibility of such a reduction given latest evidence on emissions projections and the costs and feasibility of measures to reduce emissions.

2. Latest projections for emissions

For the majority of sectors (industry, buildings, transport, agriculture and other non-CO₂), 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 DECC's Updated Emissions Projections for baseline GHG emissions for the industry, buildings, agriculture, and other non-CO₂ sectors, and the Department for Transport's National Transport Model (NTM) for Road Transport.

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, and our assessment of the appropriate generation mix.

We use DECC and DfT forecasts of GHG emissions and electricity demand to be consistent with Government's own analysis. We have suggested a range of improvements to these forecasts in the past, which have since largely been implemented (Box 1.2).

Box 1.2: Developing the approach to emissions projections

In 2011 we commissioned a review of the DECC energy and emissions model from Cambridge Econometrics. This recommended:

- Making greater use of the most recent outturn data in forming projections, including responding to recent forecast errors.
- More regular updating of key input assumptions – specifically for industry GVA at the sub-sectoral level.
- Increased transparency over the functioning of the model, the input assumptions and the drivers behind changes in the published projections.
- In the longer term, re-estimating the key relationships in the model and building in more bottom-up components (e.g. to better explain improvements in energy efficiency).

Since then there have been significant improvements to the DECC model which have substantially changed the level of emissions projected to 2030. There have been key updates to the model in each sector.

- **Power.** A new electricity supply model, the “Dynamic Dispatch Model” (DDM), has been integrated with the existing UEP demand model replacing the previous UEP electricity supply model. There have also been improvements to the modelling of the electricity sector and updated modelling of gas combined heat & power (CHP) and data.
- **Buildings.** Revisions to how public sector total energy demand is estimated to better reflect historic trends.
- **Transport.** Improved alignment with DfT’s National Transport Model (for road, rail and air), and savings from rail electrification have been incorporated into the model.
- **Industry.** New industrial sub-sector equations, which are regularly updated to make use of most recent data. There are also new fuel share equations for industrial sub-sectors, re-estimated industrial energy intensity equations and improved modelling of iron and steel energy use.

The model now uses the most recent available outturn data in demand equations across sectors. The baseline emissions scenario is now projected to be substantially lower over the carbon budget period than was assumed in 2010.

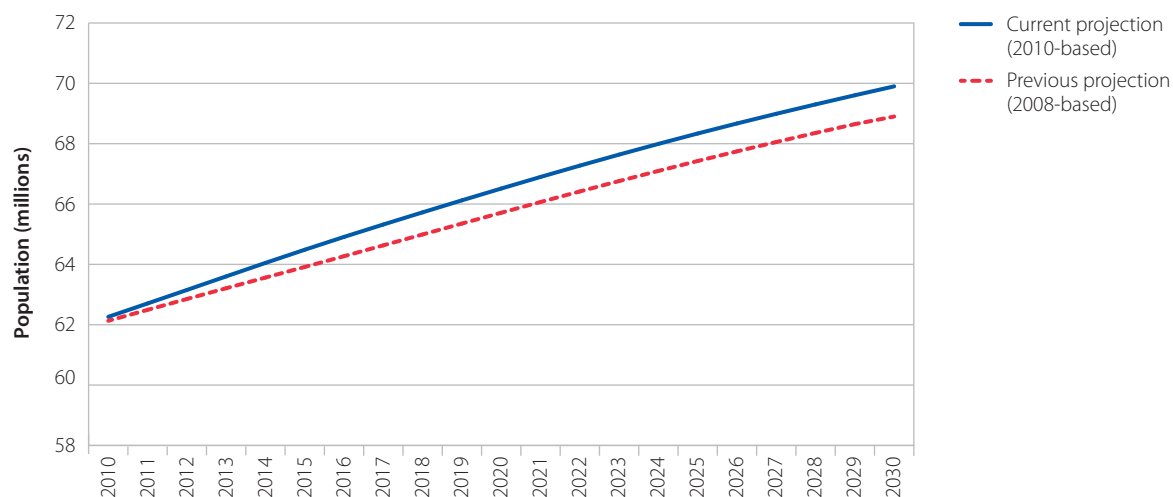
Since 2010, when we originally advised on the fourth carbon budget, there have also been updates to the assumptions of some key drivers of emissions:

- **Population.** Under the Office of National Statistics’ latest projection, the UK’s population is now expected to grow by 12% from 2010 to reach 70 million in 2030; this is 1.4% higher than was previously assumed (Figure 1.3). Other things equal, this will tend to increase energy demand and emissions.
- **Economic activity.** The latest Office of Budget Responsibility projection of UK GDP has growth of 58% between 2010 and 2030; this is 5.1% lower than assumed by 2030 in our 2010 analysis (Figure 1.4). Since lower GDP implies less economic activity and lower energy demand, other things equal this will reduce projected emissions relative to our previous analysis.
- **Fossil fuel prices.** Oil and coal prices are now projected to be higher in 2030 than under previous projections by 34% (at \$135/barrel) and 41% (at \$123/tonne) respectively, whilst gas prices are projected to be 11% lower (at 74 pence/therm) in 2030 than under previous assumptions (Figure 1.5). The higher prices will tend to help reduce emissions by encouraging behaviour changes and efficiency improvements to reduce fuel demand.

The lower relative cost of gas could also help reduce emissions as it encourages switching from coal to less carbon-intensive gas, although there may be an offsetting effect if the lower gas price discourages efficiency improvements or switches to low-carbon technologies.

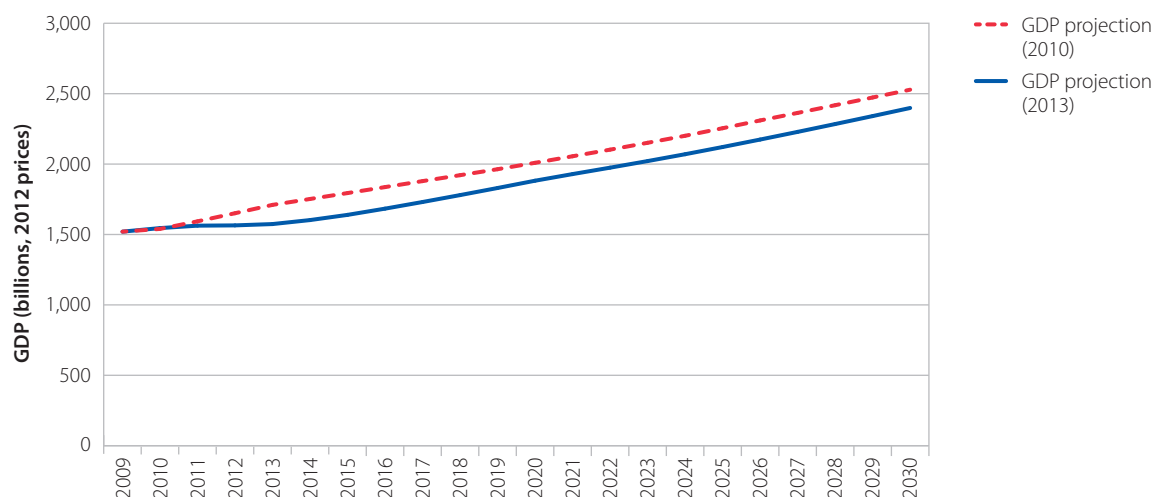
As a result of the new modelling and the new expectations for the drivers of emissions, the projections of energy demand and emissions *in the absence of abatement effort* have been revised (Figure 1.6):

Figure 1.3: UK population projections (2010-2030)



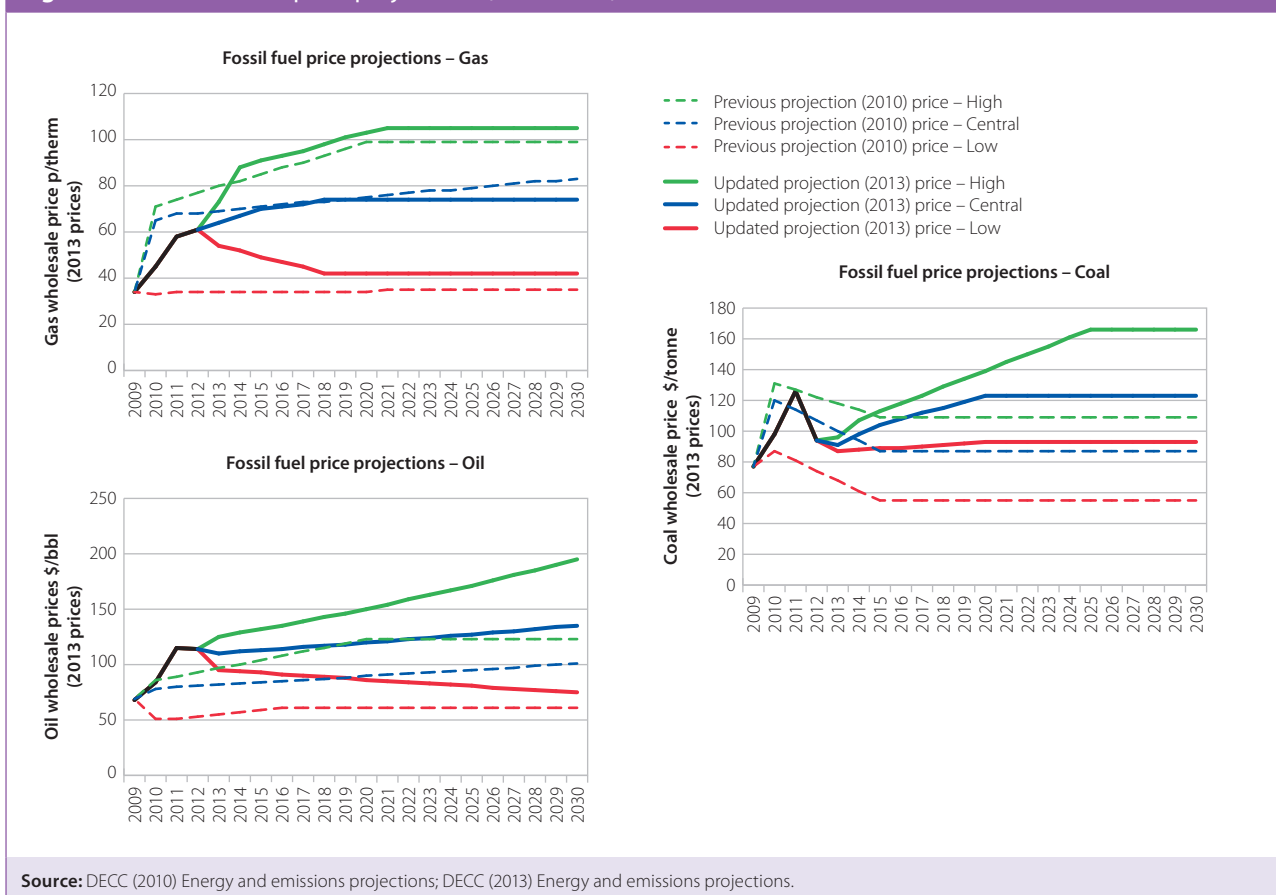
Source: ONS (2010) 2008-based population projections (low-migration variant); ONS (2011) 2010-based population projection (low-migration variant).

Figure 1.4: UK GDP projections (2009-2030)



Source: DECC modelling for CCC; DECC (2013) Energy and emissions projections.

Figure 1.5: UK fossil fuel price projections (2010-2030)

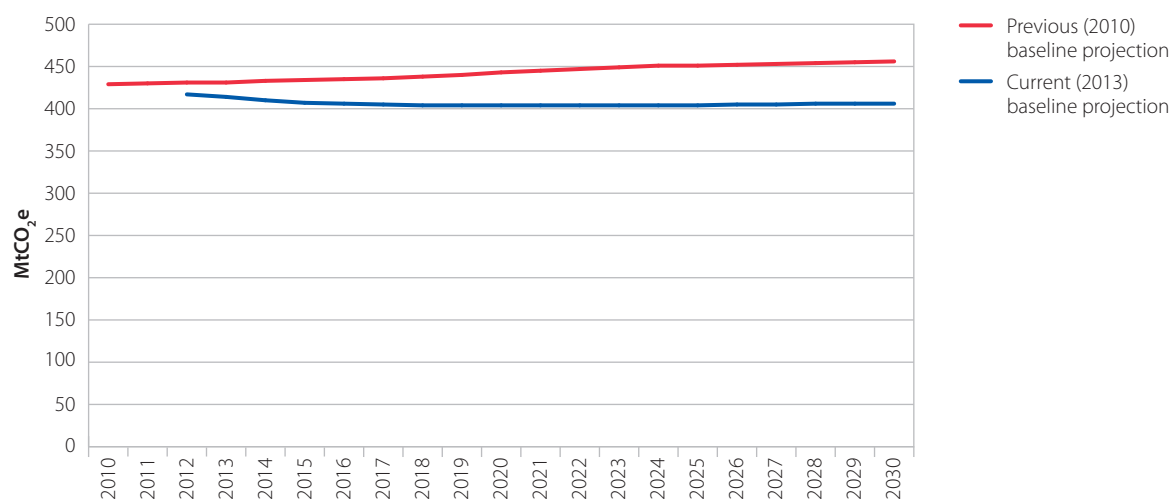


- Greenhouse gas emissions outside the power sector are now projected to fall by 6.3% from 2010 to reach 408 MtCO₂e in 2030. Relative to our previous assessment, this is a substantial reduction in projected emissions before abatement action (220 MtCO₂e less across the five-year fourth budget period). It reflects lower projections of both CO₂ and non-CO₂ emissions.
 - CO₂ emissions (excluding power emissions) are projected to fall by 1.8% from 2010 to reach 335 MtCO₂ in 2030 in our baseline projection. Across the fourth budget period CO₂ emissions are now projected to be 183 MtCO₂ lower than previously expected. The biggest change is in the industry sector, reflecting the latest economic data and DECC's improved projection methodology, where emissions are now expected to be 130 MtCO₂ lower than previously assumed across the carbon budget period.
 - Non-CO₂ emissions projections have also been revised down, primarily due to an improved methodology for measuring and projecting waste emissions. The latest projections are for a fall of 23% from 2010 to reach 73 MtCO₂e in 2030 in our baseline scenario. Projected emissions across the fourth budget period are now 37 MtCO₂e lower than previously expected.
- Electricity demand in the baseline projection is expected to increase by 22% (previously 25%) from 2010 to reach 400 TWh in 2030. Projected electricity demand during the fourth carbon budget period is now expected to average 370 TWh/year if there is no additional abatement effort; this is 2% lower than previously expected. How this translates to emissions will depend on the mix of generating technologies to meet this demand – in the absence of low-carbon policy this would be dominated by gas and coal and emissions could increase.

Even under these new lower projections, significant effort is still required to meet the legislated budget.

However, as we set out in section 4, policies to which the Government have already committed will reduce emissions below this level by 2020 and options exist to continue emissions reductions through the 2020s. We now turn to these options.

Figure 1.6: Baseline (no abatement effort) emissions projections (excluding power) (2010-2030)



Source: DECC (2013) Energy and emissions projections; CCC modelling.

Notes: Chart excludes baseline power sector emissions as we model power sector scenario emissions based on forecast electricity demand.

3. Options for reducing emissions to 2030

To construct our scenarios for emissions to 2030 we add in abatement from measures through the 2020s that are important on the path to the 2050 target and those that are cost-effective compared to expected carbon prices over investment lifetimes.

- **Measures that cost less than the projected carbon price.** The implication of constraining emissions is that there is a value to emissions reduction. This may be explicit, for example a carbon tax or a carbon price generated in a cap-and-trade scheme, or implicit, for example in meeting a regulation or emissions constraint. There is then a clear economic benefit in abatement measures that reduce emissions at a cost below the carbon price, either through avoiding emitting activities like energy use or delivering them through low-carbon means. Examples of abatement options which our previous analysis has suggested are or are likely to become cost-effective in this way for investment to 2030 include avoided waste in energy use, energy efficiency improvement in buildings, fuel efficiency improvement in vehicles, nuclear and some renewable power generation technologies.
- **Measures that are cost-effective in the context of the 2050 target.** Many abatement options that may be required to meet the 2050 target are not yet fully developed. It is important to invest in these options in the near-to-medium term given the need to drive technology innovation and market development, prior to widespread uptake in the 2030s

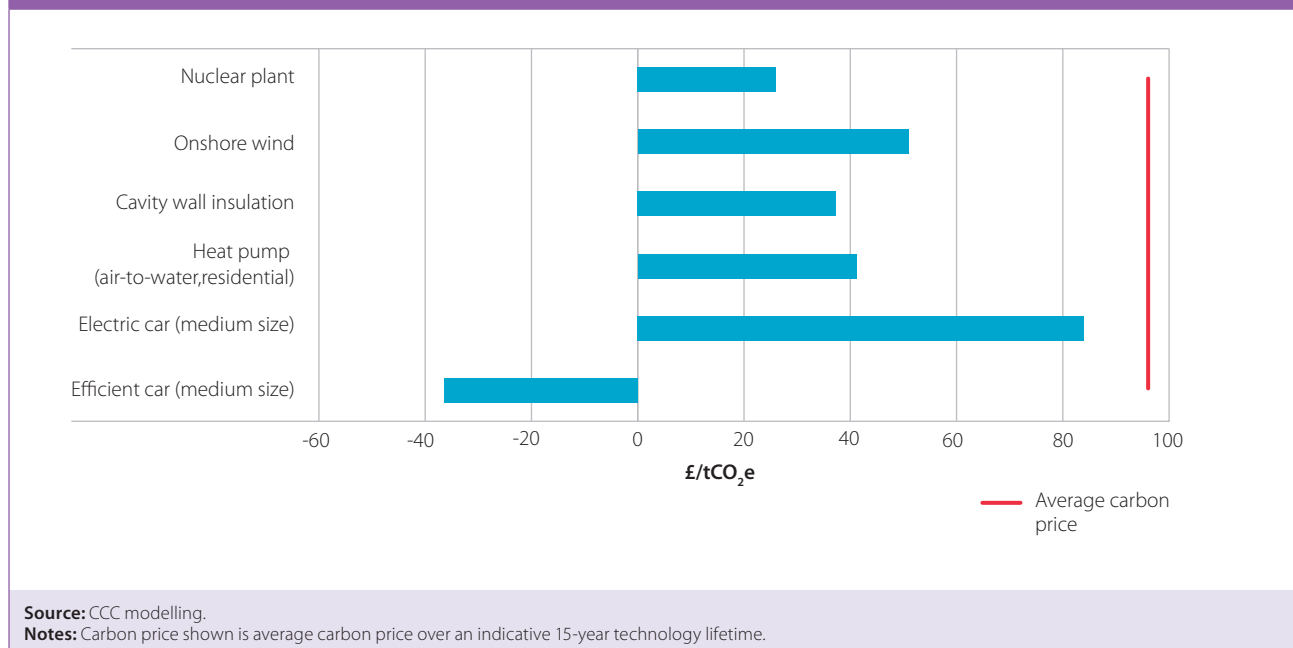
and 2040s. In the short term, this may cost more than investment in conventional fossil fuel alternatives, even when a projected carbon price is included. However, this additional cost can be justified in terms of option development and long-term reductions in cost and risk. Our previous analysis has suggested that investment in electric vehicles, offshore wind and carbon capture and storage (CCS) can be justified on this basis.

The Government's latest price projections and the latest evidence on costs and feasibility reinforces our previous finding that there are various options across the economy that are likely to offer cost-effective opportunities to reduce emissions (Figure 1.7):

- In Chapters 2-6 we set out the latest available evidence on the costs and feasibility of low-carbon measures for each sector of the economy.
- To establish relative costs compared to conventional technologies we use the Government's scenarios for fossil fuel prices (see Figure 1.5 above). Although the emergence of shale gas emphasises the uncertainty around predicting fossil fuel prices it is not expected to fundamentally alter UK prices in the foreseeable future (Box 1.3).
- When judging cost effectiveness we use carbon prices based on European Commission values for 2020 and the Government's values for 2030-2050. Our November report on climate science and international action suggested these are appropriate for a carbon-constrained world (Box 1.4). These give a carbon price which increases from £21/tCO₂ in 2020 to £76/tCO₂ in 2030 and to £216/tCO₂ in 2050.

We reflect this latest evidence in our scenarios in section 4.

Figure 1.7: Cost-effectiveness of low-carbon technologies in 2025



Box 1.3: Shale gas impact on UK gas prices

The emergence of shale gas production in the US has caused a sharp fall in natural gas prices leading to speculation that a similar pattern might occur elsewhere, including the UK. It is important to understand which parts of the US experience are transferrable to other contexts, and what it might mean for the role of shale gas in the UK. Consideration of whether these prices are replicable in the UK requires examination of how interconnected gas markets are, how physical and regulatory conditions differ in the UK and the US and relative sizes of economically recoverable reserves:

- **Interconnections.**

- The natural gas system in the US is not well connected to other countries' networks. This helps to explain why the expansion of shale gas production has had such a large impact on the price. The infrastructure and energy required to liquefy natural gas for export has a high cost. Consequently we should not expect any imports from the US to be significantly below current UK wholesale prices (e.g. 60p/therm). Furthermore, given strong demand from elsewhere (e.g. Asia), it is not clear that significant volumes would necessarily reach the UK.
- In contrast to the US, the UK natural gas system is well connected to other countries, via multiple interconnectors. As well as providing a substantial proportion of our gas supply, these connections mean that UK prices are strongly linked to those elsewhere. As such, it would take a huge volume of low-cost gas production across Europe to lower prices significantly, especially in the context of declining European conventional gas production. Therefore strong growth of shale gas production within the UK at a cost below the market price would be unlikely to drive a substantial fall in the wholesale gas price from today's levels.

- **Country-specific challenges.** Shale gas production in Europe is likely to face greater challenges than it has done in the US. These include a range of issues associated with the greater population density (especially in the UK), notably public acceptability of fracking and environmental protection. There are further important differences from the US context around required planning consents (e.g. UK land owners do not own subsurface mineral extraction rights), providing less incentive to support development. These considerations, together with the recent exits of companies from shale gas exploration activities in Poland, suggest that the US experience may well not be repeated in Europe.

- **Reserves.** Whilst there are substantial UK shale gas reserves, the amount of gas that can be extracted economically is uncertain, and is likely to remain so until significant exploration has made a detailed assessment of the geology, and of the challenges and costs of extraction in the UK context. Estimates to date suggest that UK reserves could make a significant contribution to UK gas supply, but that this is unlikely to be sufficient to meet the UK's full gas demand.

Overall it is unlikely that shale gas development will push UK gas prices significantly below today's levels. Projections by the IEA, Navigant (for DECC) and Pöyry¹ all indicate that central expectations, even with the emergence of shale gas, are for UK and European gas prices to remain at around today's level, or possibly rise slightly. Navigant's low price scenario (around 25% below today's price) requires global oil prices to fall significantly, the US and China to ramp up unconventional gas production and start exporting, and the EU to be producing shale gas to meet 20% of its gas demand by the early 2020s. Given great uncertainty within Europe about shale gas production, this appears unlikely.

¹ IEA (2011) World Energy Outlook special report – are we entering a golden age of gas?; Navigant (2013) Unconventional gas – the potential impact on UK gas prices; Pöyry (2012) How will Lancashire shale gas impact the GB energy market?

Box 1.4: Carbon prices used in our analysis

Carbon price projections have an important role in our analysis, in the identification of cost-effective abatement options and emissions pathways in the UK through the 2020s. Our budgets are based on pathways that are cost-effective relative to the carbon price and required on the path to meeting the 2050 target.

We judge the cost-effectiveness of measures by reference to carbon price projections across the asset lives of low-carbon investments (e.g. the carbon savings from an electric vehicle purchased in 2025 will accrue from that year until the vehicle is replaced in the late 2030s).

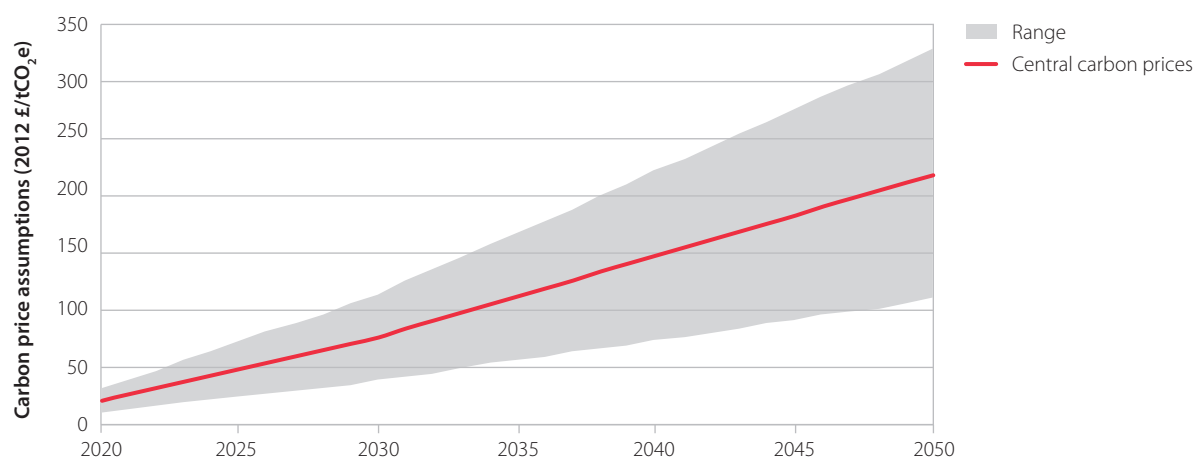
As set out in more detail in the first part of our review², our updated assessment of the cost-effective abatement path uses carbon values based mainly on the Government's projected values (Figure B1.4):

- For 2030 to 2050, we use the full range of DECC carbon appraisal values. These have central levels of £76/tonne in 2030 and £216/tonne in 2050 (2012 prices), with low and high values 50% below and above the central levels.
- For the period prior to 2030, we use the European Commission's value of €25/tonne (£21/tonne) in 2020, rising linearly through the 2020s and reaching DECC's appraisal value of £76/tonne for 2030. The EC value for 2020 represents a projection of the EU carbon price on a cost-effective trajectory towards an emissions reduction of at least 80% in 2050, going through 25% in 2020. We again use low and high values 50% below and above this central assumption (i.e. as in the Government's values post-2030) for sensitivity analysis.
- These assumptions are similar to those that we used in our original advice on the fourth carbon budget, when we assumed carbon prices of £29/tonne in 2020, £76/tonne in 2030 and £216/tonne in 2050 (£27, £70 and £200 respectively in 2009 prices).

Sensitivity analysis across the range of possible carbon prices allows us to test the robustness of the fourth carbon budget across the uncertainties that we have identified, and the extent to which flexibility may be required in approaches to meeting the budget.

Although lower prices are possible if the world fails to act sufficiently (e.g. a combination of low ambition and the economic slowdown has resulted in very low carbon prices in the European trading scheme currently), this would not be consistent with keeping expected global temperature increase close to 2°C or with the UK 2050 target to reduce emissions by 80%. Lower prices would therefore not be an appropriate basis for the carbon budget analysis.

Figure B1.4: Carbon prices used for the Fourth Carbon Budget Review analysis



Source: DECC (2009) Carbon Valuation in UK Policy Appraisal: A Revised Approach; EC (2011) Low-Carbon Roadmap.

Notes: Linear interpolation assumed between the EC point for 2020 and the DECC point for 2030, as in DECC methodology post-2030.

² CCC (November 2013) *Fourth Carbon Budget Review – part 1: Assessment of climate risk and the international response*. Available at www.theccc.org.uk/publications.

4. Abatement scenarios for emissions in the 2020s

Outlook to 2020

The starting point for our scenarios is a projection for emissions in 2020, building in measures which the Government is aiming to deliver or has committed to deliver. Since many of the policies for 2020 are already in place, this is very similar to the Government's official projection of emissions. We have updated our projection based on the new evidence since our original advice. It now involves:

- **Power.** We have significantly revised our estimate of power sector emissions to around 64 MtCO₂ in 2020, primarily reflecting a substantial decrease in the amount of generation assumed to come from coal. This would be a 59% reduction on 2010 and is 45 MtCO₂ lower than we assumed in our 2010 advice. Average grid intensity is assumed to reduce 49% to 211 gCO₂/kWh in 2020, compared to 323 gCO₂/kWh under our previous assumptions in 2010. This is due to:
 - A 72% reduction in the expected amount of unabated coal-fired generation in 2020, reflecting expectations that some existing coal units will convert to biomass; that coal CCS demonstrations would have full rather than partial CO₂ capture applied; and that more coal capacity will be reduced in the face of the Industrial Emissions Directive.
 - A 20% increase in the expected amount of nuclear generation in 2020, reflecting that several existing nuclear units that were scheduled to close before 2020 have been granted lifetime extensions to operate into the 2020s.
- **Buildings.** We now assume emissions from buildings are 80 MtCO₂ in 2020. This would be a 17% reduction on 2010 and is 9 MtCO₂ higher than we assumed in our 2010 advice. This is due to energy and carbon savings for a range of residential energy measures being updated in accordance with new evidence (presented in chapter 3) leading to a reduction in the amount of abatement assumed from these measures.
- **Transport.** We now assume emissions from road transport are 82 MtCO₂ in 2020. We add to this projected emissions from rail and domestic aviation and shipping, bringing total domestic transport emissions to 93 MtCO₂. This would be a 21% reduction on 2010 and is a slightly lower level than we assumed in our original advice. This is due to:
 - The updated reference projection from the National Transport Model being lower than our previous assumption (Chapter 5).
 - A revision to the UK emissions inventory, which reclassified a proportion of domestic shipping emissions as international (around 3 MtCO₂ per year).
 - Lower electric vehicle uptake (9% of new car and 12% of new van sales, compared to our previous assumption of 16%), reflecting an assessment of the UK's share of projected EU production.

- Updated vehicle technology and battery costs, reflecting our updated assessment, as set out in Chapter 5.
- A refined modelling approach, which disaggregates small, medium and large cars, better accounts for the ‘rebound’ effect (i.e. a change in vehicle-km as a result of changes in purchase and running costs of vehicles), and accounts for the divergence between test-cycle and ‘real-world’ emissions.
- **Industry.** We now assume emissions from industry are 92 MtCO₂ in 2020. This is a 21% reduction on 2010 and is 21 MtCO₂ lower than assumed in our 2010 advice. This is due to:
 - A significant reduction in DECC’s projections of baseline industry emissions.
 - Our review of the feasibility of energy-efficiency measures for both conventional and carbon-intensive industry, which reinforced assumptions in our 2010 advice (see chapter 4). The abatement potential from these measures has been scaled down in line with DECC’s latest energy demand projections but otherwise remains unchanged.
- **Agriculture.** We assume emissions from agriculture are 44 MtCO₂e in 2020. This is a 7% reduction on 2010. Reflecting the lack of significant new evidence since 2010, we retain the same abatement options as set out in our original advice. Combining these with the latest baseline projections implies a slightly lower level of emissions in 2020 than assumed in our 2010 advice.

As a result we now assume total UK GHG emissions are 413 MtCO₂e in 2020. This would be a 30% reduction on 2010 and 75 Mt lower than we assumed in our original advice.

Updated assessment of the cost-effective path to 2030

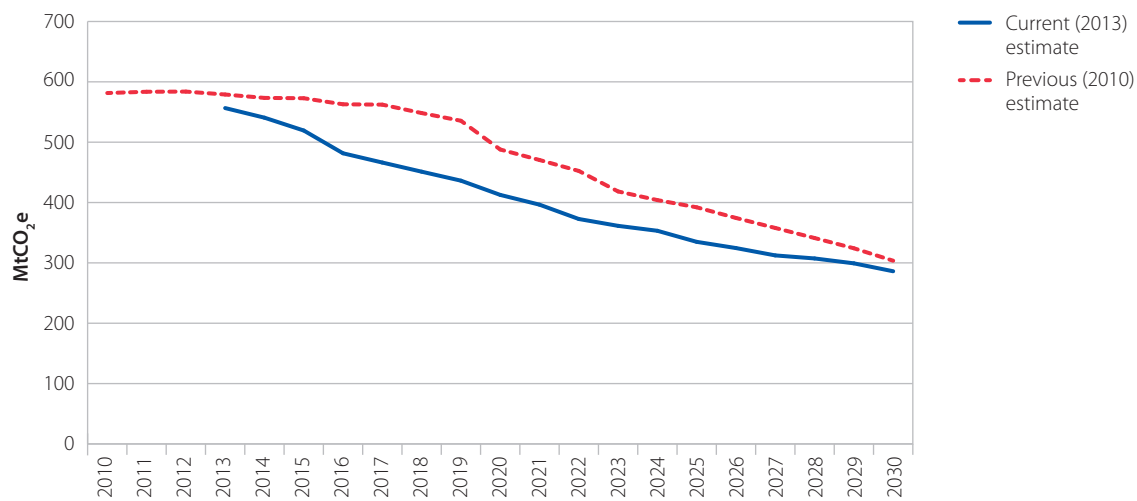
We have updated our assessment of the cost-effective path in light of new evidence on emissions projections and the costs and feasibility of abatement options. This results in an updated abatement scenario with emissions cuts of 56% in 2025 and 63% in 2030 on 1990 levels, compared to the scenario underpinning the budget which resulted in a 50% cut in 2025 and a 60% cut in 2030 on 1990 levels (Figures 1.8 and 1.9).

- **Power.** The updated abatement scenario includes portfolio investment in low-carbon technologies through the 2020s resulting in carbon-intensity of around 50 gCO₂/kWh in 2030. This results in GHG emissions of 21 Mt in 2030, an 88% reduction on 2012 levels. Estimated emissions in the 2020s are lower than we previously assumed due to the lower starting point in 2020 and lower demand projection (Chapter 2).
- **Buildings.** The updated abatement scenario involves changes in the assumed abatement across a range of measures, resulting in GHG emissions of 64 Mt in 2030, a 33% reduction on 2012 levels.
 - We have reflected the reduced estimates for effectiveness of insulation measures, but retain previous assumptions on uptake (i.e. all lofts and cavities and 3.5 million solid walls are insulated by 2030), given the importance of these measures to other goals, such

as tackling fuel poverty. We will revisit this assumption in our 2014 progress report to consider the appropriate level of ambition allowing for the full set of objectives.

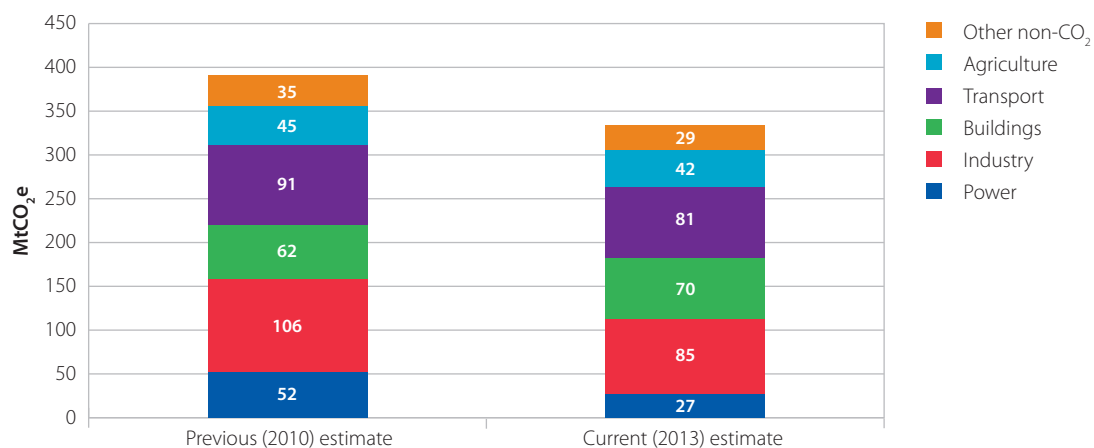
- We have revised our uptake down from 7 million heat pumps in homes to 4 million by 2030 (i.e. 13% of homes have heat pumps in 2030, rather than 21%), along with lower deployment in non-residential and industrial buildings.
- This is offset to a degree by higher uptake of district heating – increased from 10 TWh to 30 TWh (i.e. from 2% to 6% of buildings heat) in 2030.

Figure 1.8: Estimates of the cost-effective path to 2030 (total GHG)



Source: CCC modelling.

Figure 1.9: Estimates of the cost-effective level of emissions in 2025 (total GHG by sector)



Source: CCC modelling.

- **Transport.** Our updated scenario reflects lower baseline emissions, changes to the assumed mix of pure battery and plug-in hybrid electric vehicles, and lower assumed range for plug-in hybrid electric vehicles, informed by our new consumer choice modelling. This results in GHG emissions of 68 Mt in 2030, a 42% reduction on 2012 levels.
- **Industry.** Changes in the baseline scenario, reflecting lower projected output of carbon-intensive industry in the 2020s, have a significant net downward effect on industry emissions in the 2020s. The updated core scenario includes slightly less abatement from energy efficiency improvements to reflect our review of costs and feasibility. This results in GHG emissions of 69 Mt in 2030, a 39% reduction on 2012 levels.
- **Agriculture.** As in our original advice we assume a slower pace of reduction in emissions from agriculture than other sectors. We continue to build in around half of the technical potential to reduce emissions through the uptake of best practices and technologies to reduce N₂O emissions from soils and CH₄ emissions from livestock and manures. This results in GHG emissions of 39 Mt in 2030, a 18% reduction on 2012 levels.
- **Non-CO₂ greenhouse gases.** We assume that non-CO₂ greenhouse gases outside the agriculture sector are reduced by 47% from 2010 to 2030 in our updated scenario (Box 1.5). This results in GHG emissions of 25 Mt in 2030, a 43% reduction on 2012 levels, and 19% lower than we previously assumed over the fourth budget period.

Our new estimate of the cost-effective path to the 2050 target suggests emissions of 1,690 MtCO₂e across the fourth budget period, compared to the currently legislated limit of 1,950 MtCO₂e. This is our best estimate, based on the latest evidence. It implies that if all measures that we have identified as being cost-effective were to be implemented, then emissions across the economy would be 260 MtCO₂e (13%) below the level of the budget.

Emissions in our abatement scenario would be below the budget in both the traded sector (i.e. in those sectors of the economy covered by the EU ETS: power generation and energy-intensive industry) and the non-traded sector (i.e. outside the EU ETS, including buildings and surface transport).

- **Non-traded sector.** If all cost-effective measures were to be implemented in the non-traded sector, this would reduce emissions to around 1,210 MtCO₂e across the budget period. This would be around 50 MtCO₂e (4%) lower than assumed in the budget (1,260 Mt).
- **Traded sector.** If all cost-effective measures were to be implemented in the traded sector, this would reduce emissions to around 480 MtCO₂e across the budget period. This would be around 210 MtCO₂e (30%) lower than assumed in the budget (690 Mt).

Given these gaps there is the question of whether the budget should be tightened, thereby committing to full implementation of cost-effective measures. We consider this question in our *Fourth Carbon Budget Review – part 2: The cost effective path to the 2050 target*, where we conclude that the budget should be kept at the current level rather than tightened, but that the aim should still be to achieve early decarbonisation of the power sector.

- In the non-traded sector, the potential outperformance is within the likely margin of error and could provide useful flexibility.
- In the traded sector, while the implied contingency is larger than required, it would be premature to tighten the budget now given uncertainties about EU emissions reduction through the 2020s, and the ambition of any future target to reduce carbon-intensity of power generation to be set under the Energy Bill.
- Furthermore, keeping the budget at its current level would provide a degree of certainty that would be welcomed by investors.

Although we recommend the budget should be kept at the current level, this does not imply that a reduced level of effort is appropriate. Our assessment of the cost-effective path, which outperforms the currently legislated budget, offers cost-savings relative to a reduced level of effort and includes measures which are likely to be required to meet the 2050 target. It also allows a degree of flexibility to account for the range of uncertainties, including the pace and cost at which low-carbon measures can be delivered, how the UK population and economy will grow and how these will translate to energy demand and emissions. Reducing the level of effort to meet the currently legislated budget would jeopardise these benefits, and increase risks to achieving the fourth carbon budget and the 2050 target.

Box 1.5: Non-CO₂ scenarios

Non-CO₂ GHG emissions comprise methane (CH₄), nitrous oxide (N₂O) and fluorinated gases (F-gases). The main sources of these emissions outside the agriculture sector are emissions of CH₄ and N₂O from waste (e.g. waste sent to landfill, sewage waste) and emissions of F-gases, largely from leakage in refrigeration and air conditioning systems. Other sources include CH₄ leakage from gas pipes and coal mines, some industrial processes and catalytic converters in vehicles.

Non-CO₂ emissions excluding agriculture were 44 MtCO₂e in 2012. Non-CO₂ baseline projections have been revised down, primarily due to an improved methodology for measuring and projecting waste emissions. The latest projections are for non-CO₂ emissions excluding agriculture to fall to 25 MtCO₂e by 2030, a 43% reduction on 2012 levels, and 11 Mt (30%) lower than assumed in 2010.

Our assessment of the cost-effective emissions path in the 2020s includes some limited abatement in waste and other non-CO₂ emissions, and there has been no significant new evidence on potential abatement in these areas since 2010. As a result of the reduction in the baseline, non-CO₂ emissions in our scenario are 137 Mt over the fourth carbon budget period, a 33 Mt (19%) reduction on our 2010 scenario:

- **Waste.** Emissions from waste decrease 32%, from 17 MtCO₂e in 2012 to 11 Mt in 2030.
- **F-gases.** Emissions of F-gases (HFCs, PFCs and SF₆) decrease 64%, from 14 MtCO₂e in 2012 to 5 Mt in 2030.
- **Other non-CO₂.** Non-CO₂ emissions from transport, industry and other sources decrease 35%, from 13 MtCO₂e in 2012 to 8 Mt in 2030.

Preparing for 2050

In December 2012 the Government confirmed that emissions from international aviation and shipping are included in the 80% emissions reduction target for 2050. However, they are not currently included in carbon budgets.

Our previous assessments have demonstrated that achieving emissions reductions in these sectors will be particularly challenging, with limited progress possible even by 2050.³ This reinforces the need to develop options that could reduce emissions in other sectors to very low levels – emissions in the rest of the economy will need to be cut by around 85% by 2050 to achieve the 80% target across the economy, given the lower scope for cuts in international aviation and shipping.

UK GHG emissions in our updated abatement scenario decline from 572 MtCO₂e in 2012 to 287 MtCO₂e in 2030, a 3.8% annual reduction. Achieving the 2050 target of an 80% reduction on 1990 levels will require UK GHG emissions (excluding international aviation and shipping) to decline further, to around 120 MtCO₂e in 2050, a 4.3% annual reduction between 2030 and 2050. This implies an acceleration of effort beyond 2030 (Figure 1.10).

Our analysis indicates that this acceleration of effort is feasible, provided the options to deploy key technologies are developed in the 2020s:

- **Power:** Our updated abatement scenario includes deployment of 5-15 GW of carbon capture and storage, and at least 25 GW of offshore wind by 2030 (which would generate equivalent to around 10 GW of baseload capacity). This would develop the option for either or both of these two technologies to make a very significant contribution to meeting the 2050 target, subject to the overall requirement for low-carbon capacity (which we expect to be large, e.g. equivalent to 80-100 GW of baseload capacity), the potential contribution from other low-carbon technologies (which is likely to be well below the total requirement) and technological developments over the coming years, including improvements in costs of generation and operating performance.
- **Transport:** Our updated abatement scenario includes sales of battery electric and plug-in hybrid cars and vans reaching 60% of new vehicles in 2030, resulting in deployment of 10.7 million ultra-low-emission cars and 1.9 million ultra-low-emission vans (31% and 40% of the fleets respectively) by 2030. A significant market share of electric vehicles is required by 2030 to develop the option to increase deployment to 100% of the fleets by 2050, which requires close to 100% market share of new car and van sales within the 2030s.
- **Heat:** Our updated abatement scenario includes sales of around 400,000 heat pumps in 2030, with cumulative deployment of 4 million heat pumps by that year; a substantial take up of heat pumps in the 2020s will keep open the option of high heat pump deployment by 2050. We also assume some early penetration of district heating, which could help develop this option for wider application by 2050.
- **Industry.** Our updated abatement scenario includes deployment of industrial CCS to abate 5 MtCO₂ by 2030. Alongside technology and infrastructure development from deployment in the power sector, this will help to develop the option for increased deployment by 2050, consistent with capturing CO₂ from the largest industrial sources by this date through investments as part of the expected refurbishment cycle.

³ See CCC (2012): *Scope of carbon budgets – Statutory advice on inclusion of international aviation and shipping*

Whilst feasible, this remains a very challenging trajectory beyond 2030 and emphasises that the currently legislated fourth carbon budget should be seen as a minimum level of ambition for emissions reduction.

Figure 1.10: Rate of reduction of GHG emissions, excluding international aviation and shipping (2012-2050)



Source: NAEI (2013), CCC modelling.

Sensitivities and flexibilities

On the basis of current evidence, the scenario set out above has potential benefits compared to alternatives. However, new evidence could suggest departures from it are appropriate. For example, the feasible pace of investment might turn out to be limited, cost reductions might occur more slowly than assumed, or low fossil fuel and/or carbon prices could make the high-carbon alternative relatively more attractive. It would be important to demonstrate that any such departure would not put achievement of the 2050 target at risk.

We have developed a number of sensitivities to model these contingencies, including:

- **Power.** Carbon-intensity of emissions is reduced to 100 gCO₂/kWh in 2030 rather than 50 gCO₂/kWh, increasing emissions by around 65 MtCO₂ (3-4%) across the fourth budget period. This could reflect a failure of CCS, limited reduction in costs of emerging renewable technologies, or slow progress on nuclear and CCS deployment.
- **Heat pumps.** Residential heat pump deployment is limited to 2.5 million by 2030 rather than 4 million, increasing emissions by around 25 MtCO₂ (1-2%) across the fourth budget period. This could be an appropriate course of action if technology performance is poor or gas prices are low. It would reduce costs while still keeping open the option of meeting the 2050 target through extensive deployment of heat pumps – any lower level of deployment would risk closing off this option.
- **Solid wall insulation.** If no solid wall insulation is installed during the 2020s then emissions would be around 6 MtCO₂ (<1%) higher across the fourth budget period. This could save money

given the high cost of carbon savings implied by our latest evidence, but would also raise questions over how to deal with fuel poverty given the prevalence of this in solid wall homes.

- **Electric vehicles.** If the market share of electric vehicles grows more slowly, reaching 30% of car and van sales in 2030 rather than 60%, then emissions would be 14 MtCO₂e (<1%) higher across the fourth carbon budget period. Furthermore, this would make it more difficult to meet the 2050 target, as it would very likely push back beyond 2035 the point at which ultra-low emission vehicles could comprise 100% of sales.

Even where measures are implemented as in our updated abatement scenario, resulting emissions could be different to the level we have modelled. For example, if population, GDP or energy prices turn out differently to our assumptions then emissions could be higher or lower:

- If population were to increase faster than our central assumptions (e.g. according to the Office of National Statistics (ONS) “High Migration” projection), emissions could be around 3% higher; if population were to increase more slowly (e.g. according to the ONS “Low Population” projection), emissions could be around 2.5% lower.
- If GDP were to increase faster than our central assumptions (e.g. growth one quarter of a percentage point higher in each year than assumed in DECC’s baseline emissions projection), emissions could be around 1.3% higher; if GDP were to increase more slowly (one quarter of a percentage point lower in each year), emissions could be around 1% lower.⁴

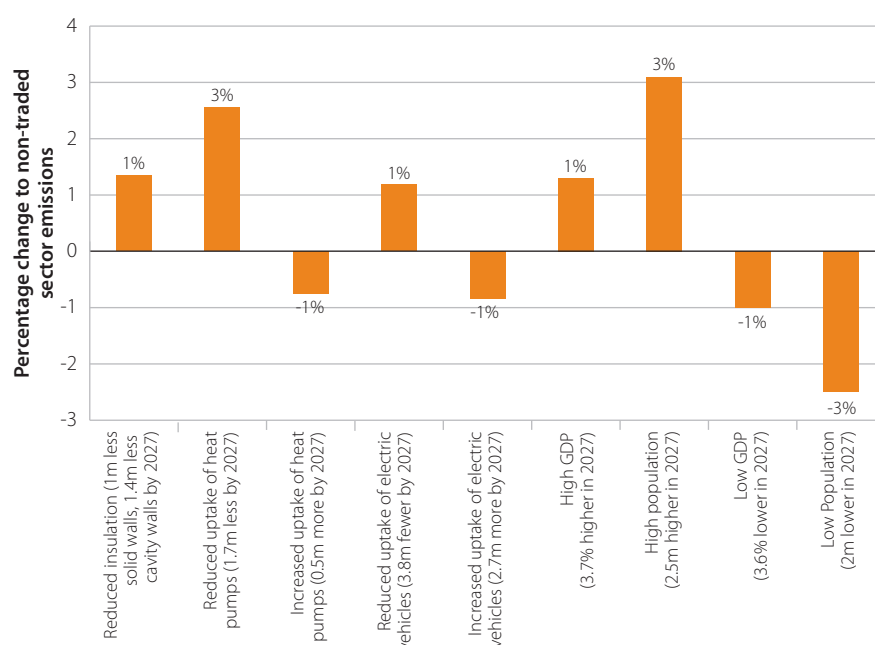
Alternatively, it may be desirable to go further than assumed in our scenario if measures prove cheaper than we have assumed, or if fossil fuel and/or carbon prices turn out to be high. This could lead to more rapid reductions in emissions than we have assumed or compensate for some of the other sensitivities listed above. For example, there could be: higher uptake of hydrogen vehicles or district heating; greater improvements in efficiency of vehicles, buildings or appliances; more behaviour change including in energy use and in diets; deeper reductions in non-CO₂ emissions than we have assumed. We demonstrated in our original advice that together these options could deliver a further 64 MtCO₂e (20%) reduction in 2030 emissions compared to our central scenario.

These sensitivities demonstrate the inherent uncertainty in modelling emissions scenarios out to 2030 (Figure 1.11). Given this uncertainty, we conclude in our main advice that the changes in emissions in our modelled scenario are within the margin of error for budget setting and not a sufficient reason to change the budget from its currently legislated level.

The importance of uncertainty was also a key message from the Committee’s Call for Evidence and stakeholder workshops run during the summer of 2013 (Box 1.6). We heard a strong message both from experts in scenario modelling and representatives of business and industry that there is considerable inherent uncertainty in the future path of the economy, energy demand and emissions. They both concluded therefore that the strong preference should be towards not changing the budget based on revised projections and that possible contingency implied by lower projected emissions could be useful for budget management in the face of the uncertainties.

⁴ These estimates are based on assumptions in the DECC energy model. We have previously questioned the responsiveness of projected emissions in the DECC model to GDP assumptions, implying that the full range of uncertainty attached to GDP is likely to be higher.

Figure 1.11: Uncertainties in non-traded sector emissions



Source: CCC modelling, DECC (2013) Energy and emissions projections, ONS (2011) 2010-based population projections.

Box 1.6: Call for Evidence, stakeholder workshops and public engagement

In reviewing the evidence around the fourth carbon budget we ran a call for evidence and a series of stakeholder workshops. Respondents and attendees included: experts in the fields of climate science, global negotiations, energy policy and scenarios; business stakeholders from across all sectors of the economy; and government officials. This allowed us to gather a wider perspective on whether there had been a significant change of circumstances since our initial advice was published in 2010 and how to respond to any changes.

Our call for evidence and stakeholder workshops focused on four key areas.

- **Scenarios.** Has there been a significant change to what constitutes a cost-effective path to meeting the 2050 target?
 - In looking at whether there has been a change in the cost-effectiveness of our scenarios the on-going impact of the recession was flagged, along with the current low level of the carbon price in the EU ETS and falling solar costs. Overall the key message was that it was important that we reflect the latest evidence in our advice; it was also noted that targets affect costs, and so reductions in ambition could lead to higher costs in future.
 - The scenarios out to 2050 should not be affected by short term fluctuations, options should be developed to protect against uncertainty (e.g. in fossil fuel prices).
 - Having some ‘headroom’ in the budget would provide useful contingency against unforeseen changes in circumstances.
- **The level of the fourth carbon budget.** Has there been any evidence to suggest that the budget should be tightened?
 - On changing the level of the budget a clear consensus was that changing the budget in either direction without a very strong reason would be bad for stability and undermine confidence in UK targets. Inherent uncertainty in projections was emphasised, suggesting that changed projections alone may not be a strong enough reason to change a budget.
 - Alignment of the budgets with the EU cap was supported but it should be done on a clearly evidenced basis and only once a cap at the EU level has been agreed.
 - In terms of the wider impacts of budgets, affordability concerns were raised and the importance of maintaining competitiveness and supporting industry was emphasised.

Box 1.6: Call for Evidence, stakeholder workshops and public engagement

- **Climate science.** Has there been any significant change in the scientific evidence around climate change to suggest that the UK's climate objective is no longer sensible?
 - There was a clear wish for the Committee to be guided by the IPCC's fifth assessment report both now and in the future, and to review and incorporate any changes to the IPCC's evidence in our modelling.
 - On climate impacts the key message was that any change to the evidence was towards climate impacts being worse than previously assumed, emphasising the need for action.
 - On climate sensitivity there was a consensus that the recent observed slowdown of increase of global temperature did not suggest a need for reduced action on emissions.
 - At the EU level it is expected that there will be a deal agreed in the next few years for the 2020s, which will be more stringent than the default trajectory. The UK should realign its budgets to the EU ETS when a 2030 package is agreed and not before.
- **International circumstances.** Is action on climate change at the international or EU levels significantly different from that in 2010?
 - The most significant change in international circumstances since 2010 has been the official recognition by the UNFCCC of a 2 degree climate objective. Given that this is slightly more ambitious than the UK's current assumed climate objective it would be counterintuitive to weaken the UK's objective whilst remaining a signatory to the UNFCCC. Other global developments since 2010 have been mainly positive with more action from individual countries especially the US and China.
 - The UK's climate objective is still considered to be technically feasible as it was in 2010. The Committee should keep the objective under review and respond to any new evidence on its achievability.
 - In terms of whether the UK should be at the forefront of global action on climate change, it was generally considered that the UK has a clear leadership role in global climate change negotiations and a weakening of UK ambition would send a damaging signal and be detrimental in reaching a global agreement. However, it was not clear that the UK was leading in terms of actual emissions reduction.

We also held three dialogue workshops (independently run by Hopkins van Mil and co-funded by Sciencewise⁵) with 25 members of the public selected to provide a representative cross-section of the population. The Committee secretariat provided short presentations on various aspects of carbon budgets – climate science, international action, measures required to meet carbon budgets, and costs including impacts on energy bills. Participants discussed these issues at length in a 'panel discussion' format before having the opportunity to provide six recommendations to the Committee. They recommended:

- Greater public debate and engagement on the sorts of measures the Committee is considering in the fourth carbon budget review.
- Education at all levels on climate change and carbon emission reductions.
- Action on climate change now by investing in safe, renewable energy sources.
- Positive contributions by individuals and businesses to be incentivised.
- Data to be kept up-to-date and current data used to inform policy advice and ensure that evidence is robust.
- The issue of climate change not to be swayed by party politics, and for advice and legislation to be independent.

The Committee are grateful to all our workshop participants and respondents to the Call for Evidence for generously giving up their time and engaging with enthusiasm.

⁵ Sciencewise is the UK's national centre for public dialogue in policy making involving science and technology issues. See www.sciencewise-erc.org.uk

5. Costs and benefits of reducing emissions

When we recommended the fourth carbon budget we set out analysis demonstrating that this could be achieved at a cost of less than 1% of GDP. This was the cost of all measures implemented to 2030 to reduce emissions compared to a scenario with no carbon constraint⁶. We argued that this cost is worth paying given the much higher costs and risks associated with dangerous climate change. We estimated the cost of measures to deliver 2020 ambition at around 0.2% of GDP in 2030, and the cost of the additional measures required in the 2020s at around 0.5% of GDP.

Our new evidence suggests these cost estimates are broadly unchanged and dominated by costs in the power sector, with cost-saving measures (i.e. efficiency improvement) offsetting the costs of switching to low-carbon energy sources outside the power sector (e.g. heat pumps and electric vehicles) (Table 1.1).

Table 1.1: Cost of the abatement scenario (annual cost in 2030)

Sector	Cost as percent of GDP
Power	0.6%
Industry	-0.1%
Buildings	0.0%
Transport	-0.1%
Total	0.5% of GDP

Source: CCC analysis
Notes: Costs and cost-savings of low-carbon electricity are allocated to the sources of additional demand or demand reduction. Numbers may not sum to totals due to rounding. We expect net abatement costs in agriculture and other non-CO₂ emitting sectors to be negative; in these calculations we assume zero costs due to uncertainties around exact magnitudes.

Some cost is unavoidable due to the carbon constraint. Since the budget is based on the cost-effective path to the 2050 emissions reduction target in the Climate Change Act, a departure from this pathway would increase costs and risks. In our advice in 2010 we did not attempt to value this relative to a path with more delayed action.

In carrying out its Impact Assessment for the fourth carbon budget, the Government adopted a methodology which suggested that the budget would cost more than a less ambitious path for emissions reduction through the 2020s. This reflected a limited treatment of the value of carbon reductions required to meet the climate objective and of the dynamics of the energy system.

- The headline figures in the Impact Assessment reflect the costs of undertaking measures within the fourth carbon budget period, but no value was ascribed to having lower UK emissions. Therefore only a handful of measures were presented as having a net benefit, on the basis that they save money even without consideration of climate change.
- Furthermore, no value was placed on emissions savings post-2027, as a result of measures undertaken within the fourth carbon budget period. As much of the economic benefit of these measures derives from a lower emissions path following the budget period, this approach considerably understated the long-term value of action during the 2020s in meeting long-term emissions targets in a carbon-constrained world.

⁶ Our analysis is based on a 'resource cost' methodology (i.e. it sums the direct additional costs of implementing measures in our scenarios to reduce emissions). As in our original advice on the fourth carbon budget, we have not undertaken detailed macroeconomic modelling for this report. This reflects the finding of our previous work using HMRC's general equilibrium model and Cambridge Econometrics' macroeconomic model that a resource cost estimate is likely to capture the most important elements of the GDP cost (see CCC (2008) *Building a low-carbon economy*).

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- As a result the Impact Assessment suggested that a looser budget would have lower costs as it ignored the benefits of measures that reduce emissions at a cost below the carbon price, both within the budget period and over the period to 2050.

In order to reflect full costs and benefits of action to cut emissions in the 2020s, it is necessary to attach value to carbon as implied by the climate objective, and to consider dynamics of the energy system over time, including path dependency associated with investment choices in the 2020s.

For example, while a reduction in ambition could reduce costs of abatement a full analysis must reflect that higher emissions also increase climate risk and associated costs, and that in a carbon-constrained world this will translate to a value of carbon reductions. It should also allow for the likelihood that lower implementation of measures in the medium term would limit options for later emissions reduction, implying higher costs may be incurred in the long term.

Therefore, in this report we include an analysis of cost savings where carbon is valued as implied by our climate objective, and where we consider system costs to 2050 under the requirement that the 2050 target to reduce emissions by 80% relative to 1990 is met.

We now set out that assessment based on a comparison of measures to meet the fourth carbon budget versus an alternative scenario where implementation of measures is delayed until 2030 and beyond (see Chapters 2-5 for a description of the assumed delay).

Our analysis suggests that delivering our abatement scenario to 2030 rather than delaying action beyond 2030 offers a saving of over £100 billion in present value terms under central case assumptions for technology costs, fossil fuel prices and carbon prices. Further benefits upwards of £15 billion could be associated with development of CCS in the 2020s.

- A substantial part of the cost saving associated with the abatement scenario under central assumptions comes from the power sector. In our report *Next steps on Electricity Market Reform*, published in May 2013, we estimated this at £25-45 billion. This reflects the benefits of investing in nuclear power generation and onshore wind rather than gas-fired generation subject to a carbon price, and the option value associated with developing less mature technologies such as offshore wind and CCS.
 - Under central assumptions, deployment during the 2020s of 18 GW of nuclear and 10 GW of onshore wind (generating the equivalent of 3 GW of baseload capacity) would save around £25 billion over their lifetimes. This is relative to gas-fired generation subject to a rising carbon price in line with the Government's carbon price underpin reaching £76/tCO₂ in 2030 and continuing to rise thereafter (see Box 1.4).
 - Deployment of offshore wind and CCS in power generation during the 2020s creates options for further deployment post-2030, at lower costs and at faster rates if required. This investment saves up to £40 billion over the lifetime of investments, relative to unabated gas-fired generation with a rising carbon price and depending on the availability of mature alternatives like nuclear (i.e. up to £20 billion if nuclear is available and £40 billion if not).

- Roll-out of heat pumps, district heating and electric vehicles during the 2020s develops markets that will be important for further deployment between 2030 and 2050. These measures are cost-effective against a rising carbon price when considering the entire timeframe to 2050, offering a potential present value saving of around £55 billion versus a scenario where their deployment is delayed.
- Other measures, like energy efficiency improvement in cars and buildings, are generally cost-effective compared to the carbon price. Together these offer a potential saving of around £35 billion compared to a scenario that does not roll them out through the 2020s.
- Deployment of CCS in the 2020s, primarily in the power sector, provides the necessary scale to develop CO₂ infrastructure clusters and drive down the cost of capital associated with CCS in all sectors. In addition to the benefits of developing CCS for deployment in the power sector, this also enables CCS applications in industry and on bioenergy, both of which are likely to be important in meeting the 2050 target. Assuming that a delay to CCS roll-out would reduce the deployability of CCS for industry and bioenergy by 25% to 2050, investment in CCS would reduce the costs of meeting long-term emissions targets by £15 billion in addition to the benefits for power sector decarbonisation (Box 1.7).

Box 1.7: Value of CCS in meeting long-term emissions targets

Carbon capture and storage (CCS) has a large value in meeting long-term emissions targets, due to the possibility to deploy it not just in the power sector, but also on carbon-intensive industry, bioenergy facilities and for hydrogen production.

While in principle its use for power generation and hydrogen production could be substituted by other low-carbon energy sources (i.e. renewable and nuclear), its application to industry and bioenergy provides abatement that cannot be provided by other technologies:

- **Industry.** In a range of carbon-intensive industries, notably the cement, iron and steel, chemicals and refinery sectors, CO₂ is produced via chemical reactions as well as the use of fossil fuels for energy. While in principle the energy could be decarbonised using renewables or nuclear energy, the only way to abate the emissions from chemical reactions is with CCS.
- **Bioenergy.** Sustainable supplies of bioenergy are likely to be scarce, and therefore it will be important to maximise the amount of emissions reduction achieved from the available resource. As we set out in our 2011 Bioenergy Review, the use of bioenergy with CCS can achieve around twice the abatement per tonne of solid biomass compared to producing liquid fuels for transport without CCS.

Analysis for our 2012 report *The 2050 target* suggested that having CCS available as an option could reduce the resource cost of meeting the 2050 target by 0.4% of GDP in 2050, suggesting a very high value to its development as an option.

For this report we have used the Energy Technology Institute's ESME (Energy Systems Modelling Environment) cost-optimising model to examine the impact that a delay in CCS development would have on the cost of reducing UK emissions through to 2050. This modelling indicated that a failure to develop CCS in the 2020s, leading to a reduction of 25% in its deployment in industry and on bioenergy by 2050, would increase costs by around £15 billion at DECC's central carbon prices. To the extent that potential deployment in 2050 could be reduced further by a delay in development, the cost increase would be larger.

The total cost saving from delivering our abatement scenario increases to around £200 billion in present value terms under assumptions of high fossil fuel or carbon prices. Under low fossil fuel prices or low carbon prices, the cost saving is eroded, but does not become negative. Only if there is the combination of low fossil fuel prices and low carbon prices might the core scenario have significant additional costs compared to a more back-ended approach to meeting the 2050 target.

- The cost savings increase under assumptions of high fossil fuel or carbon prices, both of which improve the cost effectiveness of low-carbon technologies. A faster pace of investment in low-carbon technologies may be appropriate with high fossil fuel or carbon prices, which could lead to an outperformance of the budget, and larger cost savings.
- Although cost savings are eroded under assumptions of low fossil fuel or carbon prices, both of which make low-carbon investment relatively more expensive, the core scenario still offers a potential cost saving relative to a more back-ended emissions reduction path to the 2050 target. A slightly slower pace of investment in low-carbon technologies may be an appropriate response to either low fossil fuel or low carbon prices provided it still prepares sufficiently for the 2050 target, and as set out in section 4 could still be consistent with the legislated budget.
- There could be significant additional costs associated with the core scenario under assumptions of both low fossil fuel prices and low carbon prices. In these circumstances, significantly delaying investment in low-carbon technologies could reduce costs, but this would be inconsistent with UN-agreed climate objectives and counter to expectations for fossil fuel prices.

This analysis assumes that delayed action can be compensated for by faster deployment of low-carbon technologies in the 2030s and 2040s than under the core emissions scenario, so partially catching up with the path to meeting the 80% target in 2050. It also assumes that any shortfall in abatement can be made up by purchase of international credits at a cost in line with the Government's carbon values. Both of these assumptions may be optimistic:

- In reality, a back-ended path would entail a very rapid transformation of the system. This would be likely to raise the costs and risks of meeting the 2050 target, given the need for consumer acceptance of new technologies to grow very quickly, high build rates across a wide range of low-carbon technologies and the need for scrappage of high-carbon technologies in some areas (Box 1.8).
- Such a path would therefore most likely imply the need for the UK to purchase international emissions credits to meet the 2050 target. The Government assumes that the cost of carbon credits will rise strongly to 2050 (e.g. to reach £110-325/tCO₂e), while our previous analysis has identified significant risks that carbon prices could be even higher (e.g. if sustainable bioenergy is limited or if the world follows a back-ended path to meeting the climate objective)⁷. Furthermore, were this shortfall to be replicated internationally, this would jeopardise meeting of the climate objective.

⁷ CCC (November 2013) *Fourth Carbon Budget Review – part 1: Assessment of climate risk and the international response*. Available at www.theccc.org.uk/publications

This analysis suggests that investment in low-carbon technologies as in our abatement scenario and as reflected in the fourth carbon budget is low-regrets with potentially significant benefits across plausible scenarios. While it is possible that fossil fuel prices will turn out to be low, this would imply that carbon prices would need to be correspondingly higher in order to drive emissions reduction. A combination of low fossil fuel prices and low carbon prices would therefore imply a lowering of ambition in the climate objective and is not a suitable basis on which to plan.

While there may be structural costs associated with the transition to a low-carbon economy if it is not well managed, these could be minimised by a steady and stable path as implied in our abatement scenario, and as could be signalled by an early confirmation of the fourth carbon budget at its current level. There may also be benefits such as the opportunity to export low-carbon goods and services and improved energy security, while impacts on fuel poverty, competitiveness, fiscal circumstances are likely to be limited and manageable (see *Fourth Carbon Budget Review – part 2: The cost effective path to the 2050 target*).

The substantial cost saving achieved through delivering an abatement scenario to 2030 along the lines we have modelled, rather than delaying action beyond 2030, is a compelling reason why Government should aim to deliver the level of ambition characterised by our scenario. This will require further development of policies to build a low-carbon economy through the 2020s. In particular, Government should ensure that the Electricity Market Reform (EMR) aims to achieve deep decarbonisation of the power sector by 2030, that policies to drive energy efficiency improvement are effective, and that policies to support uptake of renewable heat and low-carbon vehicles are extended into the 2020s. We will report on existing policies and requirements for the future in our 2014 progress report to Parliament, as part of our statutory assessment of the first carbon budget period.

Box 1.8: Evidence on transitions and the potential role of scrappage

In order to achieve the UK's legally binding target of an 80% reduction in emissions by 2050, the UK will have to make transitions to low-carbon in several sectors simultaneously. Some insights on how these transitions could succeed can be drawn from the extensive academic literature that considers how technology and energy system transitions occur. Looking across a wide variety of transitions both in the UK and internationally, some key themes emerge:

- Energy system transitions generally take at least 40 years, and often considerably longer (e.g. up to 130 years). This suggests that the transitions required will happen over a relatively short timescale by historical standards and therefore immediate action is needed to drive them forward. For example,
 - the transition in the UK from traditional renewable energy sources (e.g. wind and water mills, biomass for heat) to coal took around 130 years;
 - the shift from a coal-dominated energy system to one with major roles for oil, gas and electricity took around 80 years.
- In general, larger transitions that require a lot of new infrastructure, and which will interact with other systems, will take longer to complete. Given the challenges involved in some of the transitions required by 2050 (e.g. introduction of electric vehicles, low-carbon heat and CCS), it is likely that most of these will be slower than rapid transitions such as the 'dash for gas' in the power sector during the 1990s.
- There is potential for faster transitions to occur when new technologies have an immediate advantage over previous technologies, or where they have had a chance to develop in niche markets prior to wider deployment.
 - Without a carbon price, many of the technologies required for a low-carbon transition will remain more expensive than incumbents, which also have the advantage of established infrastructure.
 - Targeted support may be required to drive uptake of new technologies in niche markets, ahead of mass-market roll-out.
 - As transitions will be driven primarily by the social need to reduce emissions, a switch to low-carbon technologies may not involve significant private benefits to end-users, making the transition more challenging.

Overall this indicates that our approach of allowing long lead-times in key markets such as electric vehicles, and keeping options open for a portfolio of technologies in 2050, is appropriate. It also suggests that, given the comparatively short period for this transition to occur, reductions in shorter-term ambition for key technologies may make it extremely challenging/expensive to meet the 2050 target domestically.

If markets for key technologies are not developed sufficiently early, they may not reach the levels of uptake required by 2050 to meet the 80% target. Under these circumstances, scrappage policies may be required in the 2040s to accelerate introduction of low-carbon technologies at a faster pace than could be achieved simply via end-of-life replacement of high-carbon capital, even though this would entail higher costs:

- **Heat pumps.** Scrapping a gas boiler in the mid-2040s to replace it with a heat pump would have an effective cost of between £75-220/tCO₂, depending on the type of building. While this is more expensive than installing a heat pump instead of a gas boiler under the natural replacement cycle, and therefore should not be planned for, in most cases it is less than the level of the 2045 carbon price of £180/tCO₂.
- **Ultra-low emission vehicles.** Scrapping an internal combustion engine vehicle to replace it with an electric vehicle would have an effective cost of over £1200/tCO₂, well in excess of the carbon price.

This suggests that failure to create a market for ultra-low emission vehicles will lead to higher emissions in the transport sector by 2050, but that failure to deploy low-carbon heat in a timely fashion could be partially mitigated through scrapping gas boilers in the 2040s.

Chapter 2: Reducing emissions from the power sector

Introduction and key messages

In 2012 power sector emissions were 156 MtCO₂ and accounted for 27% of UK emissions covered by carbon budgets.

In our original 2010 advice on the fourth carbon budget we proposed that deep cuts in power sector emissions through the 2020s are feasible, cost-effective and desirable in meeting the fourth carbon budget and preparing for meeting subsequent carbon budgets and the statutory 2050 target.

Our analysis suggested the need for investment in 30-40 GW of low-carbon capacity in the decade from 2020, to replace ageing capacity currently on the system and to meet demand growth. This investment in low-carbon power generation reflected an assessment of the economics and potential build constraints, as well as a range of possible growth scenarios for electric vehicles and heat demand. It would drive carbon intensity of power generation from current levels (around 500 gCO₂/kWh) down to around 50 gCO₂/kWh by 2030.

We revisited our analysis of scenarios to reduce power sector emissions in our May 2013 report *Next steps on Electricity Market Reform – securing the benefits of low-carbon investment*¹. In that report, we concluded that decarbonising the power sector to an average grid intensity of around 50 gCO₂/kWh remained an appropriate objective for 2030. This reflected the latest evidence on costs and feasibility of deploying key low-carbon technologies as well as the importance of developing less-mature technologies and preparing for meeting the 2050 target to reduce economy-wide emissions by at least 80% relative to 1990.

In this chapter we update our scenario for power sector emissions in the 2020s to reflect that evidence as well as: latest projections of electricity demand, including our revised assessment of uptake of energy efficiency and heat pumps in buildings and industry and electric vehicles in transport (see chapters 3, 4, and 5); and the Government's latest views and analysis in its draft Delivery Plan for Electricity Market Reform (July 2013), including funding commitment in the Levy Control Framework for investment in low-carbon generation to 2020.

Our updated scenario still leads to a power sector that is decarbonised to an average grid intensity of around 50 gCO₂/kWh in 2030 but with lower emissions through the 2020s.

This reflects the specific conclusions from our new analysis:

- **Path to 2020.** Power sector emissions are projected to decrease much more rapidly to 2020 than assumed in our advice in 2010. This is due to revised demand projections and substantially revised projections for coal-fired and nuclear generation.

¹ <http://www.theccc.org.uk/publication/next-steps-on-electricity-market-reform-23-may-2013/>

- **Demand.** Electricity demand after reflecting our updated assessment of uptake of abatement measures (e.g. energy efficiency in buildings) is now forecast to fall 9% from 2010 to around 300 TWh in 2020, which is 7% lower than projected in our 2010 advice.
- **Coal.** The assumed amount of unabated coal-fired generation in 2020 has been reduced by 72% to 21 TWh. This is because we now expect: some existing coal units to convert to biomass by 2020; that any coal CCS demonstrations would have CO₂ capture applied to all units rather than our previous assumption that just one unit would be fitted with capture equipment (and all others would burn coal unabated); more coal capacity to close or face limits on running hours in the face of the Industrial Emissions Directive; and that the impact of the carbon price underpin and a lower level of demand will limit market-pull towards coal generation. If coal generation does not fall significantly, power sector emissions will be much higher in 2020 than we have assumed in our updated assessment.
- **Nuclear.** The amount of assumed nuclear generation in 2020 has increased by 20% to 58 TWh, reflecting that several existing nuclear units that were scheduled to close before 2020 are now expected to receive lifetime extensions to operate into the 2020s. We assume that no new nuclear capacity begins generating until the early 2020s.
- **Renewables.** The amount of assumed generation from renewables remains similar to the previous estimate in our 2010 advice (i.e. around 120 TWh in 2020).
- **Emissions.** As a result, we have revised our estimate of power sector emissions to around 64 MtCO₂ in 2020 (compared to our previous estimate of 109 MtCO₂ in our 2010 advice). Average grid intensity is assumed to reduce 58% to 211 gCO₂/kWh in 2020 from current levels, compared to 323 gCO₂/kWh under our previous assumptions.
- **Path from 2020 to 2030.** Our scenario for power sector emissions in the 2020s reflects the latest evidence explored in scenarios developed for our May 2013 EMR report (*Next steps on Electricity Market Reform*) and new projections for electricity demand after uptake of abatement measures in the end-use sectors. Given new estimates of much lower power sector emissions in 2020, the pace of required emissions reductions during the 2020s to reach an average grid intensity of around 50 gCO₂/kWh in 2030 is less steep. This implies lower power sector emissions during the fourth carbon budget period (2023-27) than we previously assessed, but a similar 2030 end-point.
- **Demand.** Based on the latest energy projections from DECC and our updated assessment of abatement action in this report (i.e. uptake of energy efficiency, heat pumps and electric vehicles as set out in Chapters 3, 4 and 5), our scenario for electricity demand now has growth of 22% from 2020 to 2030, reaching 368 TWh, which is 13% lower than the estimate in our original 2010 advice.

- **Low-carbon capacity.** There are multiple possible scenarios to reach around 50 gCO₂/kWh in 2030 based on a portfolio of low-carbon technologies. These involve deployment through the 2020s of a significant nuclear programme (e.g. 8-16 GW of capacity), major commercialisation programmes for CCS and offshore wind and possibly significant contributions from other renewables (e.g. onshore wind, solar, marine technologies) depending on costs and deliverability.
- **Emissions.** If these scenarios for demand and capacity are delivered power sector emissions would be around 20 MtCO₂ in 2030.
- **The fourth budget period.** Our updated scenario has cumulative emissions during the fourth carbon budget period (2023-27) of 140 MtCO₂, roughly half the level we assumed in our original 2010 advice.
- **2030 objective.** Although our revised assessment implies that our scenario for the power sector now delivers emissions reductions well beyond what is required in the fourth budget period, it is still appropriate to deploy low-carbon capacity through the 2020s in preference to new fossil-fired plant. This is required to reach the same 2030 end-point, which will minimise costs in the face of expected rising carbon prices and develop technologies likely to be required in meeting the 2050 target.

We set out the analysis underpinning these conclusions in five sections:

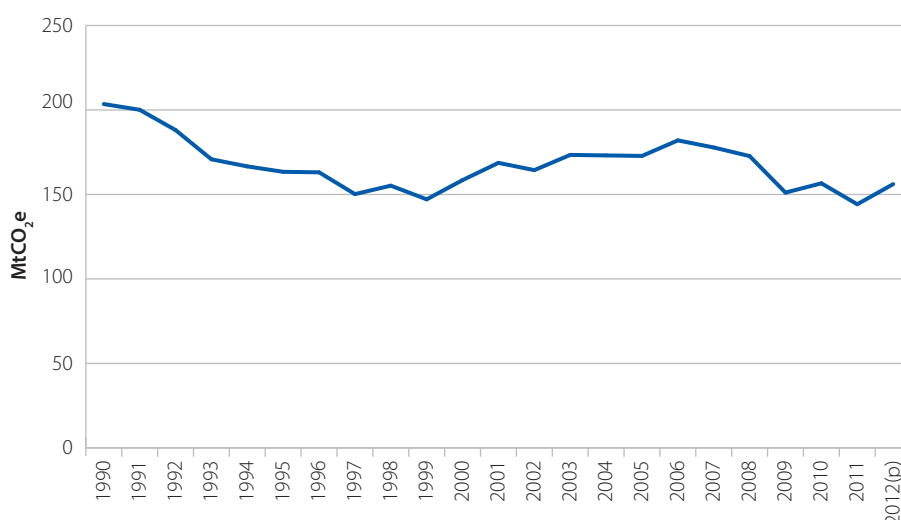
1. Current emissions from electricity generation
2. Latest projections for emissions before abatement action
3. Options for reducing emissions from electricity generation and associated costs
4. Projected emissions with abatement – an updated scenario for the 2020s
5. Benefits of early decarbonisation of the power sector

1. Current emissions from electricity generation

In 2012, power sector emissions in the UK were 156 MtCO₂, accounting for 27% of economy-wide emissions. Generation comprised 25% gas, 41% coal, 20% nuclear and 12% renewables. In 2011 (the latest year for which detailed data are available), gas and coal accounted for 35% and 63% of sector emissions respectively.

Emissions have fallen 23% overall since 1990, mainly as a result of the ‘dash for gas’ during the 1990s (Figure 2.1):

Figure 2.1: Power sector emissions (1990-2012)



Source: DECC (2013) *UK Greenhouse Gas Emissions 1990-2013*.

Notes: 2012 data are provisional.

- Emissions fell by 28% between 1990 and 1999 due to investment in new-gas fired capacity in the early 1990s which substituted for coal-fired generation (the ‘dash for gas’).
- Emissions increased by 24% between 1999 and 2006 due to an increase in demand and a slowdown in the substitution of coal-fired capacity with gas-fired capacity.
- Emissions decreased 21% between 2006 and 2011 due to the economic slowdown.
- In 2012 CO₂ emissions in the power sector increased 8% due to an increase of coal generation at the expense of gas, driven by low coal and carbon prices.

We noted in our 2013 Parliament report² that there is scope to significantly reduce power sector emissions within the existing stock of power stations based on analysis of achievable emissions intensity. Achievable emissions intensity is the carbon intensity of electricity supply that would be achievable if power plants were dispatched in order of least emissions rather than least cost, while still delivering security of supply. In practice this means meeting demand with nuclear and renewables first, followed by gas, and finally coal plant.

In 2012, achievable emission intensity continued to improve, falling by 28 gCO₂/kWh (9%) compared to 2011, from 311 gCO₂/kWh to 283 gCO₂/kWh (Figure 2.2). This reduction was due to renewables capacity added to the system in 2012, including 2.4 GW of wind and 0.7 GW of solar.

Over time as more low-carbon capacity is added to the system and old coal plant is retired or reduces its running hours, we expect the gap between actual and achievable emissions intensity to close, while the achievable emissions intensity should continue to fall.

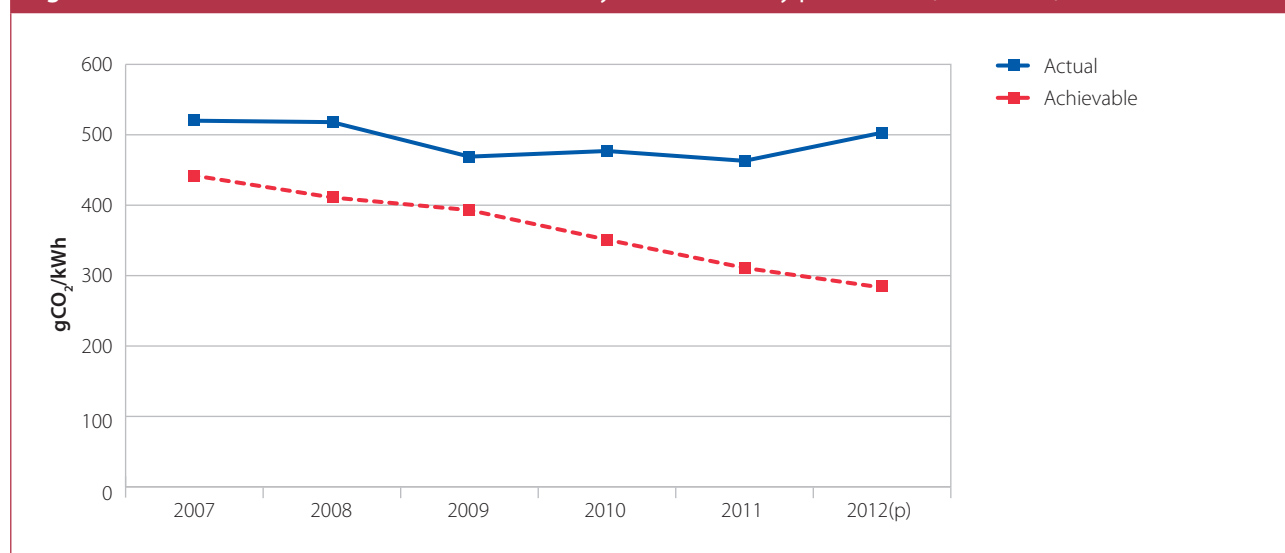
² CCC (June 2013) *Meeting Carbon Budgets – 2013 Progress Report to Parliament*.

We concluded in our original fourth carbon budget advice that decarbonising the power sector is key to economy-wide decarbonisation given that:

- Power is a major source of UK emissions.
- Low-carbon technologies are available for power generation which are or are likely to become cost-effective (i.e. cheaper than fossil fuel generation facing a rising carbon price – see Chapter 1 for our assumptions on carbon prices).
- Over the next two decades there will be significant capital stock turnover in the UK's power system as assets retire, creating an opportunity for early investment in low-carbon generation.
- Power can be used as a route to decarbonisation in other sectors (buildings, transport and industry).

We now consider the latest evidence on projected emissions and options to reduce power sector emissions, and then set out an updated scenario to 2030 in section 4.

Figure 2.2: Actual and achievable emissions intensity of UK electricity production (2007-2012)



Source: CCC calculations based on various sources including Defra GHG conversion factors; DECC (March 2013) *Energy Trends*; DECC (June 2012) *DUKES*.

Notes: Achievable emissions intensity is the minimum average emissions intensity that could be achieved in a year, given the installed capacity, demand and the demand profile of that demand. Emissions intensity is UK-based useable generation, i.e. adjusted for losses.

2. Latest projections for emissions before abatement action

Our starting point when building scenarios is to develop demand and emissions projections without any action to reduce emissions. To develop this 'baseline' for the power sector, we use baseline electricity demand and generation projections from DECC's energy model³. DECC electricity demand projections are based on assumptions of future economic growth, fossil fuel prices, electricity generation costs, population, and other key variables. Inevitably they also involve some judgement over how these will be reflected in new build of capacity and how capacity is run.

³ DECC (17 September 2013) *Updated energy and emissions projections*.

The baseline projections assume that requirements for new-build capacity are met by a mix of unabated coal- and gas-fired generation. They include some deployment of renewable technologies (e.g. wind, solar) through the 2010s and 2020s, but in insufficient levels to meet the UK's 2020 renewable energy target.

Since our original advice, projections for baseline electricity demand have been revised downwards, given slower expected growth in GDP. Electricity demand (excluding demand for autogeneration, which is met by on-site generation, rather than generation from the grid), before abatement measures to improve efficiency is now projected to increase 5% from 2010 to around 345 TWh in 2020 and to around 400 TWh in 2030 (both 3% lower than previously expected in our 2010 advice).

Our baseline scenario suggests that even with limited efforts to incentivise new low-carbon generation, power sector emissions could fall 16% between 2012 and 2030 to around 130 MtCO₂e. This largely reflects an assumed continuing shift from coal to gas-fired generation in the longer term.

However policies to which the Government have already committed will support investment in low-carbon generation to 2020 and therefore further reduce power sector emissions. These include the Renewables Obligation and contracts for difference offered under Electricity Market Reform, which to 2020 are aiming to deliver investment in new renewable capacity consistent with meeting the UK's target under the EU Renewable Energy Directive (i.e. to meet 15% of all energy through renewable sources). Furthermore, options exist to continue to decarbonise power generation through the 2020s. We now turn to these options.

3. Options for reducing emissions from electricity generation and associated costs

Options for reducing power sector emissions

As we have set out previously, there is scope for significant reduction in power sector emissions over the next two decades and beyond, through investment in a portfolio of low-carbon technologies which are or are likely to become cost-effective (i.e. cheaper than fossil fuel generation facing a carbon price). These technologies include nuclear energy, renewables (including onshore and offshore wind, solar and marine and biomass conversion), and carbon capture and storage (CCS).

In our advice on the fourth carbon budget (2010) we set out detailed technical and economic assessments of these low-carbon technologies. Since 2010, we have reassessed the costs and potential of deploying these technologies on a regular basis.⁴ These assessments have reinforced our previous conclusions that there are plausible scenarios where nuclear, renewables and CCS will be feasible and cost-effective within the next two decades provided effective policy is in place.

⁴ See for example CCC (May 2011) *The renewable energy review*; CCC (April 2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*; CCC (May 2013) *Next steps on Electricity Market Reform – securing the benefits of low-carbon investment*.

Previous and updated estimates of costs of abatement options

We recently commissioned Pöyry to assess the latest information on costs of low-carbon technologies for our May 2013 report *Next Steps on Electricity Market Reform – securing the benefits of low-carbon investment*.⁵ DECC has also reassessed electricity generation costs⁶ in developing its draft EMR Delivery Plan. Our new assessment of costs is largely consistent with the latest DECC views of generation costs. We summarise analysis of these technology costs and compare to previous assessments below (Figures 2.3, 2.4 and 2.5).

- **Nuclear.** We assumed a cost of around £85-100/MWh for delivering the first UK project, slightly higher than our 2010 assumptions, reflecting further delays in delivering European projects (Flamanville and Olkiluoto), although projects outside Europe have progressed to time and budget. We identified significant scope for costs to fall after the first plant (e.g. to £60-70/MWh by 2030), capturing domestic and international learning effects. The recently announced 'strike price' for the first nuclear project of £92.50/MWh is consistent with these assumptions, and the contract terms explicitly recognise the scope for costs to fall for future projects.
- **Onshore wind.** Our new estimates of the current and future costs of onshore wind remain unchanged from our 2010 assessment. Current costs are estimated up to around £100/MWh although there are significant differences in costs between individual projects due to different load factors, project size and connection costs. Potential cost reductions for onshore wind are limited as the technology is already mature, although there may be small gains in the cost of capital once new market arrangements are tested and proven to work.
- **Offshore wind.** Current costs for the majority of projects in the pipeline are estimated around £140-165/MWh. Offshore wind is at an earlier stage of development to onshore wind but offers significant scope for cost reduction. We assume costs fall close to £100/MWh by 2030, although others have suggested faster reductions are possible subject to certain conditions such as confidence about long-term development of the market, steady deployment over 2015-2025, and supply-chain competition to spur innovation.⁷
- **Carbon capture and storage (CCS).** Pöyry estimate costs for the first CCS projects of up to £180/MWh under central fuel prices, with gas projects estimated to be significantly cheaper than coal. These costs reflect the risky nature of successfully deploying a new technology at scale for the first time (i.e. high cost of capital and high capital expenditures). Our estimates of future costs of CCS are similar to our previous 2010 assessment, where costs could be reduced to around £100/MWh by the late 2020s assuming successful commercialisation of the technology, including measures to de-risk transport and storage infrastructure.
- **Biomass conversion.** We estimated the levelised costs of converting existing coal plants and running them with solid biomass fuels at around £80-90/MWh under central fuel price assumptions. However recent DECC estimates reflect more up-to-date data on biomass fuel prices, and estimate a higher cost of between £105-115/MWh for projects commissioning in 2014.

⁵ Pöyry (June 2013) *Technology Supply Curves for Low-Carbon Power Generation*, a report to the CCC.

⁶ DECC (July 2013) *Electricity Generation Costs*, <https://www.gov.uk/government/publications/decc-electricity-generation-costs-2013>

⁷ The Crown Estate (May 2012) *Offshore wind cost reduction pathways study*; Offshore Wind Cost Reduction Task Force Report (June 2012).

- **Solar.** Solar generation costs have fallen substantially since our 2010 advice reflecting reductions in the cost of solar panels (which have fallen by 50%⁸), with further cost reductions expected between now and 2020 reflecting further technological and supply-chain development. DECC estimates current costs for large-scale solar PV projects to range between £115-130/MWh with costs falling to £65-75/MWh by 2030.
- **Marine.** Both wave and tidal technologies are yet to be demonstrated commercially and currently operate on a very small scale (e.g. total capacity in 2012 was 6 MW). Given its early stage, it is unlikely to be cost-effective within the next two decades, but with commercialisation and rapid cost reductions it could play a significant role as part of a diverse mix in the longer term.

Since publishing our May 2013 EMR report, the Government announced the strike prices that will be offered for long-term contracts for renewable energy projects under the Electricity Market Reform.⁹

It is important to note that strike prices are not the same as levelised costs of generation.

- Contract strike prices need to cover generation costs as well as 'basis risk' discounts applied to the wholesale market price. For example, generators do not receive the full wholesale price when selling electricity to the market due to costs associated with managing the intermittency of wind output or risks of unplanned nuclear outages, along with more general transaction costs between power purchasers and generators. Strike prices therefore need to be higher than levelised costs in order to compensate for these discounts.
- Required strike prices will also depend on contract length: the shorter the contract length, the higher the price that would have to be paid under the contract, since expected returns outside the contract period are likely to be lower than those during the contract. The Government has taken a decision to offer shorter contract lengths (e.g. 15-year contracts for offshore wind projects when the technical lifetime of an offshore wind farm can be around 24 years).

Setting strike prices at the right level is important to ensure projects continue to come forward. In general, the Government's strike prices are broadly in line with our levelised cost estimates after making the necessary adjustments:

- Final strike prices for onshore wind are £95/MWh for projects commissioning in 2014/15 and reduce to £90/MWh for projects commissioning in 2018/19.
- Final strike prices for offshore wind begin at £155/MWh for projects commissioning in 2014/15 then fall to £140/MWh in 2018/19. These have been revised up from draft prices published in June, following advice from the Committee that the proposed degression was faster than implied by the evidence, albeit the revision was smaller than we suggested may be needed.

⁸ DECC (October 2013) *UK Solar PV Strategy Part 1: Roadmap to a Brighter Future*.

⁹ National Grid (July 2013), *EMR Analytical report*; DECC (December 2013) *Investing in renewable technologies – CfD contract terms and strike prices*.

The implication of our cost estimates is that nuclear and onshore wind are likely to have broadly comparable costs to new unabated gas-fired generation under projected carbon prices (which at around £50/tonne in 2025 implies a cost of gas generation of £80/MWh in that year, and an average of £100/MWh over a 15-year lifetime, given rising carbon prices). Investing in these technologies in preference to unabated gas can therefore offer a cost saving over plant lifetimes. Investment in other low-carbon technologies (e.g. offshore wind, CCS) is also desirable in preparing for the 2050 target where this can drive cost reduction and increase deployment potential for later years.

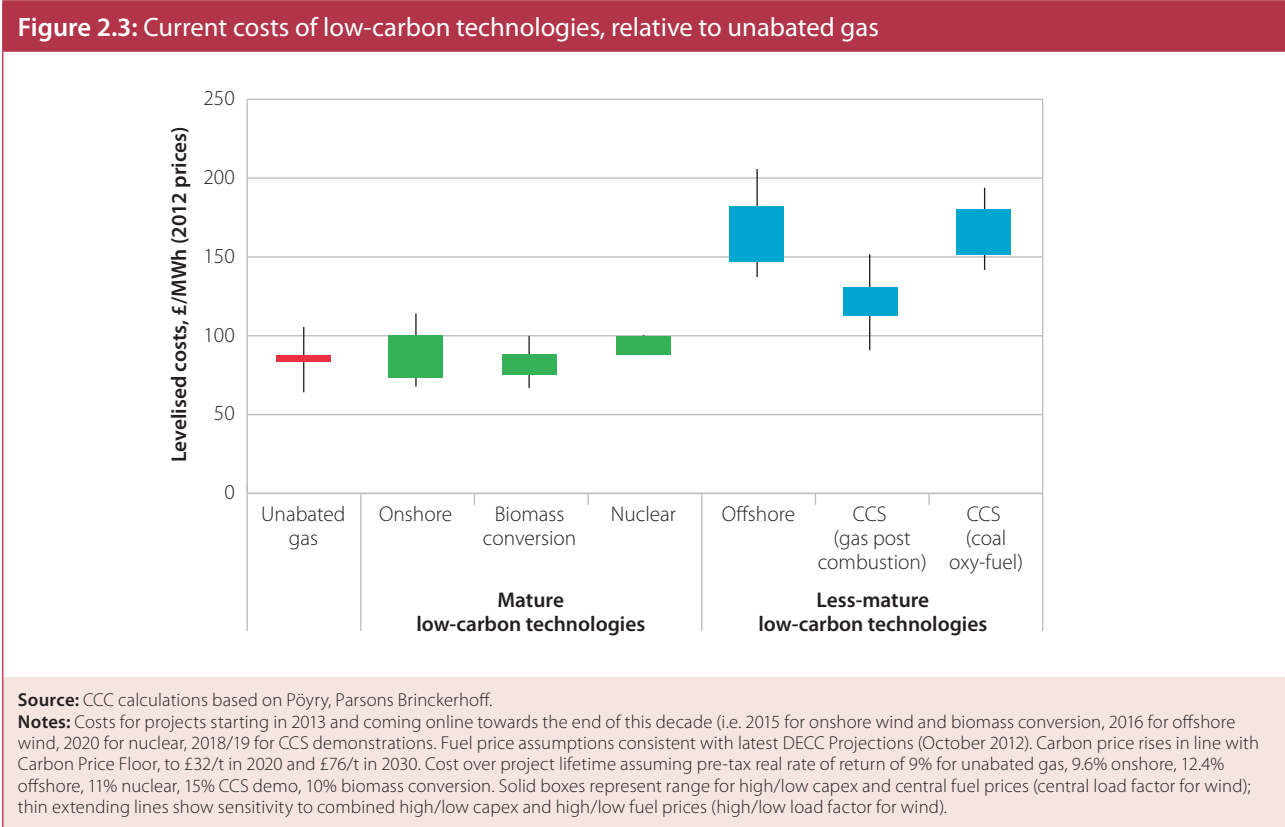
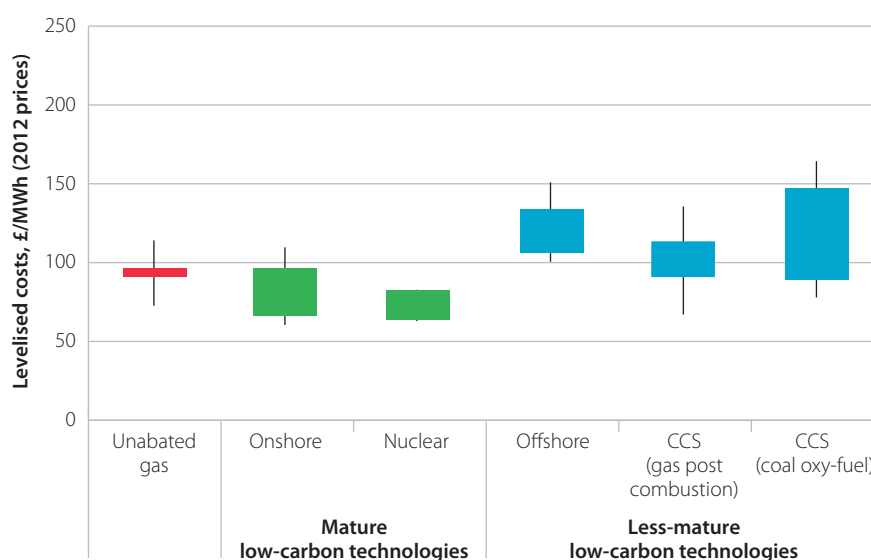


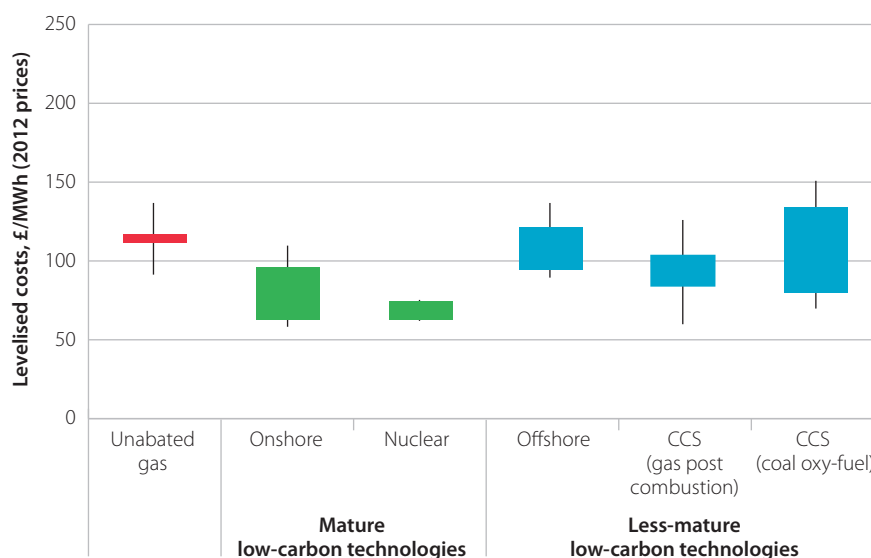
Figure 2.4: Projected costs of low-carbon technologies (2020), relative to unabated gas



Source: CCC calculations based on Pöyry, Parsons Brinckerhoff.

Notes: Costs for projects starting construction in 2020. Excludes biomass conversion which comes on in 2010s. Fuel price assumptions consistent with latest DECC Projections (October 2012). Carbon price rises in line with Carbon Price Floor, to £32/t in 2020 and £76/t in 2030. Beyond 2030 rises in line with Government 'central' carbon price values (£147/t in 2040 and £217/t in 2050). Cost over project lifetime assuming pre-tax real rate of return of 9% for unabated gas, 9.1% onshore, 9.1% offshore, 9.2-10.2% nuclear, 13% CCS. Solid boxes represent range for high/low capex and central fuel prices (central load factor for wind); thin extending lines show sensitivity to combined high/low capex and high/low fuel prices (high/low load factor for wind).

Figure 2.5: Projected costs of low-carbon technologies (2030), relative to unabated gas



Source: CCC calculations based on Pöyry, Parsons Brinckerhoff.

Notes: Costs for projects starting construction in 2030. Excludes biomass conversion which comes on in 2010s. Fuel price assumptions consistent with latest DECC Projections (October 2012). Carbon price rises in line with Carbon Price Floor, to £76/t in 2030; beyond 2030 rises in line with Government 'central' carbon price values (£147/t in 2040 and £217/t in 2050). Cost over project lifetime assuming pre-tax real rate of return of 9% for unabated gas, 9.1% onshore, 9.1% offshore, 9.2% nuclear, 10% CCS. Solid boxes represent range for high/low capex and central fuel prices (central load factor for wind); thin extending lines show sensitivity to combined high/low capex and high/low fuel prices (high/low load factor for wind).

Previous and updated estimates of potential uptake of abatement options

In our original 2010 advice on the fourth carbon budget we suggested the need for investment in 30-40 GW of low-carbon capacity (in baseload-equivalent terms)¹⁰ in the decade from 2020 to replace ageing capacity currently on the system and to meet demand growth.

Our updated analysis in our May 2013 EMR report suggests that there is potential to add up to 60 GW of low-carbon capacity in total over the next two decades, on a baseload-equivalent basis, compared to around 45 GW required to reduce carbon intensity to around 50 gCO₂/kWh. This suggests scope to achieve carbon-intensity of around 50 gCO₂/kWh through different combinations of nuclear, renewables and CCS.

There is currently a strong project pipeline for onshore and offshore wind and biomass conversion. Nuclear and CCS are at an earlier stage in the project cycle, but all have the potential to make a major contribution to 2030 decarbonisation.

- **Onshore wind.** Deployment is slightly ahead of the indicators against which we monitor when reporting to Parliament, and which reach 15 GW of installed capacity by 2020. New project proposals continue to be brought forward and planning approval rates have remained fairly steady. Given the 8 GW capacity already commissioned or in construction, the 4.4 GW already consented and the 8.8 GW awaiting planning consent and the continuing stream of new projects, Pöyry consider deployment of 25 GW total installed capacity to be achievable by 2030 (capable of generating around 60 TWh in an average year). However, in its draft EMR Delivery Plan the Government assume only 11 GW of capacity is deployed by 2020.
- **Offshore wind.** At the end of 2012, there were 3 GW of offshore wind installed and operating in UK waters. The Crown Estate has granted leases for a total of around 47 GW of capacity. Availability of sites is therefore unlikely to be a constraint on deployment for the foreseeable future, although supply chain capacity and availability of finance could limit roll-out, as could developer interest more generally. Based on an assessment of existing and potential future projects, Pöyry estimate that 25 GW total installed capacity could be delivered by 2030, and 40 GW or more would be possible with sufficient funding to incentivise a further ramp-up of the supply chain.
- **Biomass conversion.** Several existing coal plants could potentially convert to run on woody biomass instead of coal. We estimated in our 2011 Bioenergy Review that potential generation from converted coal plants could be more than enough to meet the Government's ambition for biomass power generation (i.e. at that time 32-50 TWh/year in 2020, equivalent to 4-6 GW capacity, and further revised down in the scenarios in the draft Delivery Plan). As we have previously recommended, investment should be subject to stringent sustainability standards, otherwise emissions reductions may not follow.

¹⁰ We adjust the capacity of intermittent technologies to a baseload-equivalent basis to account for the fact that they do not generate at their full rated capacity throughout the year. For example, assuming a non-intermittent plant is available to generate for 90% of the year, and offshore wind generates the equivalent of 42% of its full-rated capacity over the year, 1 GW of offshore wind is equivalent to $(42\%/90\%) \times 1 \text{ GW} = 0.47 \text{ GW}$ of baseload-equivalent capacity.

-
- **Nuclear.** The Government has announced strike prices for EDF to develop the first new nuclear plant at Hinkley. The Horizon venture was acquired by Hitachi in November 2012, and has announced plans to build four to five 1.3 GW advanced boiling water reactors by 2030. The NuGen consortium also maintains an interest in nuclear development. The existing sites owned by these three consortia and approved for new nuclear development under the National Policy Statement of July 2011 could accommodate 21-25 GW of new nuclear projects. Pöyry identified existing plans for 16 GW as being more realistic by 2030, with potential to reach deployment of over 20 GW if new developers enter the market (e.g. once the CfD regime has been established).
 - **Carbon capture and storage (CCS).** The Government announced in March 2013 that it had selected two preferred bidders to be supported under its CCS Commercialisation Programme: a gas post-combustion project at Peterhead and a coal oxy-fuel project at Drax. The next step for these projects is to proceed with detailed Front End Engineering Design studies, with a view to take final investment decisions by early 2015. Two projects remain in reserve and several other projects have been put forward for the DECC programme and/or EU funding, some of which may be viable in future, while new projects may also emerge. Pöyry suggest the need for a second phase of pre-commercial deployment before commercial plants can be rolled out in the late 2020s. This could give a total of around 10 GW of capacity by 2030.

Given the above assessments, we have recommended that a portfolio approach be adopted under which each of the technologies above is developed possibly supplemented by other technologies like solar and marine. This is appropriate given the scale of challenge in decarbonising the power sector, cost uncertainties, scope for reducing costs of less-mature technologies, and the potential constraints or risks around the deployment of individual technologies. It is reflected in the Government's approach, under which tailored support is or will be available for less-mature low-carbon technologies under the Electricity Market Reform.

Barriers to deploying low-carbon generation in the 2020s

Key barriers to deploying low-carbon generation include regulatory and political uncertainty impacting the investment conditions and the availability of finance.

Investor uncertainties

In our original fourth carbon budget assessment we advised that current market arrangements were unlikely to deliver required investments in low-carbon generation and that tendering long-term contracts would reduce risks which energy companies are not well placed to manage and would provide confidence that required investments will be forthcoming at least cost to consumer.

Since then, the Government has introduced Electricity Market Reform (EMR) to support the transition to a low-carbon power sector, which includes provision of long-term contracts to developers/generators to provide revenue certainty for low-carbon projects. The Government has recently published final strike prices for various low-carbon technologies as well as contract terms, and has established a Levy Control Framework to control subsidy costs.

The EMR should work to support portfolio investment in low-carbon technologies and supply-chain investment, thereby ensuring early decarbonisation of the power sector. Remaining challenges include ensuring that strike prices have been set at the right level and providing confidence to investors that there will be sufficient and ongoing volume to 2020 and beyond.

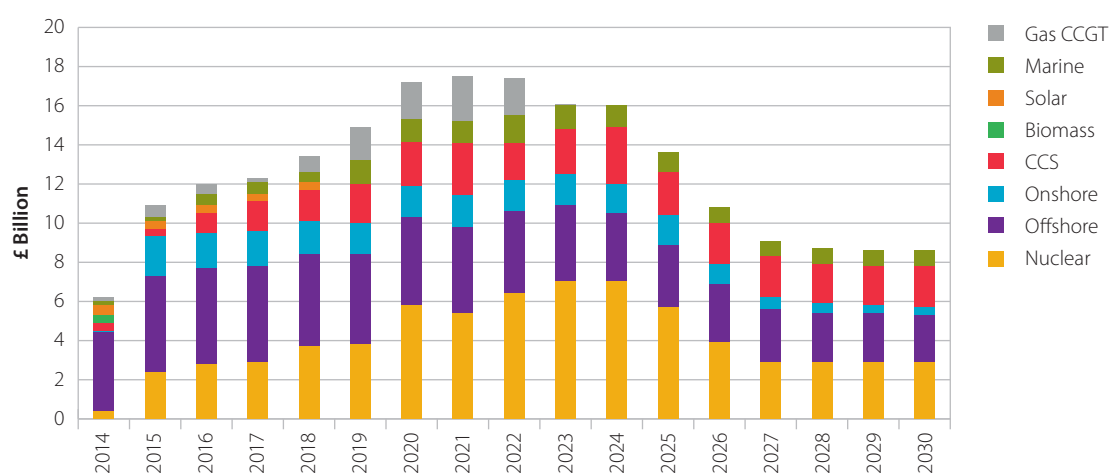
Possible barriers to finance

We have also looked further into the infrastructure and financing challenge to deploying low-carbon generation over the next two decades.

While over the past years capacity has ramped up quickly under support from the Renewables Obligation (renewables capacity has doubled from around 6 to 12 GW over the past 5 years)¹¹, there is the question as to whether these deployment rates can be sustained. Renewables deployment will need to continue, while at the same time significant capital expenditures on nuclear and CCS projects will be required.

We estimate that the total capital costs of scenarios reaching around 50gCO₂/kWh by 2030 could be up to £200 billion between 2014 and 2030 (Figure 2.6).

Figure 2.6: Capital expenditure on low-carbon technologies in CCC 'Higher Energy Efficiency' scenario reaching 50gCO₂/kWh by 2030



Source: CCC calculations based on Poyry (2013) and Redpoint (2013) modelling.

Notes: One of several scenarios developed for CCC May 2013 EMR report. Figures are in £2012 prices.

¹¹ DUKES (2013) Chapter 6 – Renewables sources of energy.

We have not undertaken a detailed analysis of all possible sources of finance or of current capital market conditions. However, it is clear that a substantial increase in finance is required, and that a challenge exists in delivering this, particularly around risky projects (e.g. offshore wind and CCS). The Government can and has started to address this challenge (e.g. through establishment of the Green Investment Bank) and will have to keep this under review (Box 2.1).

Box 2.1: Building low-carbon power capacity – potential sources of finance

Low-carbon technologies require a very large amount of up-front investment and the balance sheet strength of energy companies to finance new projects may be limited. Furthermore, many projects are perceived as risky (e.g. offshore wind and CCS) and therefore the appetite from banks and institutional investors for project finance is unclear. Traditional and potential new sources of finance for low-carbon deployment are summarised below:

- **Balance sheet capital.** To date, investments in relatively high-risk low-carbon technologies (i.e. offshore wind) have typically been financed using the balance sheets of energy companies to secure debt. However this current source of finance available to developers may be insufficient to deliver the increased levels of investment required for these technologies:
 - Balance sheets may not be sufficiently strong to support the level of investment required going forward because: many energy company assets are largely depreciated, existing assets are of low capital intensity compared to low-carbon technologies, energy companies operate in many markets where investment requirements are often also high, over-exposure could negatively affect credit ratings.
 - Banks have become less willing to provide long-term capital and have moved to shorter-term lending.
- **Project finance.** Investment might proceed using project finance – where debt is secured against future project cash flows. However appetite from banks to provide project finance during the early stages of projects where risks are high is unclear, and likely to be harder to secure until new market arrangements are proven.
- **Institutional investors.** These include non-commercial banks, pension funds, insurance companies and asset management funds that are willing to provide long-term loans where commercial banks are not. Currently the share of institutional investors in the UK offshore wind market is less than 5%, suggesting that these investors do not necessarily have the skills to assess project risk or are unwilling to fund projects based on an assessment of risk/reward. The introduction of EMR may encourage further investment from institutional investors.

The risk is that a funding gap becomes a binding constraint on the level of investment in low-carbon technologies.

Since publishing our 2010 advice, the Government has set up the Green Investment Bank (GIB) to provide financial solutions to accelerating private sector investment in the green economy, including bridging the gap left by the financial crisis, to drive innovation and to advise Government on the finance impacts of their policy. One of the GIB's key areas of focus is offshore wind and it is working towards addressing bottlenecks in financing initial construction and refinancing projects once operational:

- **Leveraging finance.** The GIB has been capitalised with £3.8 billion and since inception, has committed more than £700 million and mobilised a further £2 billion for construction through the backing of 21 projects.
- **Capital recycling.** Initial investment in the risky construction phase of a project is difficult for developers to secure from elsewhere and so this is usually funded on balance sheet by the utility companies. When the project is operational, the risk falls substantially and utilities are able to sell parts of their assets to commercial banks and institutional investors, freeing up cash to invest in new projects. If this cycle continues, capital can be recycled through many projects. Without the perceived option to refinance once operational, developers may not take on new projects. The GIB is aiming to help develop secondary markets for buying shares in operational projects.

4. Projected emissions with abatement – an updated scenario for the 2020s

In our advice on the fourth carbon budget we developed an emissions scenario involving measures that were likely to be economically sensible in a carbon-constrained world – measures that are important on the path to the 2050 target and that are cost-effective compared to expected carbon prices over investment lifetimes. This was our best estimate of the cost-effective path to the 2050 target and formed the basis for the fourth carbon budget.

This scenario included investment in around 20 GW of (baseload-equivalent) low-carbon capacity to 2020, with an additional 35 GW to 2030, which we identified as feasible based on an assessment of build constraints. We expected this scenario to reduce sector emissions to around 16 MtCO₂ in 2030 with an average grid intensity of around 50 gCO₂/kWh in 2030.

We now develop a new power sector scenario based on the latest evidence as set out above.

Outlook to 2020

The starting point for our scenario is a projection for emissions in 2020. We have projected emissions in 2020 on the basis of the Government's latest view in its draft EMR Delivery Plan, which reflects latest projections for electricity demand and funding commitment in the Levy Control Framework for investment in low-carbon generation to 2020.

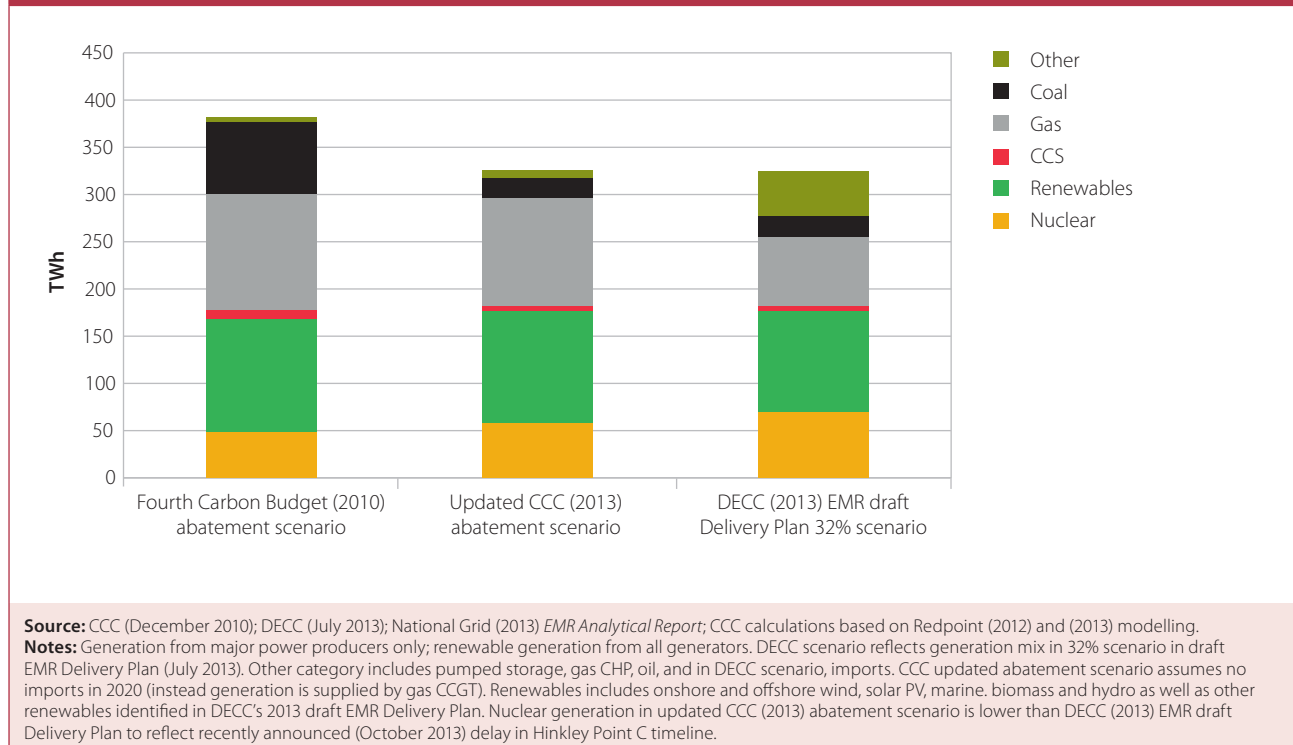
Power sector emissions are now projected to decrease substantially more rapidly to 2020 compared to assumptions in our advice in 2010. This is partly due to revised demand projections but mainly due to new assumptions for coal-fired and nuclear generation (Figure 2.7):

- Electricity demand after reflecting our updated assessment of uptake of abatement measures (e.g. energy efficiency in buildings) is now forecast to fall by around 10% relative to 2010, to be around 300 TWh in 2020, or 7% lower than projected in our 2010 advice.
- The assumed amount of unabated coal-fired generation in 2020 has been reduced by 72% to 21 TWh. This reflects new assumptions regarding: the conversion of existing coal units to biomass, that any coal CCS demonstrations would have CO₂ capture applied to all units rather than our previous assumption that just one unit would be fitted with capture equipment (and all others would burn coal unabated), the impact of the Industrial Emissions Directive, and the impact of the carbon price underpin. We note that projections for power sector emissions reduction to 2020 are highly sensitive to these new coal assumptions. If coal generation does not fall significantly, then power sector emissions will be much higher in 2020 than we have assumed in our updated assessment.
- The amount of nuclear on the system to 2020 has been revised upwards due to plant lifetime extensions. Whereas previously we assumed closure of around 3.5 GW of nuclear capacity by 2020 we now assume that these plants will receive an average lifetime extension of at least five years in line with public announcements. We assume that no new nuclear capacity is built until the early 2020s. Given lifetime extensions, the assumed amount of nuclear generation in 2020 has increased by 20% to 58 TWh from our 2010 assessment.

- The amount of renewables generation in 2020 is assumed to be similar to our previous assessment in our 2010 advice (around 120 TWh).
- Our new scenario for power sector emissions in 2020 includes 13 GW of onshore wind, 11 GW of offshore wind, 9.5 GW of existing nuclear capacity, 0.6 GW of demonstration CCS (gas and coal), and 33 GW and 13.5 GW respectively of unabated gas- and coal-fired capacity. This reflects the Government's latest views on 2020 investment in its draft EMR Delivery Plan. We have adjusted the deployment of nuclear capacity to reflect the delayed timeline for Hinkley (announced in October 2013) and adjusted investment upwards in onshore and offshore wind within the limits of the Levy Control Framework¹² to be closer to the feasible deployment set out in our progress report indicators.
- Total generation in 2020 is projected to be 326 TWh, or 14% lower than the level we assumed in our 2010 advice. This reflects lower demand projections, with nuclear generating 58 TWh, renewables 119 TWh, coal 21 TWh and gas 114 TWh (Figure 2.7).

As a result, we have revised our estimate of power sector emissions to around 64 MtCO₂ in 2020 (compared to our previous estimate of 109 MtCO₂ in our 2010 advice), with average grid intensity falling rapidly between now (around 500 gCO₂/kWh) and 2020 to around 210 gCO₂/kWh, compared to 323 gCO₂/kWh in 2020 under our previous assumptions. Our new estimate of power sector emissions implies a 60% reduction on current emissions.

Figure 2.7: Scenarios for UK power generation in 2020



¹² The levy control framework put a limit on the total spending to cover the following policies: the Renewables obligation (RO), Feed-in Tariffs (FiTs) Warm Home Discount, and Contracts for Difference (CfDs).

The path from 2020 to 2030

Scenarios developed for advice on Electricity Market Reform (May 2013)

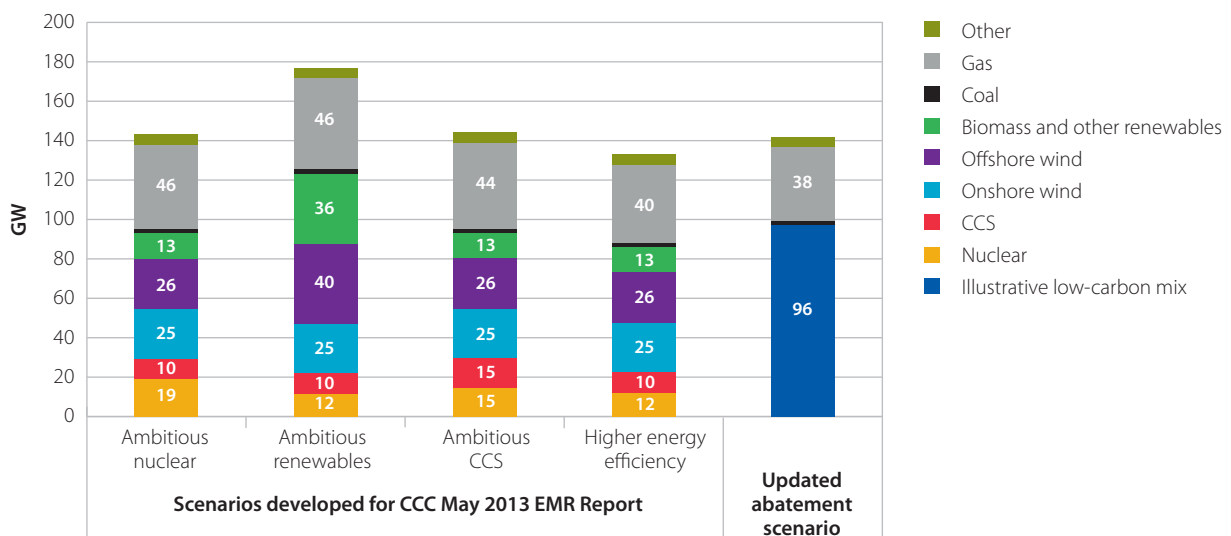
Since our original 2010 advice, we have looked further into technology mixes that could allow the power sector to largely decarbonise to an average grid intensity of around 50 gCO₂/kWh by 2030 in the most economically efficient path. Specifically, in our May 2013 report, *Next steps on Electricity Market Reform*, we developed four scenarios with differing emphasis on the four key options for decarbonisation (i.e. nuclear, renewables, CCS and energy efficiency). These scenarios:

- Allow for flexibility for one technology to substitute for another. For example while the scenario in our advice on the fourth carbon budget was more nuclear-focused, these scenarios explore the potential of going further with CCS if the technology develops more quickly and favourably; with renewables if offshore wind costs fall towards the lower end of our range; with nuclear if sufficient capital and developer interest is available; or demand reduction if cost-effective opportunities can be found and delivered.
- Include a minimum roll-out of less-mature technologies – with around 25 GW offshore wind and 10 GW of CCS installed by 2030 (Figure 2.8). This is intended to develop a portfolio of options for ongoing provision of low-carbon electricity after 2030 and create flexibility to response to changing costs.
- Involve limited roll-out of other renewables (e.g. marine technologies, solar) given currently high costs. However these options may be viable and could provide alternatives should the others deliver less.
- Involve a significant increase in deployment of flexibility options in order to limit costs and maintain system security. Sources of flexibility include:
 - **Demand-side response.** Active management of demand (e.g. charging electric vehicles or running washing machines overnight when other demand is low) can help smooth the profile of demand and reduce the requirement for capacity during peak periods. Widespread deployment and use of smart technologies (such as smart meters) will facilitate increases in demand-side response given sufficient consumer engagement.
 - **Interconnection.** Interconnection already provides a valuable source of flexibility to the UK, with around 4 GW of capacity with Ireland, France and the Netherlands. Flows are price-driven according to relative demand and supply, and to the extent that these differ across countries, will continue to be an important source of flexibility.
 - **Storage.** Bulk storage, such as pumped storage, can be used both to provide fast response and to help provide flexibility over several days (providing supply at times of peak daily demand rather than continuously over the whole period). Other storage options could emerge in the future.

- **Flexible generation.** Gas-fired capacity offers the potential to meet demand when output from intermittent technologies is low, and can be operated reasonably flexibly. There may also be some scope for using low-carbon capacity flexibly – for example scheduling maintenance outages for summer when demand is low, or running CCS at slightly reduced load factors.

The scenarios therefore reduce CO₂ emissions and generation costs while maintaining system security.

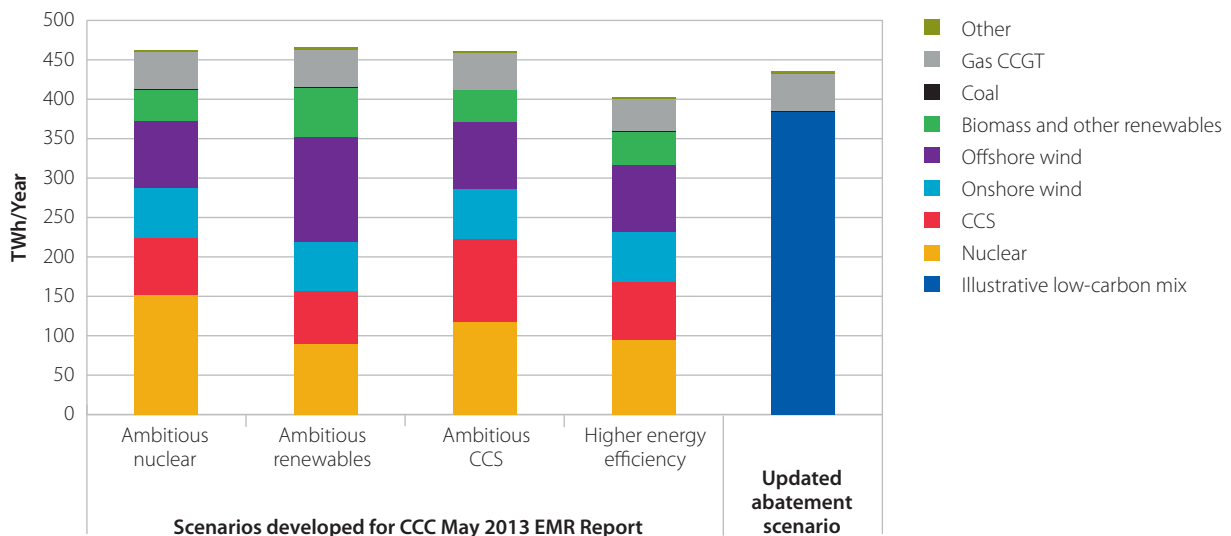
Figure 2.8: Power sector scenarios reaching 50gCO₂/kWh by 2030 – capacity (GW)



Source: CCC (April 2013) *Next steps on Electricity Market Reform*; CCC calculations based on Redpoint modelling (2012 and 2013).

Notes: Other includes Pumped Storage and Gas CHP. Other renewables includes solar PV, marine and hydro. Excludes autogeneration consumed onsite. CCGT: Combined Cycle Gas Turbine. All the scenario data are presented at UK level, including an adjustment to add Northern Ireland to the GB-level outputs of the Redpoint modelling.

Figure 2.9: Power sector scenarios reaching 50gCO₂/kWh by 2030 – generation (TWh/year)



Source: CCC (May 2013) *Next steps on Electricity Market Reform*; CCC calculations based on Redpoint modelling (2012 and 2013).

Notes: Other includes Pumped Storage and Gas CHP. Other renewables includes solar PV, marine and hydro. Excludes autogeneration consumed onsite. CCGT: Combined Cycle Gas Turbine. All the scenario data are presented at UK level, including an adjustment to add Northern Ireland to the GB-level outputs of the Redpoint modelling.

Updated scenario for fourth carbon budget review advice

We have revisited our scenario for the 2020s based on the analysis in our May 2013 EMR report, the Government's latest views on the entry point for power sector emissions in 2020, and our latest views of electricity demand after abatement in other sectors or uptake of energy efficiency measures, heat pumps and electric vehicles (see chapters 3, 4, and 5). We have assumed, as before, that the power sector reaches an average grid intensity of around 50 gCO₂/kWh by 2030. This reflects that our reassessment of the latest evidence on costs and feasibility of deploying key low-carbon technologies implies that this continues to be an achievable and desirable goal, offering significant cost saving relative to delayed decarbonisation.

- **Demand projections from existing sectors.** The DECC energy model projects electricity demand (excluding autogeneration) of 398 TWh in 2030, or 3% lower than we assumed in our 2010 advice.
- **Demand projections from new sectors.** We have reassessed uptake of abatement measures in other key emitting sectors (buildings, heat and transport) and the impact on electricity demand. The combination of energy efficiency improvements in lights and appliances, heat pumps in buildings and industry, and electric vehicles in transport (see Chapters 3-5), reduces electricity demand in 2030 by 8% versus the DECC projection, to 368 TWh. Overall, our projection for demand after abatement is 13% lower than the level we assumed in our original 2010 advice.
- **2020 entry point.** Given the new lower projection for power sector emissions in 2020 (see above), the pace of emission reductions required to reach a 50 gCO₂/kWh grid intensity by 2030 is less steep than in our original 2010 advice.
- **2030 capacity.** It is not possible or necessary to predict the precise mix of low-carbon technologies, with different mixes potentially appropriate depending on how costs and deliverability develop. It is important however that any mix involves a portfolio of low-carbon technologies, including not just those with the lowest cost (e.g. nuclear and onshore wind in our central assumptions), but also emerging technologies with scope to drive down costs through deployment and with large potential beyond 2030 (e.g. offshore wind and CCS). For our updated abatement scenario we assume an illustrative mix in line with our May 2013 scenarios: up to 17 GW of nuclear (of which 8-16 GW is new capacity added during the 2020s), 15-25 GW of onshore wind, at least 25 GW of offshore wind and 5-15 GW of CCS in 2030 (Figure 2.8 and 2.9). This appears to be feasible based on current project pipelines and developer plans, assumptions for cost reduction and technological development, and the scenarios in the Government's draft EMR Delivery Plan.
- **Security of supply requirements.** Our new power sector scenario has been designed to meet DECC's recently proposed reliability standard for the Great Britain electricity market, which targets a loss-of-load expectation of no more than three hours per year.¹³ This represents the number of hours per year in which, over the long term, it is statistically expected that supply will not meet demand.

¹³ DECC (July 2013) *Draft EMR Delivery Plan – Annex C: Reliability Standard Methodology*.

This updated abatement scenario results in emissions intensity in 2030 of 50 gCO₂/kWh and emissions of 21 MtCO₂, an 87% reduction on 2012 and similar to our previous estimate (Figure 2.10 and 2.11).

Cumulative power sector emissions over the fourth carbon budget are estimated to be 140 MtCO₂, or half the level we estimated in our original 2010 fourth carbon budget advice (280 MtCO₂) (Figure 2.11).

Although our revised assessment implies that our scenario for the power sector now delivers emissions reductions well beyond that required in the fourth budget period, it is still appropriate to deploy low-carbon capacity through the 2020s in preference to new fossil-fired plant. This is required to reach the same 2030 end-point and will minimise costs in the face of expected rising carbon prices (e.g. as in the Government's carbon price underpin) and develop technologies likely to be required in meeting the 2050 target at least cost.

Foregoing cost-effective investment in the 2020s could increase costs and require unachievable build requirements after 2030 in order to meet the 2050 target, particularly given the limited range of low-carbon options implied under such an approach.

Figure 2.10: Emissions intensity of electricity (2010-2030)

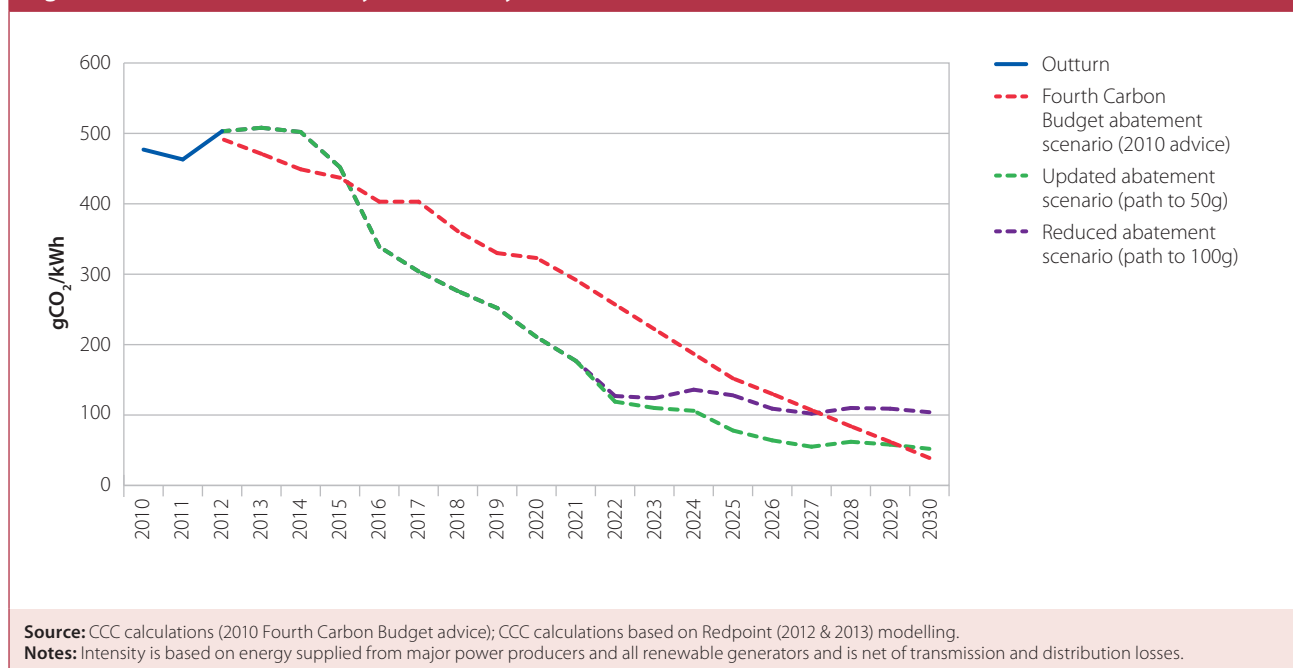


Figure 2.11: Scenarios for UK power sector emissions (2010-2030)



Source: CCC calculations (2010 Fourth Carbon Budget advice); CCC calculations based on Redpoint (2012 & 2013) modelling.

Notes: Redpoint modelling adjusted to assume no imports into UK between 2014-2023 and instead demand is assumed to be met with additional gas CCGT generation; modelling suggests UK will be a net exporter of power generation between 2024 and 2030.

Sensitivities and flexibilities

The scenarios above are an appropriate basis for policy under the current best evidence regarding costs and feasible investment rates. However, conditions for decarbonisation could be less favourable, making a 50g scenario undesirable or unachievable. This could be because, for example: nuclear costs do not come down, or developers are not able to finance projects; CCS does not progress as an effective decarbonisation technology; costs of offshore wind do not fall with deployment; and/or further demand reduction cannot be delivered. In the nearer term, there is a risk that coal-fired capacity stays on the system longer than our current assumption. Finally, low gas and/or carbon prices could make unabated gas generation relatively more attractive.

We have captured some of these uncertainties by modelling scenarios that results in an average carbon intensity of around 100 gCO₂/kWh in 2030, with emissions of around 42 MtCO₂ (Figures 2.10 and 2.11). A 100g scenario could still prepare sufficiently for the 2050 target, provided it sufficiently develops emerging options, and would still enable meeting of the fourth carbon budget through UK emissions reductions:

- A 100g scenario would need faster roll-out after 2030 to achieve the same levels of decarbonisation by 2050 (e.g. an extra 0.5 GW each year on average compared to a 50g scenario). This is likely to be achievable provided that the full set of options is available, and specifically provided that the programme in the 2020s has sufficiently developed the less-mature technologies (e.g. CCS and offshore wind). For example, a 100g scenario with high nuclear deployment but low investment in CCS and offshore wind during the 2020s would leave the UK overly reliant on a single low-carbon technology. This would imply unacceptable costs and risks of achieving the 2050 target and/or of very high electricity prices required to deploy uncommercialised low-carbon options at scale after 2030.

- Power sector emissions during the fourth carbon budget would be higher by on average around 13 MtCO₂ per year in these scenarios compared to the 50g scenarios. At 205 MtCO₂ across the fourth budget period, power sector emissions would still be lower than in our original fourth budget scenario, given the lower emissions from coal that we now expect through the 2020s.

It will therefore be important to monitor the relevant factors (e.g. costs and deliverability) and retain flexibility in policy to respond. For example, it will be important that the 2030 target for power sector decarbonisation due to be set in 2016 under the EMR sufficiently recognises these uncertainties.

5. Benefits of early decarbonisation of the power sector

In our May 2013 EMR report¹⁴, we compared the costs of UK portfolio investment in low-carbon technologies through the 2020s with the alternative of a strategy focused on gas investment in the 2020s followed by a ramping up of investment in low-carbon technologies in the 2030s, as required to meet the 2050 target. This delayed strategy could result in an average emissions intensity of close to 200 gCO₂/kWh in 2030. Our analysis has suggested that earlier investment – through the 2020s – is cheaper or is required to prepare for meeting the 2050 target. A delay in investment would therefore increase costs.

We quantified the cost for such a delay:

- **Early versus delayed investment in mature low-carbon technologies.**
 - Investment in nuclear rather than gas-fired power generation through the 2020s would result in a present value benefit of £23 billion across project lifetimes under DECC central case assumptions for fossil fuel and carbon prices¹⁵. This is due to the rising carbon price through the 2020s and beyond. The analysis suggested significantly higher benefits under high gas and/or carbon prices (£40 billion in DECC's 'high' gas price scenario, rising by a further £20 billion if carbon prices are also high). Costs of investment in nuclear and gas-fired generation would be broadly comparable (i.e. the net present value would be close to zero) under DECC's extreme scenario for low gas prices, or if carbon prices were at half the current levels (i.e. well below the planned floor price, at £38/tCO₂ in 2030).
 - Investment in 10 GW of onshore wind capacity – generating equivalent to around 3 GW of baseload capacity – could result in benefits of the order £2-3 billion under central case assumptions.
- **Early versus delayed investment in less-mature low-carbon technologies (offshore wind and CCS).**

¹⁴ CCC (May 2013), *Next steps on electricity market reform – securing the benefits of low-carbon investment*, available at www.theccc.org.uk.

¹⁵ DECC's carbon appraisal values have central levels of £216/tonne in 2050 (2012 prices) with low and high values 50% below and above the central levels; DECC's central gas prices scenario anticipates an increase in gas prices to 74p/therm in 2020 and then remains constant to that level in 2030 (with a range between 42-105p/therm); see Chapter 1.

- We calculate a net present value of up to £40 billion under central cost assumptions of investment in offshore wind and CCS. The benefit would be small (i.e. net present value close to zero) if the long-term requirement for less-mature technologies is low, but would reach £40 billion where there is a high need for less-mature technologies, reflecting limits to deployment of mature technologies and/or a very high level of electricity demand in 2050. In a case where nuclear is available but limited to existing sites the net present value would be around £20 billion under central assumptions.
- There would be significantly higher savings (e.g. up to £70 billion) if gas and carbon prices are high. Under low gas or carbon price assumptions, net costs of investment in offshore wind and CCS (i.e. a negative net present value) could be at most £15 billion, and only where the long-term need for these technologies turns out to be low.

We therefore concluded that investment in mature low-carbon technologies and in less-mature low-carbon technologies (as part of an early commercialisation programme) rather than investment in gas-fired generation in the 2020s is a low-regrets option with potentially significant benefits in a carbon-constrained world.

The combined benefit of investment in mature and less-mature technologies through the 2020s is therefore around £25-45 billion under central gas and carbon price assumptions, rising to over £100 billion in scenarios with higher gas and carbon prices, and limited downside risk in a carbon-constrained world.

There are also significant additional benefits from avoiding delay in this portfolio investment:

- **Spillovers.** CCS is a crucial technology for broader decarbonisation; developing CCS therefore has major spillovers for other sectors (e.g. use of CCS in industry and as a route to negative emissions in combination with bioenergy are key options for meeting the 2050 target; see Box 1.7 in Chapter 1). CCS is also likely to be a key abatement option globally, with significant spillovers to international action to reduce emissions from the UK contribution to commercialisation.
- **Flexibility.** Earlier deployment of low-carbon power technologies gives more time to respond to difficulties and develop other decarbonisation options should they be needed (e.g. if CCS is unsuccessful, then more focus can be put on developing offshore wind and electrifying processes in industry).
- **Economics benefits.** Preparing to invest in a low-carbon portfolio in the 2020s will put the UK amongst the early movers on decarbonisation and continue investment programmes currently underway. That may allow the UK to gain an industrial advantage in supply chains for low-carbon technologies, which may bring economic benefits given expected ongoing domestic and international markets for these technologies, and could contribute to objectives to increase employment in manufacturing industries.

-
- **Import dependency.** Investing in a portfolio of low-carbon technologies would enhance the UK's energy sovereignty. It would also reduce exposure to volatility in fossil fuel prices, and the associated risk of damaging economic impacts.

Given potentially significant benefits and low regrets, investment in a portfolio of low-carbon technologies is a sensible strategy to commit to in a carbon-constrained world. Such a commitment would help to improve conditions for investment and bring forward investments in low-carbon technologies and associated benefits.

Delivering this investment and the associated benefits will require strong policies. The Government has recognised this in introducing long-term contracts for low-carbon capacity under EMR. Ensuring success in this will require sufficient visibility for investors (e.g. through setting a carbon-intensity target in 2016 for 2030 and developing commercialisation strategies for offshore wind and CCS). It will also require that barriers to delivery, such as finance and infrastructure, are tackled.

We will return to consider policy success through the first budget period in our 2014 progress report to Parliament and draw out any lessons for the future.

Chapter 3: Reducing emissions from buildings

Introduction and key messages

In 2012, direct buildings emissions (mainly from the use of gas for heating) accounted for 37% of UK greenhouse gas emissions (91 MtCO₂). Buildings also were responsible for 67% of electricity consumption and related (i.e. indirect) emissions.

In our 2010 advice on the fourth carbon budget, we suggested that the cost-effective path to the 2050 target involved direct emission reductions in buildings of 36% by 2025 and 53% by 2030 from 2007 levels. Measures to achieve these reductions included increased home insulation (in particular solid wall insulation), widespread deployment of heat pumps in both residential and non-residential sectors, as well as bioenergy and district heating from low-carbon sources. In addition, we identified significant potential for reducing electricity consumption (and hence indirect emissions) through more efficient appliances and lighting. Most of these measures were cost-effective compared to our carbon price assumptions, with some less immediately cost-effective measures required to prepare for meeting the statutory 2050 target.

In this chapter, we set out new evidence on buildings emissions and abatement options. We then update our assessment of what is feasible and desirable over the next two decades. Changes in the evidence base include: new data on the performance of insulation measures, revised estimates of uptake of a range of energy efficiency measures, new research on barriers to heat pump uptake, new evidence on the feasibility of district heating, as well as updated emissions projections from DECC.

Our updated analysis suggests a lower emissions reduction on the cost-effective path than our 2010 advice (28% by 2025 and 35% by 2030).

- Carbon savings from some home energy efficiency options, in particular insulation measures are lower than we previously assumed, reflecting new evidence on energy use in homes and energy performance of solid walls. Overall, we have revised down the annual direct emissions abatement from residential energy efficiency in our cost-effective path by 22% to around 7 MtCO₂ in 2030.
- There is limited new evidence on abatement potential from non-residential buildings. However, improved approaches to projecting emissions imply lower reductions to 2030 than we previously assumed. Additionally, new EU regulations for improving the efficiency of electric appliances and lighting are expected to deliver a further 3% (4 TWh) electricity savings in non-residential buildings 2030, with some increased direct emissions to replace waste heat output.

- New evidence on the capital costs, performance and durability of heat pumps suggests that they are less cost-effective in the 2020s than we previously assumed. We have therefore revised downwards our estimates of heat pump uptake across buildings, including 3 million fewer heat pumps in homes by 2030 (down from 7 to 4 million). This would reduce abatement from heat pumps from 31 MtCO₂ to 14 MtCO₂ in 2030.
- We have assumed increased uptake of district heating to 2030, from 2 to 6% of heat demand, reflecting policy developments in DECC and new analysis (including from National Grid). This would imply building up heat networks consistent with the 40% potential for meeting heat demand identified in our 2050 analysis.
- Compared to a path with no progress during the 2020s, the measures in our updated scenario offer a saving of around £30 billion in present value terms under central case assumptions for fossil fuel and carbon prices.

We set out the analysis underpinning these conclusions in five sections:

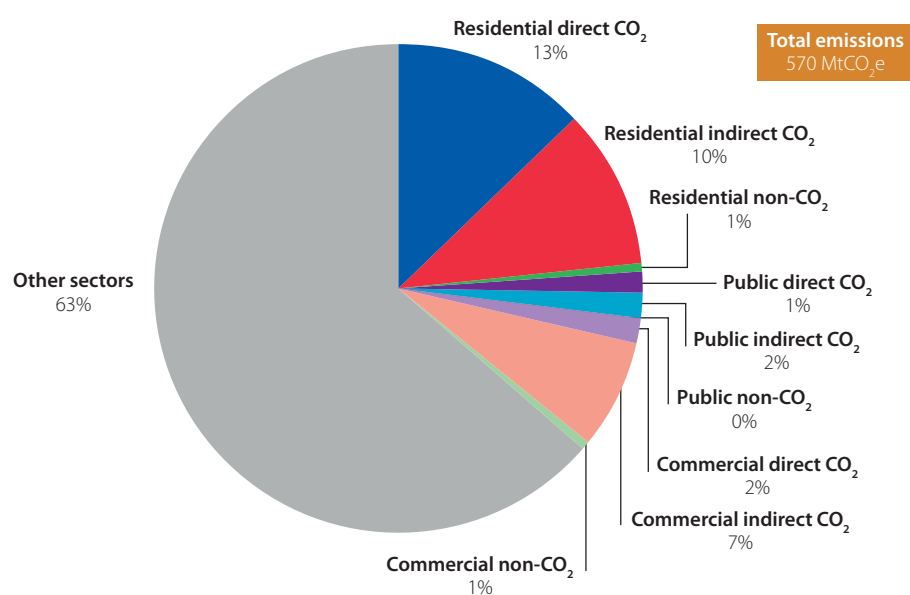
1. Current emissions
2. Projected emissions before abatement action
3. Updated evidence on abatement options and costs
4. Projected emissions with abatement – an updated assessment for the 2020s
5. Benefits of delivering the measures in the fourth carbon budget

1. Current emissions

Overall buildings emissions accounted for 37% of total UK greenhouse gas emissions in 2012 (Figure 3.1). Direct CO₂ emissions from buildings were 91 MtCO₂ in 2012. Buildings were also responsible for 67% (212 TWh) of electricity consumption and associated CO₂ emissions (111 MtCO₂):

- The residential sector accounted for 66% of overall buildings CO₂ emissions (134 MtCO₂), 55% of which were direct emissions (mainly from gas).
- Non-residential emissions from the commercial and public sector accounted for 26% and 8% of buildings emissions respectively. 82% of commercial sector emissions and 57% of public sector emissions were electricity-related.
- Overall buildings CO₂ emissions have fallen by 8% since 2008 but have shown year-to-year fluctuations due to economic and temperature effects.
- Heating (in particular gas) accounted for over 80% of direct buildings emissions.

Figure 3.1: GHG Emissions from buildings in the context of total UK emissions (2012)



Source: NAEI (2013), DECC (2013), Energy Trends, March 2013, DECC (2012) DUKES; CCC calculations.

Notes: 2012 emission estimates are provisional. Commercial sector and non-CO₂ are based on CCC estimates.

There is considerable scope for reducing emissions from the buildings sector through energy efficiency and decarbonising heat. In the residential sector, a large number of energy efficiency measures have been installed since we published the fourth carbon budget in 2010, although there has been a slow-down in 2013 due to policy changes. In the non-residential sector emissions have been fairly flat, with not much sign of significant energy efficiency improvement.

We now consider the latest evidence on projected emissions (section 2) and options to reduce these (section 3), before setting out a new updated assessment of abatement options to 2030 in section 4.

2. Projected emissions before abatement action

The starting point for our new assessment is DECC's updated emissions projections (UEP). The UEP 2013 'baseline scenario' projects emissions to 2030 without the effects of policies that have been implemented since the 2007 Energy White Paper (i.e. pre-first carbon budget). The scenario allows for economic growth, demographics and changing fossil fuel prices. In 2010, we used the DECC model to provide a similar baseline run for our reference projection.

Since our original fourth carbon budget advice, assumptions for key drivers of buildings energy demand have changed (see chapter 1). For residential buildings emissions, demographic assumptions are particularly relevant:

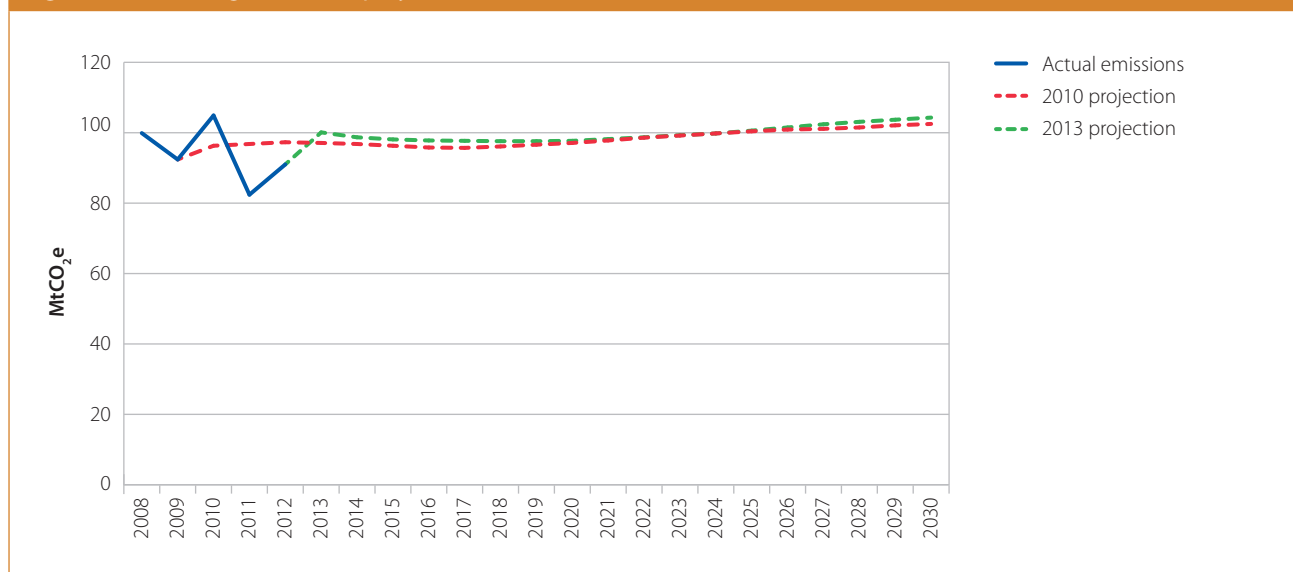
- UEP 2013 uses adjusted population numbers, in line with updated population growth projections. This projects the number of households to increase to 32 million in 2030.
- The size of households is also relevant for emissions – there is a trend towards smaller households which on a per capita basis use more energy.

Direct emissions from the buildings sector in 2030 in UEP 2013 are almost identical to our 2010 reference projection (104 MtCO₂ vs 102 MtCO₂, Figure 3.2). However, there are some significant changes in the component sub-sectors, as well as to electricity demand (and therefore indirect emissions):

- For residential buildings, baseline emissions are now expected to be almost 13% higher in the fourth carbon budget period compared to our assumption in 2010. The main reason for this higher baseline is a revision in the demand equations for residential gas demand. We have therefore scaled up direct abatement accordingly (Figure 3.3).
- Commercial and public sector emissions are expected to be lower (16 MtCO₂ instead of 26 MtCO₂ in 2030), primarily reflecting improvements to the estimation of public sector demand equations. In contrast, electricity demand in these sectors is now projected to grow by 31% to 2030, where previously it was forecast to remain flat.

While the new UEP baseline projects an increase in direct buildings emissions of around 10% by 2030 (compared to 2012), policies to which the Government is already committed, as well as further options, will reduce emissions below this level. We now turn to these options.

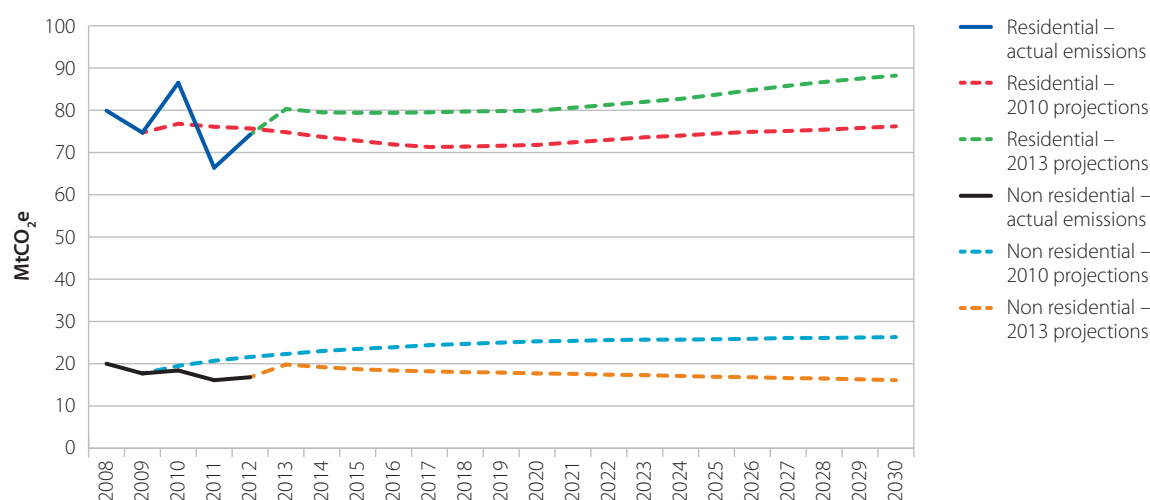
Figure 3.2: Buildings: baseline projections of direct emissions (2010 and 2013)



Source: DECC (2013).

Notes: Direct emissions only.

Figure 3.3: Residential and non-residential buildings: baseline projections of direct emissions (2010 and 2030)



Source: DECC (2013).

Notes: Direct emissions only.

3. Updated evidence on abatement options and costs

In our advice on the fourth carbon budget (2010), we set out detailed assessments of the options for reducing emissions from buildings. Since then, new evidence on residential energy efficiency measures has allowed us to reassess costs and abatement potential. We have also carried out new analysis on heat pumps and reviewed recent evidence on district heating. For the non-residential sector, the evidence base continues to be less developed, with limited new evidence since 2010.

Residential energy efficiency

Energy efficiency improvements in homes are important for emissions savings and (in the case of building fabric measures) making homes suitable for heat pumps. They also help improve energy affordability and address fuel poverty. Better insulation also offers health benefits associated with warmer homes. Furthermore, electricity efficiency measures reduce the need for additional power capacity. Options include:

- Building fabric insulation measures such as loft insulation, cavity wall insulation and solid wall insulation.
- Other measures to improve heating and hot water energy efficiency such as efficient boilers, heating controls (e.g. room thermostats and thermostatic radiator valves) and hot water cylinder jackets.
- Highly efficient electrical appliances and lighting.
- Behavioural measures such as turning off lights or turning down thermostats.
- Zero carbon new-built homes which are highly energy efficient and meet the remaining heat and electricity needs from renewable sources.

The evidence on abatement potential and costs of energy efficiency measures has continued to develop since our original 2010 advice on the fourth carbon budget (Box 3.1 and Box 3.2). We therefore commissioned Element Energy and the Energy Saving Trust (EST) to review the latest evidence and inform the update of our assessment of the costs and feasibility of measures¹.

Box 3.1: Residential energy efficiency: policy changes and new evidence

The analysis underpinning our recommended carbon budgets to 2027 was undertaken in 2008/09 (for the first three carbon budgets) and 2010 for the fourth carbon budget. Since then there have been significant changes in Government policies, as well as developments in the evidence base for key measures.

Policy changes

In 2010, the Government dropped the target to insulate all lofts and cavities 'where practicable' by 2015. This change has implications for meeting our current indicator trajectories in which we assumed that 10.5m under-insulated lofts and 8m unfilled cavity walls would be insulated between 2008 and 2015.

In addition, in 2013 a major change in energy efficiency policy took place with the introduction of the Green Deal and the Energy Company Obligation (ECO). Initially, this meant the removal of subsidies for easy-to-treat cavity and loft insulation, except for low-income and vulnerable households. DECC's 2012 impact assessment² suggested that as a result, only 2.3 million cavity walls would be insulated between 2013 and 2020. This falls far short of the available potential and our indicator trajectories which suggest that 8 million cavity walls should be insulated by 2015.

However, in December 2013, the Government announced some changes to the scheme, including a widening of the carbon obligation of the scheme to fund easy-to-treat cavity walls and lofts. The implications of these changes on future numbers of installations are not yet clear.

New evidence on energy use and energy 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 SAP³.

Evidence from NEED (e.g. typical savings from cavity wall insulation and condensing boilers are less than predicted) fed into the development of DECC's in-use factors for the purposes of the Green Deal and ECO (Box 3.2).

Further evidence is being collected by DECC that will provide a better understanding of the gap between actual energy use and predicted energy use in the model. These include:

- The English Housing Survey Energy Follow-Up Survey (EFUS, to be published at the end of 2013) will show that the average number of hours that a house is typically heated and the length of the heating season are less than predicted in the model. In addition, the average temperature setting is below the assumed level of 21.3 degrees C for the living room and 20.3 degrees for other rooms. Combined these factors imply that less energy is being used in the average house than had previously been assumed.
- A two year project launched earlier this year by DECC and BRE will look to improve the understanding of heat losses from solid wall properties. Smaller field trials to date have found that the thermal performance of uninsulated solid wall homes, as measured by the u-value, is better than previously assumed. The level of energy savings that can be achieved by installing solid wall insulation is therefore less.

New cavity wall categorisation

Since our 2010 report, DECC has categorised cavity walls as being either easy-to-treat (standard) or hard-to-treat (unconventional). Standard cavity walls tend to be constructed of brick-brick or brick-block with a cavity of more than 50mm wide. This means insulation can be achieved easily and without additional cost. However, hard-to-treat cavity walls are generally more expensive and difficult to fill due to a variety of physical reasons, which can include narrowness of the cavity (e.g. less than 50mm wide), and the frame being made of timber or steel.

Despite having higher costs, the energy saving potential from treating an unconventional cavity wall can be as high as an easy-to-treat wall and therefore insulation is still recommended. The main exception are walls that contain a narrow cavity, where energy savings potential are considered to be low.

¹ Frontier Economics and Element Energy (2013) Pathways to high penetration of heat pumps, report prepared for the Committee on Climate Change. Available online <http://www.theccc.org.uk/publication/fourth-carbon-budget-review>

² DECC (2012) Final stage impact assessment for the Green Deal and Energy Company Obligation. Can be accessed on www.gov.uk

³ Standard Assessment Procedure (SAP) is used by DECC to assess and compare the energy and environmental performance of dwellings.

Box 3.1: Residential energy efficiency: policy changes and new evidence

New cost data

Our trajectories for insulation measures are based on 2008 data for installation costs. More recent DECC data has higher costs in general and more granularity (e.g. costs for cavity wall are split between easy-to-treat (£376) and hard-to-treat (£1,620), whereas we previously only estimated a single cost for cavity wall insulation of £380 which took no account of the ease of treatment).

The combination of adjusted savings, in-use factors and new cost data has a major impact on the cost-effectiveness of insulation measures (in particular solid wall insulation) which has reduced carbon savings compared to our previous assumptions.

Box 3.2: Reduction ('in-use') factors

Reduction factors were introduced by DECC to bring SAP savings in line with NEED values for a number of measures.

In our previous analysis of energy efficiency measures, we only accounted for a 15% comfort taking reduction factor for the main insulation measures (e.g. solid wall, cavity wall, loft and floor insulation). This took account of evidence at the time that savings were in practice lower than the modelling suggested.

Following a critical evaluation of DECC's in-use factors by Element Energy and the EST, our assessment of the abatement potential for this report incorporates further in-use factors. The in-use factors are split between three elements that contribute to an overall reduction factor per measure (Table B3.1):

- *In-use factor*: accounts for the physical underperformance or systematic difference between the theoretical model of building energy demand and in-situ performance. This factor is applicable to a cross section of measures.
- *Comfort factor*: takes into account the underperformance of a measure which is attributed to the rebound effect, whereby householders for example may decide to increase the temperature in their home following the installation of loft insulation. This factor is applicable to fabric insulation measures only.
- *Inaccessibility*: applicable to solid wall, cavity wall, and loft insulation only. Reduced energy savings reflect the loss of performance by not being able to treat the whole surface area (e.g. architectural features on the façade of a house may prevent the whole wall being externally insulated).

DECC is planning to review the in-use factors each year with the intention of updating the values based on new research and evidence (e.g. heating hours and savings from solid wall insulation).

Table B3.1: In-use factors for main residential energy efficiency measures

Measure	In-use	Comfort	Inaccessibility	Total reduction factor
Solid wall	33%	15%	10%	49%
Cavity wall	35%	15%	10%	50%
Loft insulation	35%	15%	10%	50%
Heating controls	50%	0	0	50%
Double glazing	15%	15%	0	28%
Floor insulation	15%	15%	0	28%
Condensing boiler	25%	0	0	25%
Hot water tank insulation	15%	0	0	15%

Source: DECC

Notes: As the savings are multiplied by each of the factors, the separate factors do not add up to the total reduction factor. For more information see Element Energy & Energy Saving Trust (2013).

The review concluded that the technical potential to implement measures is similar to the level we previously assumed, but that these measures could be more expensive to install and deliver less emissions reduction than previously expected:

- **Insulation.**

- *Cavity wall insulation.* We estimate a technical potential of around 4.6 million cavity walls left to insulate that would deliver high carbon savings. This technical potential is split between 1.6 million cavity walls that are categorised as easy-to-treat, and the remaining 2.9 million as hard-to-treat. If all these cavity walls were insulated by 2023, carbon saving in our updated assessment would reach 2.0 MtCO₂ by 2030, which is unchanged from our 2010 fourth carbon budget advice.
- *Loft insulation.* Over 10.3 million easy-to-treat lofts remain to be insulated, which we estimate could deliver annual savings of 0.7 MtCO₂ by 2030, down from 1 MtCO₂ in our 2010 advice. Over 80% of the savings are derived from insulating lofts that are currently filled to between 50mm-125mm only.
- *Solid wall insulation:* In our 2010 advice, we assumed a high uptake of solid wall insulation through the 2020s reaching 3.5m by 2030. We assumed this would deliver annual savings of 4.9 MtCO₂ by 2030. However, our updated analysis indicates that based on the same level of uptake, annual savings potential would decline to 2.5 MtCO₂ by 2030.

- **Other energy efficiency measures.** Our new analysis reinforces our previous assumptions on the level of cost-effective abatement from other energy efficiency measures, after allowing for replacement of waste heat from inefficient electrical appliances. These measures include floor insulation, improved glazing, installation and use of heating controls and some households choosing to turn their thermostats down by one degree (Box 3.3).
- **Zero Carbon Homes:** Since our 2010 report, the Government has decided to limit the definition of Zero Carbon Homes to regulated energy use only (i.e. heating and fixed lighting) and has proposed off-site 'allowable' solutions. Savings potential by 2030 is now 1.1 MtCO₂, up from our 2010 estimate of 0.7 MtCO₂.

Box 3.3: Summary carbon savings from other energy efficiency measures

In addition to insulation measures, the review by Element Energy and the EST reassessed a number of different energy efficiency measures previously included in our analysis, such as lights and appliances. It also assessed the potential for new measures such as reduced flow showers, and for behavioural change measures:

- **Other heating energy efficiency measures.** Despite a 50% reduction in carbon savings per measure based on the latest evidence, a more ambitious level of uptake for heating controls in our updated assessment delivers 1.4 MtCO₂ by 2030 compared to less than 1 MtCO₂ from our previous estimate. This reflects the high number of households that still continue to lack basic heating controls. The costs of installing heating controls can be reduced at point of boiler replacement.
- **Lighting.** We now have a better disaggregation of the types of efficient lighting that could be installed, either by switching from incandescent lamps to compact fluorescents or from halogens to LEDs. While more efficient lighting offers considerable savings in electricity-related emissions, there is an increase in direct emissions to 1.2 MtCO₂ by 2030 compared to 0.4 MtCO₂ previously due to the heat replacement effect⁴.
- **Appliances.** Driven by end of lifetime replacements and tightening EU energy efficiency standards, we also expect a high uptake of efficient cold and wet energy efficient appliances (e.g. fridges and dishwashers) over the same period. This will provide significant electricity saving but would increase direct emissions to 0.7 MtCO₂ in 2030. We assume an ambitious uptake of the most energy efficient televisions (A+++ energy rating) by the mid-2020s. As these will be 90% more efficient than the current stock, heat related emissions are estimated to increase to 0.8 MtCO₂ by 2030. We also assume further increases (to a total of 3.2 MtCO₂) from other appliances (e.g. computers and various electrical gadgets).
- **Behavioural change.** By 2030, we estimate direct emission savings of 2 MtCO₂ from turning down the heating by one degree centigrade, down from our 2010 estimate of 3 MtCO₂.
- **New measures.** Based on new evidence, we also have included abatement from an additional measure. Reduced flow showers, which is a hot water efficiency measure, could save 0.9 MtCO₂ by 2030. Currently, hot water demand accounts for 6% of CO₂ emissions and reduced flow showers are a very cost-effective measure at -£172 t/CO₂.

Annual direct emissions savings from all the residential energy efficiency measures considered for this report could save 7.2 MtCO₂ by 2030. This represents a 22% reduction (equivalent to 2.1 MtCO₂) from what we previously estimated in 2010 (Table B3.2). In addition, electricity-related measures would provide electricity demand savings of around 14 TWh by 2030.

Table B3.2: Summary of direct carbon savings by 2030 (MtCO₂)

Measure	Old 2010 estimates	Revised 2013 estimates
Solid wall insulation	4.9	2.5
Cavity wall and loft insulation	3.0	2.7
Other fabric measures	0.4	0.7
Heating controls	0.1	1.4
Heating 1 degree centigrade decrease	3.1	2.0
Lighting	-0.4	-1.2
Cold & wet appliances	-0.2	-0.7
Electrical products (e.g. computers, televisions, other appliances)	-2.2	-3.2
Other measures	0.6	3.0
Total	9.3	7.2

Source: CCC modelling

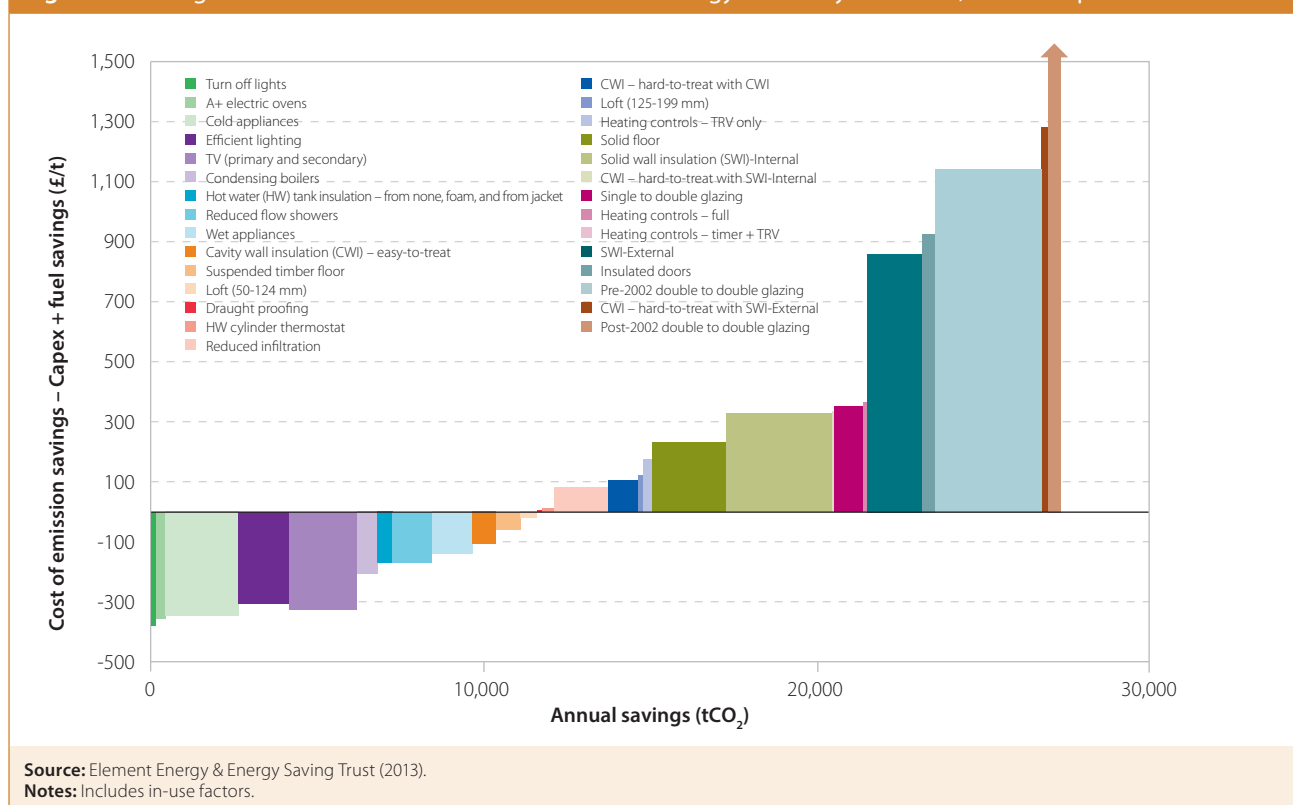
⁴ As appliances become more efficient, they produce less waste heat. We assume this needs to be compensated for with a small amount of additional heating.

The reduction of estimated energy/carbon savings for some measures combined with updated data on the costs of measures also implies an increase in the cost per tonne of abatement:

- **Solid wall insulation.** The reduced level of carbon savings per unit of insulation combined with higher costs estimates (e.g. cost estimates for external insulation range £3,600-8,400) have sharply increased the average cost of carbon abatement from the fourth carbon budget estimate of £18/tCO₂ to a range of £88 to £2,000/tCO₂ for external insulation and -£70 to £890/tCO₂ for internal insulation. Solid wall insulation is found to be most cost-effective if applied to large electrically-heated homes, and least cost-effective for small homes heated by gas or district heating. We recognise however that in practice the costs of installing solid wall insulation can be much lower if done in conjunction with general home renovation works. For example, fixed costs for external solid wall insulation will be less if the scaffolding is already in place for other works (e.g. a loft conversion).
- **Cavity wall insulation.** Easy-to-treat cavity walls continue to remain cost-effective, saving -£100/tCO₂. Harder-to-treat cavities all have positive costs, ranging between £106-£1,290/tCO₂, which reflects the different method that can be used to treat a house with a cavity wall, with the most expensive being the installation of an external solid wall should the cavity prove unsuitable to fill.
- **Loft insulation.** Topping-up lofts with existing low levels of insulation (50-125mm) remains cost-effective, saving -£22/tCO₂. Reduced savings are obtained from topping-up lofts with more insulation already in place (125-199mm) makes them less cost-effective (£123/tCO₂).

In addition to easy-to-treat cavity wall insulation and loft insulation, other cost-saving measures include efficient appliances, lighting, and reduced flow showers (Figure 3.4).

Figure 3.4: Marginal abatement cost curve for residential energy efficiency measures, technical potential



There is a question over whether more expensive measures should be targeted by low-carbon policies. However, it is important to consider their role in abating fuel poverty (e.g. fuel poverty is more prevalent in solid wall homes), as well as health benefits (section 5). We will return to this question in our 2014 progress report. In the meantime, we include a sensitivity where we assume a lower uptake of more expensive solid wall and hard-to-treat cavity wall insulation measures (section 4).

Non-residential energy efficiency

There is significant variation in energy usage profiles across non-residential buildings due to differences in buildings type, size and use. As noted in our previous reports, the evidence base for abatement potential in the non-residential sector needs to be strengthened and efforts are underway by Government to address this (Box 3.4).

Our fourth carbon budget abatement scenario assumed the uptake of all carbon abatement measures to 2020 that are cost-effective relative to the carbon price, including efficient lights and appliances, heating controls and energy management measures. No further savings were identified in the 2020s.

Overall, our evidence review suggests this is broadly the right level but we have also identified some small additional electricity savings from appliances to 2030 as a result of the new EU regulations on product standards. These are expected to deliver a further 3% of electricity savings in 2030 (4 TWh higher than our original estimate of 5 TWh of savings).

These savings, together with the decarbonisation of the power sector, could lead emissions from public and commercial buildings to be close to zero by 2030.

Box 3.4: Non-domestic evidence gathering project in DECC

DECC are undertaking a major new evidence-gathering project in order to address the lack of evidence on the energy demand and carbon abatement potential of non-domestic buildings.

- The aims are to build a bottom-up dataset of energy end usage and abatement potential, and to review barriers to energy efficiency.
- The project will take a sectoral approach, using a combination of telephone and online surveys, site audits and buildings energy modelling to supplement the existing data from energy bills and building information from the Valuations Office Agency.
- First results will be delivered in 2014, starting with the public sector and the project will complete in early 2015.

As a result, we expect to have improved estimates of abatement potential in our future analysis (e.g. for the fifth carbon budget report).

Source: DECC, 2013.

Low-carbon heat

Low-carbon heat has a critical role to play in meeting the 2050 target, given the need to reduce the emissions from heat to very low levels in 2050. Our previous analysis identified a mix of cost-effective technologies in the 2020s, including heat pumps, bioenergy and district heating. Heat pumps in particular made up a significant portion of abatement in our 2010 analysis – around 70% of all low-

carbon heat abatement in 2030 – with just under 7 million heat pumps in homes. However, we also recognised the existence of significant barriers to uptake.

Since 2010, there is new evidence – on heat pump uptake, transitional technologies such as hybrid heat pumps and district heating – which has implications for the fourth carbon budget period. We have therefore carried out new analysis to update our assessment of the feasibility and desirability of heat pumps to 2030.

We set out the results of our new analysis in two parts:

- a) Heat pumps
- b) Other low-carbon options – bioenergy and district heating

a) Heat pumps

Since we provided our advice on the fourth carbon budget in 2010, the uptake of heat pumps has been slower than expected, although support has also been more limited than we assumed:

- Total sales have remained below 30,000 per year, mainly consisting of air source heat pumps, and in recent years, often installed in social housing.
- Government support for the sector has had limited impact. The domestic Renewable Heat Incentive (RHI) scheme has been postponed to 2014, while the interim Renewable Heat Premium Payment has only delivered a few thousand heat pump installations since 2011. Heat pump tariffs in the non-domestic scheme were initially set too low to drive uptake.

Given the changed circumstances, we commissioned Frontier Economics and Element Energy to review the feasibility of our heat pump assumptions. This identified new evidence on additional costs, lower performance and lower durability of Air Source Heat Pumps (ASHPs) which affects our estimates of the cost-effectiveness of heat pumps (Box 3.5).

We have updated our previous modelling to reflect this new evidence. Lifetime assumptions in particular have a major impact on uptake numbers. Since substantial uncertainty remains, our approach has been to consider the range of impacts on cost-effectiveness:

- Assuming that ASHPs last on average 15 years would suggest cost-effective uptake of around 2 million heat pumps in homes in 2030.
- Increasing the lifetime to 20 years increases cost-effective uptake to 6 million heat pumps in 2030.
- Reflecting this uncertainty, we have adopted a central estimate of 4 million heat pumps in homes in 2030.
- For non-residential buildings, numbers of installations are more difficult to estimate as there is a huge variation of heat demand between buildings. We assume an overall contribution of around 30% of non-residential heat demand (27 TWh), down from 62 TWh previously.

Box 3.5: New evidence on the cost-effectiveness of heat pumps

The study by Frontier Economics and Element Energy identified higher financial barriers than we previously assumed, as a result of higher capital costs, lower performance and shorter lifetimes.

Capital costs

New capital cost data is available from a number of sources, with relatively good agreement between sources:

- The study compared the assumptions used for Phase II of the RHI (AEA, 2012) with costs collected by the Sweett Group for DECC (2013)⁵ and estimates supplied through the stakeholder consultation.
- Based on the review, it recommended using ASHP cost data from the RHI Phase II study, and Ground Source Heat Pumps (GSHP) cost data supplied during a stakeholder consultation, including the cost for upgrading heat emitters.
 - The review suggested including additional capital costs of £275/kW (typically over £1,000 per heat pump) from the need to upgrade heat emitters, as heat pumps perform better at lower flow temperatures.
- The advantage of these costs are that they provide a clear breakdown between costs attributed to the heat pump, and the costs to refurbishment of the heating distribution system, and compare closely to those reported in the Sweett Group report. We have therefore reflected the new data in our estimates.

In the residential sector, this corresponds to total installation costs of £5,000 – £15,000 for ASHPs and £8,000 – £23,000 for GSHPs, compared to £6,000 – £10,000 for ASHPs and £9,000 – £17,000 for GSHPs in our previous assumptions.

Consultation with industry stakeholders and experts found that they generally consider the opportunity for reducing equipment costs limited, with no significant economies of scale expected to result from growth of the heat pump industry. Some learning is expected to bring down installation costs, equivalent to 10% of the installed cost by 2030. For GSHPs, communal ground arrays and more widespread drilling rigs could help bring down costs, but there is limited evidence on this to date.

Heat pump performance

Energy efficiency is one of the main factors determining the cost-effectiveness of heat pumps, as it leads to the running cost savings which offset the higher capital costs relative to conventional heating technologies:

- The efficiency of heat pumps – referred to as the Seasonal Performance Factor (SPF)⁶ – is calculated as the ratio of heat output to electricity input. It typically ranges in the region of 2-3 for residential ASHPs and up to around 4 for GSHPs without solar recharge (i.e. producing heat equivalent to four times the amount of electricity consumed).
- As the electricity required for heat pumps is more expensive than gas, in the absence of policy intervention, operating cost savings would depend on achieving a level of performance of typically 3.5 or higher where replacing a gas boiler.

Heat pumps efficiency is not expected to improve dramatically over time. The Energy Saving Trust (EST) recently published the second phase results of its heat pumps field trials, where it measured the impact of targeted improvements to the first round of installations. These indicate that there is some potential for improvement in heat pump performance, but that it is likely to remain low compared to some other EU countries, partly due to the low UK housing stock efficiency.

We have therefore limited the improvements to an increase of up to 1 in the SPF, over a 10 year period.

Durability of ASHPs

The evidence on the lifetime of heat pumps is weak. Lifetime estimates for ASHPs are commonly in the range of 15 to 20 years. This suggests that our previous assumption of 20 years for all heat pumps was a high end estimate in the case of ASHPs.

These assumptions are only partially offset by lower supply-side constraints compared to our previous estimates.

Source: Frontier Economics and Element Energy (2013) Pathways to high penetration of heat pumps, and Energy Saving Trust and DECC (2013) Detailed analysis from the second phase of the Energy Saving Trust's heat pump field trial.

⁵ Sweett Group for DECC (2013), Research on the costs and performance of heating and cooling technologies, Final report. Available on the gov.uk website.

⁶ The term Coefficient of Performance (COP) is also used. This is a term used by the manufacturer and indicates design performance, whereas SPF refers to the seasonal average, or what is achieved in practice.

Taken together, this evidence suggests cost-effective uptake to 2030 of 4 million heat pumps in homes, and 27 TWh in non-residential buildings.

We had not previously considered hybrid heat pumps (i.e. a heat pump combined with a gas boiler) but new evidence suggests that they could play a role as transitional technologies in the medium term:

- Their advantages include fewer barriers to installation, but carbon savings would be lower.
- The level of uptake of hybrid heat pumps is highly uncertain, with significant variations between different uptake model estimates.

We have therefore not explicitly included hybrid heat pumps in our assessment. Whilst an assumption that all electric heat pumps are replaced with hybrid heat pumps would lead to lower levels of abatement, we consider that this would be within the range explored in our low sensitivities (Box 3.6).

Even at the scaled-down uptake numbers, significant financial and non-financial barriers remain which make this a challenging area for carbon policies:

- Financial barriers – primarily the high upfront costs relative to conventional heating technologies.
- Non-financial barriers – including consumer confidence and awareness, the suitability of the housing stock and a lack of installer capacity.

However, the Frontier Economics and Element Energy study suggests these can largely be addressed by a set of cost-effective policy options. We will return to these in our 2014 progress report.

Box 3.6: Hybrid heat pumps

The term hybrid heat pump is commonly used to refer to an electric heat pump combined with a gas boiler. These can either operate in tandem, or the gas boiler can be used as a top-up for the coldest days in the year. An alternative product is the gas absorption heat pump, which runs off natural gas as opposed to electricity. Hybrid heat pumps are typically less efficient than electric heat pumps, achieving SPF_s of around 1.5 (or 150%), compared to typically around 2-3 for ASHPs (Box 3.5)

Recent analysis by National Grid and DECC⁷ has suggested that these technologies could play an important role in the transition to decarbonisation, with high uptake of hybrid or gas absorption heat pumps in the 2020s and 2030s. These would then be phased out in the 2040s with the rising carbon price.

Some uptake is likely under the Renewable Heat Incentive (RHI), as the heat output qualifies for RHI payments on the portion of the output that comes from the heat pump, subject to metering.

We asked Frontier Economics and Element Energy to look at the impact of including hybrid heat pumps in our cost-effective path. The headline conclusions were:

- There are some advantages to hybrid heat pumps as a transitional technology (including the practicality of top-up gas, fewer barriers to installation, higher acceptability to consumers, and lower peak load electricity demand).
- The benefits of gas absorption heat pumps are less clear – these are only around 150% efficient, with lower carbon savings and therefore do not hold the same long-term decarbonisation potential relative to gas boilers. Whilst there are some products on the market in Europe, for example in Germany, there are none so far in the UK.
- Consumer uptake modelling suggests we could see uptake of several million under a range of policies. These would be partly replacing other uptake of ASHPs, and partly additional.

Other evidence suggests a range of potential uptake scenarios:

- Modelling by DECC and National Grid suggests that uptake to 2030 may be dominated by either hybrid heat pumps or gas absorption heat pumps, with different models favouring either one or the other technology.

Our approach has been not to include hybrid or gas heat pumps in our assessment. However, assuming a hybrid heat pump involves using a gas boiler to meet around 25% of heat demand during the coldest days of the year, the reduction in abatement from substituting all electric heat pumps in our scenario for hybrids would be within the range bounded our low sensitivity of 2.5 million heat pumps in 2030 (see section 4).

Source: Frontier Economics and Element Energy, 2013.

b) Other low-carbon options – district heating and bioenergy

District heating

We have raised our assumptions about the level of district heating deployment by 2030 to 6% of heat demand (30 TWh/year), based on a combination of low-carbon sources and natural gas combined heat and power (CHP). This is within the range of our previous high scenario of 8% (40 TWh).

- In our fourth carbon budget advice, we assumed deployment of 10 TWh/year, out of a total estimated potential of 90 TWh/year. Since 2010, the evidence base on the potential for district heating to contribute to low-carbon heat supply has been strengthened.

⁷ Esme and Resom modelling results presented in DECC (2013) *The Future of Heating: Meeting the challenge*.

- In 2012, we commissioned AEA and Element Energy to look at scenarios for low-carbon heat to 2050 for our report on the 2050 Target⁸, published alongside our advice on whether international aviation and shipping should be included in the budgets. This identified greater potential for district heating deployment, at 160 TWh/year by 2050, and showed that a mix of district heat and heat pumps would have similar emissions and overall cost to a scenario with very high level of heat pump uptake.
- DECC's 2013 heat strategy (The Future of Heating) has also identified a greater role for district heating, delivering heat from a range of low-carbon sources including a potentially important contribution from larger-scale heat pumps.

In order to keep in play this greater cost-effective potential for long-term deployment, we assume that it is necessary by 2030 to reach a greater level of roll-out than we had previously envisaged. Whilst this would include some gas CHP in the near-term, this is likely to be phased out over time with a rising carbon price.

Bioenergy

In our 2011 Bioenergy Review, we found that the role for bioenergy in heating buildings is likely to be relatively limited in the longer term, given heat pumps as alternative low-carbon options. Our assessment suggests that broadly the same level of bioenergy in buildings remains sensible (around 8.5 MtCO₂ in 2030).

Given limits to the global supply of sustainable bioenergy, it is important that bioenergy is used in an optimal fashion. For heat, Combined Heat and Power (CHP) using local waste or bioenergy and supplying district heating, and bioenergy boilers using local bioenergy in rural homes are likely to provide the best options.

4. Projected emissions with abatement – an updated assessment for the 2020s

In our 2010 advice, we presented an abatement scenario involving measures that were likely to be economically-sensible in a carbon-constrained world. This was our best estimate of the cost-effective path to the 2050 target, and included measures that were cost-effective against the projected carbon prices or were considered important on the path to the 2050 target. For 2030, it included for example the insulation of all technically-feasible lofts and cavity walls, as well as 3.5 million solid walls, a range of energy efficiency measures in non-residential buildings and 37% of heat demand met by low-carbon heat sources, including 6.8 million heat pumps in homes. We expected these measures to reduce direct buildings emissions to 62 MtCO₂ in 2025 and 46 MtCO₂ in 2030.

⁸ CCC (2012) The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping. Available online at <http://www.theccc.org.uk/publication/international-aviation-shipping-review/>

Outlook to 2020

The starting point for our analysis was a projection for emissions in 2020, building in measures which the Government is aiming to deliver, or has committed to deliver. Since many of the policies for 2020 are already in place, this is very similar to DECC's 'Reference' projection in UEP. We have updated our projection based on new evidence since our original advice. The main changes are:

- We have adjusted the energy and carbon savings for a range of residential energy measures, in accordance with the new evidence presented in section 3.
- We have scaled abatement from energy efficiency measures in residential and non-residential buildings, in line with DECC's latest energy demand projections.

As a result, we now assume emissions from buildings will be 80 MtCO₂ in 2020. This would be a 12% reduction on 2012 levels but is 9 Mt higher than we assumed in our 2010 fourth budget advice.

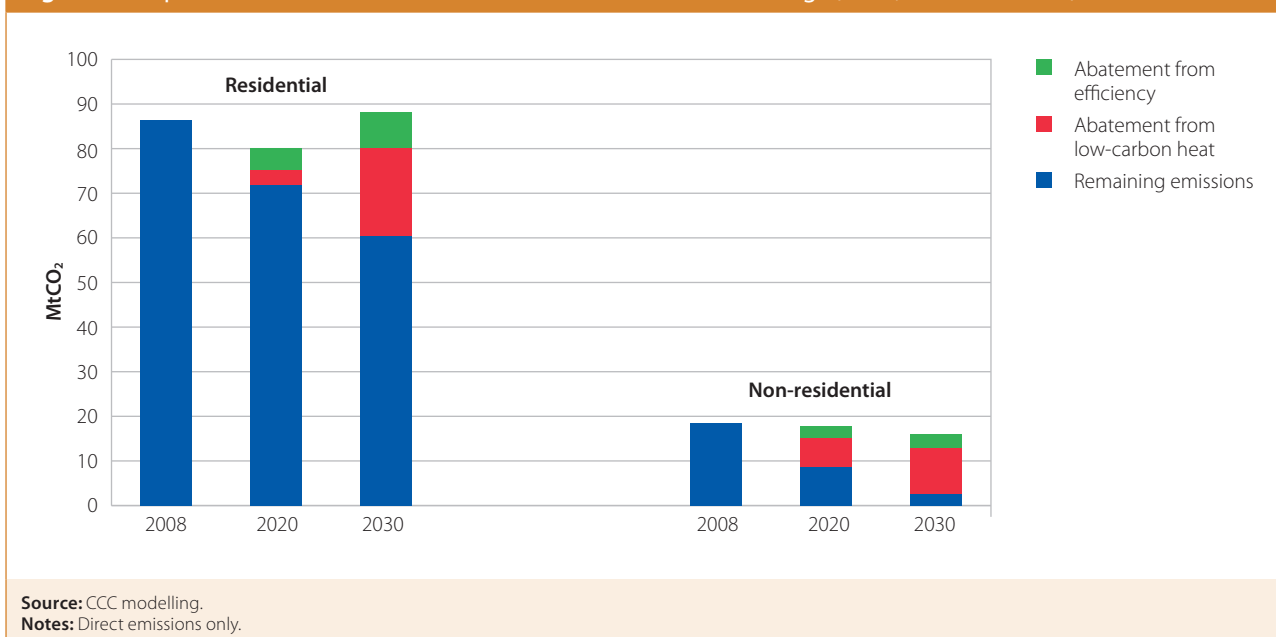
The path from 2020 to 2030

We have updated our assessment for building sector emissions to reflect the new evidence on the effectiveness of energy efficiency measures in the residential sector, on low-carbon heat and on emissions projections:

- **Residential energy efficiency.** Given our new evidence on reduced energy savings, we now assume that wall and loft insulation reduce direct annual emissions from residential buildings by 5% (previously 8%) compared to the baseline without abatement measures by 2030. As in our original fourth carbon budget advice, we assume that other energy efficiency and behavioural measures (e.g. other fabric measures, turning down thermostats by one degree centigrade and zero-carbon homes) reduce emissions by a further 2% against the baseline.
- **Low-carbon heat.** We have revised our assumptions about heat pump uptake down from 7 million installations in 2030 (meeting 143 TWh of heat demand) to 4 million (72 TWh). This is partly offset by an assumed increase in penetration of district heating (up from 2% (10 TWh) to 6% (30 TWh) in 2030).
- **Emissions projections.** We adopt the latest DECC baseline projection, implying an increase in residential direct emissions of 16% in 2030 relative to our previous assumptions, while for non-residential buildings, we assume a reduction in 2030 by 39% compared to our 2010 advice.

Together, these changes mean that we now assume that direct emissions from buildings reduce to 70 MtCO₂ in 2025 (down 32% on 1990) and 64 MtCO₂ in 2030 (down 38% on 1990, Figure 3.5).

Figure 3.5: Updated scenario for direct emissions abatement in buildings (2010, 2020 and 2030)



We now assume that emissions over the whole fourth budget period that are 50 Mt higher than we originally assumed (and 18 MtCO₂ higher in 2030, Figure 3.6). This reflects our more prudent assumptions over heat pump uptake and the effectiveness of insulation measures in use, with no material impact from DECC's new emissions projections, which are – across all buildings – relatively unchanged from those in 2010.

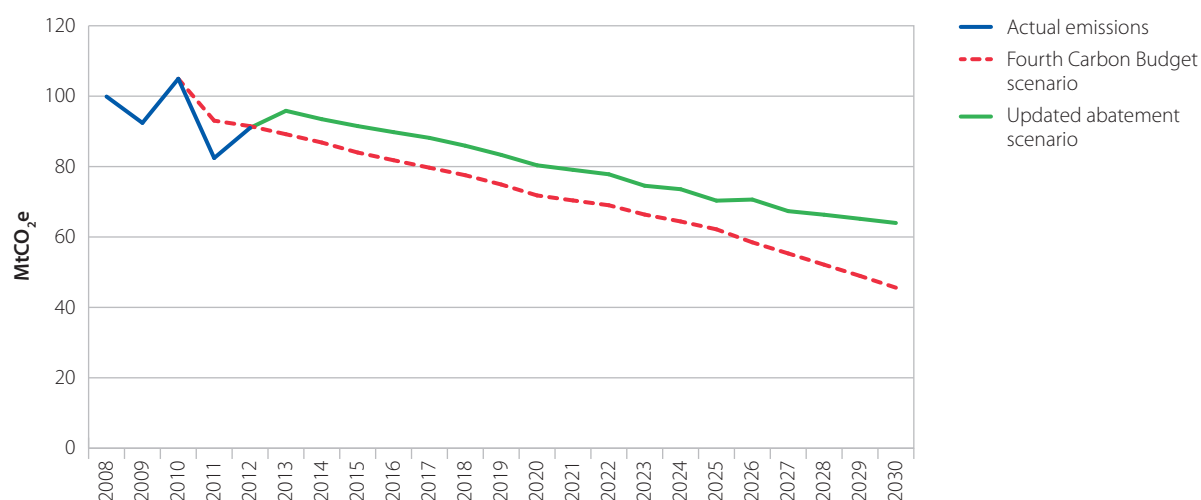
Preparing for 2050

Beyond 2030, this scenario would keep open the option of reducing emissions to a very low level in 2050:

- There is further potential for fabric energy efficiency in the residential sector, with insulation of many of the remaining 4 million or so solid wall properties, as well as potentially additional insulation measures to some of the lower efficiency cavity-walled stock.
- Further efficiency improvements in the commercial sector are possible, linked to refurbishment opportunities.
- Further roll-out of heat pumps and low-carbon district heating to all sectors would be possible as a result of supply-chain development in the 2020s.

By 2050, we assume that these measures could reduce buildings emissions close to zero carbon.

Figure 3.6: Updated abatement scenario for buildings to 2030



Source: CCC modelling.

Notes: Direct emissions only.

Sensitivities and flexibilities

While the measures included in our updated analysis are all feasible and in most cases cost-effective, deliverability will be challenging, especially in the residential sector where uptake in millions of households is required. Some of the measures are potentially high hassle (e.g. internal solid wall insulation) or provide a different kind of service from the incumbent technology (e.g. heat pumps). Furthermore, as outlined in section 3, some measures (in particular solid wall insulation and some cavity wall insulation) are now less cost-effective than we previously assumed.

In view of these uptake challenges, we have considered various sensitivities around key measures:

- **Lower uptake of solid wall insulation.** If we assume that uptake reaches 1 million⁹ by 2022 and is flat out to 2030, direct abatement over the fourth carbon budget period would decline by 6 MtCO₂ to 3 MtCO₂.
- **Lower uptake of cavity wall insulation.** If uptake is focused on the most cost-effective cavity walls only (e.g. easy-to-treat and low-cost hard-to-treat), up to 2 MtCO₂ of direct abatement from the more expensive hard-to-treat cavities would be lost during the fourth carbon budget.

⁹ The level assumed by DECC's 2012 Green Deal/ECO Impact Assessment.

- **Lower deployment of heat pumps.** We have considered a case where uptake in the residential sector rises to only 2.5 million by 2030 (under 1 million in 2025). This is based on the minimum level of uptake required to keep open the option of decarbonising heat to 2050 with heat pumps as the main technology¹⁰. In the public and commercial sectors, we consider lower uptake consistent with lower ambition to 2020 under the RHI. Altogether, this is equivalent to 24 Mt CO₂ less abatement between 2023 and 2027.
- **Turning down the thermostat.** There is considerable uncertainty over whether it will be possible to realise savings from turning down thermostats. This reflects several uncertainties: it is unclear what internal temperature is assumed in DECC's projections; some households have already turned down temperatures and may have limited scope to do so again (e.g. 2011 EST survey found that 60% of households claimed to have done this), and consumer behaviour is inherently uncertain. We therefore consider a sensitivity where no further households turn down their thermostats, which would increase annual direct emissions by 2 MtCO₂ by 2030.

As set out in chapter 1, the fourth carbon budget has some flexibility to accommodate these sensitivities. Lower delivery in some areas could be offset by increased delivery elsewhere. Additionally, our overall assessment of the cost-effective path is that this would reduce emissions by more than required under the legislated budget, so that some under-delivery can be accommodated.

5. Benefits of delivering the measures in the fourth carbon budget

The majority of measures in our analysis are lower cost than the expected carbon price and/or are required to prepare for 2050. A delay in their deployment would therefore increase costs. We have quantified the costs for such a delay:

- Overall, the benefits of the fourth carbon budget buildings abatement versus a ten-year delay are around £31 billion. This includes benefits of £35 billion from low-carbon heat, offset slightly by a cost of £4 billion from energy efficiency where we assume some uptake of insulation measures which are not cost-effective in the 2020s.
 - Significant abatement from low-carbon heat is cost-effective in the 2020s compared to our central scenario for carbon prices (see Chapter 1). In the case of heat pumps, the costs range from negative abatement costs where these are replacing oil boilers or electric heating, to higher abatement costs where they replace gas boilers of around £50/tCO₂. The cost data is weaker for district heating, and we therefore assume abatement costs are zero, on the basis that our analysis to 2050 shows that levelised district heating costs are close to the levelised costs of heat from a gas boiler (not including the carbon cost).

¹⁰ As calculated by Frontier Economics for CCC (2013) Pathways to high penetration of heat pumps. The critical path scenario developed in this study considered the minimum level of uptake given supply and demand constraints to keep in play a 2050 decarbonisation scenario with a high heat pump component. It implies additional costs as it is below the cost-effective level of uptake. Failing to achieve this critical path uptake could imply further costs from boiler scrappage in order to meet the 2050 target.

- Based on average solid wall insulation costs (e.g. £859/tCO₂ for external insulation and £329/tCO₂ for internal insulation) solid wall insulation is not cost-effective in 2030 and does not offer a saving relative to delayed action. However, they are important for the roll-out of heat pumps and for addressing social factors (e.g. fuel poverty). The costs and benefits of the measures are set out in table 3.1.
- The benefits would be larger in a world of high fossil fuel or carbon prices. Even in a world of low fossil fuel prices or carbon prices, the benefits would outweigh the costs (see table 3.2). Aiming for the cost-effective path is therefore a low-regrets strategy.

Table 3.1: Abatement costs of measures and importance to 2050

Measure	Cost per tonne CO ₂ in 2025 (weighted average)	Importance to 2050
Residential buildings, energy efficiency – mainly solid wall insulation	£686	Thermal insulation measures are critical for preparing buildings for low-carbon heating measures such as heat pumps.
Non-residential buildings, energy efficiency	Negative	In residential buildings, the average abatement costs for insulation measures are higher through the 2020s than in the previous years as they consist of more expensive measures such as solid wall insulation.
Low-carbon heat	£17	Decarbonising heat in buildings to 2050 requires building up capacity and supply-chains through the 2020s, particularly in the case of heat pumps and district heating. Abatement costs for low-carbon heating technologies mostly decrease throughout the 2020s with learning.
of which heat pumps	c. £0	Take up of at least 2.5 million heat pumps in homes by 2030 keeps open the option of high heat pump deployment to 2050.
of which district heating	£0	Building up capacity to 30 TWh in 2030 keeps in play a high penetration to 2050, of up to 160 TWh/year.
Notes: Abatement costs are calculated for measures taken up in the 2020s.		

Table 3.2: Value of buildings abatement – cost sensitivities

Central	Low carbon prices	High carbon prices	Low fossil fuel prices	High fossil fuel prices
£30 billion	£15 billion	£50 billion	£20 billion	£45 billion
Source: CCC modelling. Rounded to the nearest 5 billion.				

Residential energy efficiency measures also have important benefits beyond carbon saving – they increase affordability, reduce fuel poverty and can have health benefits:

- **Affordability:** Home energy bills are expected to increase by around £150 between now and 2030 due to low-carbon measures and the rising carbon price. Energy efficiency measures can help to offset these increases (see chapter 4 of the Advice Report for more detail).
- **Fuel poverty:** Depending on the definition used, there up to 4.5 million fuel poor households in the UK. Fuel poverty is particularly prevalent in the devolved administrations. The 2012 Hills Review on Fuel Poverty has argued that energy efficiency measures are the most effective way of dealing with fuel poverty (see chapter 4 of the Advice Report).
- **Health benefits:** Even where affordability is not an issue, better insulated homes (e.g. less condensation) can have benefits for people with health conditions such as asthma. For example, research for DECC suggests that the value of the health saving per measure installed amounts to £969 for cavity wall insulation and £742 for solid wall insulation.

It is therefore appropriate to aim to deliver significant abatement in buildings, as included in our updated assessment. This will require policy strengthening to ensure that incentives for investment are in place and that barriers to deployment are addressed. We will consider policy in more detail in our 2014 progress report to Parliament, as part of our review of progress over the first budget period.

Chapter 4: Reducing emissions from industry

Introduction and key messages

In 2012, industry directly accounted for around 152 MtCO₂ (27%) of UK greenhouse gas (GHG) emissions, of which 116 Mt were CO₂ emissions. Industry also consumed 89 TWh (30%) of electricity in the UK, which equates to a further 47 MtCO₂ indirect emissions.

In our original 2010 advice on the fourth carbon budget, we suggested that the cost-effective path to the 2050 target involved direct emission reductions of 27% in industry by 2030 from 2008 levels. Measures to achieve these reductions included conventional energy efficiency, further efficiency improvements within carbon-intensive industries, deployment of low-carbon heat and use of Carbon Capture and Storage (CCS). These measures were cost-effective compared to our carbon price assumptions required to prepare for meeting the statutory 2050 target.

In this chapter we set out new evidence on industry emissions and abatement, updating our analysis accordingly. The key messages in the chapter are:

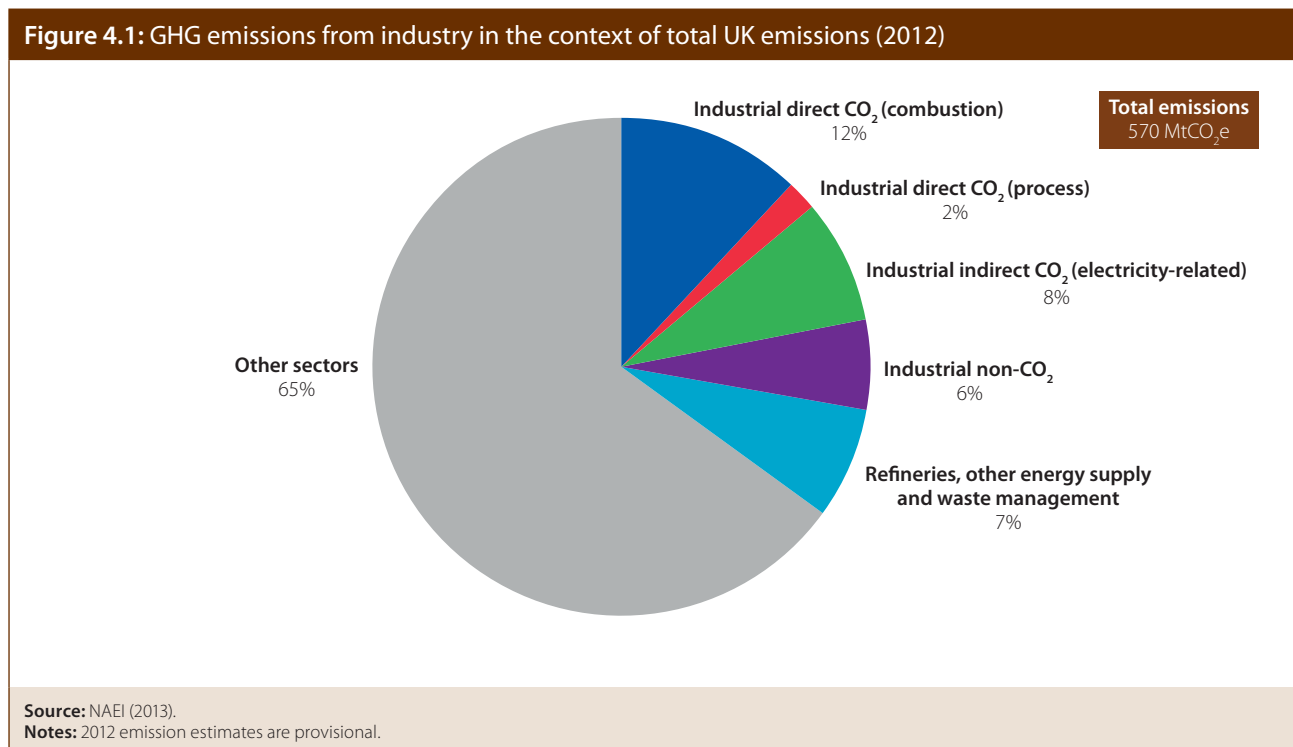
- DECC's projection of baseline industry emissions (without abatement) has fallen due to projected lower economic growth, higher energy costs and the impact of improvements to the modelling approach in line with the Committee's previous recommendations.
 - The 2010 projections estimated that industry would directly produce 127 MtCO₂ in 2030 – 90 MtCO₂ in the traded sector and 37 MtCO₂ in the non-traded sector.
 - The new projections estimate that industry will directly produce 95 MtCO₂ in 2030 – 70 MtCO₂ in the traded sector and 25 MtCO₂ in the non-traded sector.
- Our review of abatement opportunities in industry suggests a slightly lower level of abatement potential for industry to 2030 than in our original advice.
- Taken together, our updated estimate of the cost-effective path to 2050 involves lower emissions in industry to 2030. We now estimate that after abatement, industry will directly produce 65 MtCO₂ in 2030 (previously 86 MtCO₂) – 47 MtCO₂ in the traded sector (previously 61 MtCO₂) and 18 MtCO₂ in the non-traded sector (previously 25 MtCO₂).
- Relative to a path with no progress during the 2020s, our updated assessment suggests a saving of around £20 billion in present value terms under central case assumptions for fossil fuel and carbon prices.

We set out the analysis underpinning these conclusions in five sections:

1. Current emissions
2. Projected emissions before abatement action
3. Updated evidence on abatement options and costs
4. Projected emissions with abatement – an updated scenario for the 2020s
5. Benefits of delivering the measures in our scenario

1. Current emissions

In 2012, industry directly accounted for around 152 MtCO₂ (27%) of UK GHG emissions, of which 116 Mt were CO₂ emissions. Industry also consumed 89 TWh (30%) of electricity in the UK which equates to a further 47 MtCO₂ indirect emissions (Figure 4.1).



By 2030, three-quarters of CO₂ emissions and abatement will be from emissions covered by the EU Emission Trading Scheme (EU ETS).

- As of 2013, the EU ETS covers more than 11,000 factories, power stations, and other installations.
- In 2012, around 64% of all UK industry direct emissions were covered by the ETS. This 'traded sector' proportion is expected to rise to 74% by 2030.
- We assume that 76% of the direct CO₂ abatement in 2030 for industry is from traded sector emissions covered by the EU ETS.

We now consider the latest evidence on projected emissions and options to reduce these, and then set out a new updated scenario to 2030 in section 4.

2. Projected emissions before abatement action

The starting point for our analysis are energy demand and emissions projections without any action to reduce emissions. We use DECC Energy Model projections for this baseline which does not include any action to reduce emissions beyond those laid out in the Energy White Paper of 2007.

Since our original advice, DECC's baseline projections of industry energy use and emissions to 2030 have significantly reduced.

- We therefore assume that industry direct emissions reduce by 11% from 2012 to 2030, reaching 95 MtCO₂, 32 MtCO₂ lower than we previously assumed.
- We also assume that industry electricity demand falls 5% from 2012 to 2030, reaching 94 TWh, 48 TWh lower than we previously assumed.

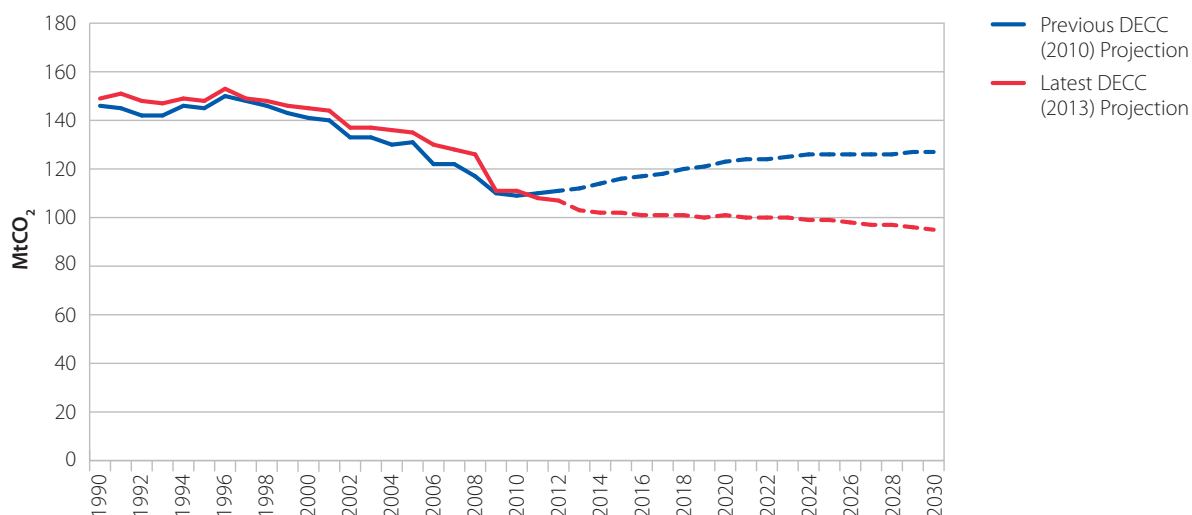
This lower baseline projection can be explained through assumptions about slower economic growth and higher energy prices, as well as the impact of improvements to the modelling approach (Box 4.1).

Box 4.1: Change in DECC baseline industry emission projections to 2030

DECC's projection of baseline industry emissions (without abatement) to 2030 has fallen significantly:

- In 2010, DECC projected that for a baseline with no emission abatement measures, direct emissions from industry and refineries from 2009 to 2030 would increase by 16%.
- However, the latest 2013 DECC projection estimates that baseline direct emissions from 2009 to 2030 will fall by 14%.
- Thus the projection of the 2030 baseline direct emissions from industry and refineries has fallen by 25% (Figure B4.1).

Figure B4.1: DECC Industry & Refineries Direct CO₂ Emission Projections (MtCO₂)



Source: DECC 2010 and 2013 Energy and Emission projections.

This substantial change in the emission projections between 2010 and 2013 is not unexpected:

- For our 2011 progress report to Parliament we commissioned Cambridge Econometrics¹ to review the DECC model and to provide alternative emissions projections.
- Cambridge's forecasts were around 20% lower than projected by DECC.
- The review suggested that the DECC model did not fully capture the impacts of the recession and other macroeconomic impacts on emissions.

DECC instituted a model review in 2011 and has since made significant modelling approach improvements, including: major changes to assumptions about industrial sub-sector growth, energy intensity and fuel share equations, as well as lower projections of industrial combined heat and power. These changes to the modelling have brought DECC's forecasts closer to the Cambridge Econometrics projection.

¹ <http://www.theccc.org.uk/publication/meeting-carbon-budgets-3rd-progress-report-to-parliament/>

3. Updated evidence on abatement options and costs

In our advice on the fourth carbon budget in 2010², we set out detailed assessments of the options for reducing emissions from industry. Since then, we have reassessed their costs and potential for deployment. This section sets out that updated evidence.

There is scope for reducing industry emissions through a range of measures over the next two decades and beyond. The majority of these measures are either negative cost or are, or are likely to become, cost-effective compared to the projected carbon price over this period (see chapter 1 for our price of carbon assumptions). They include:

- **Conventional energy efficiency.** Upgrades and replacements to existing processes and equipment to improve their energy efficiency, often at low cost with short payback periods.
- **Further options within carbon-intensive industry.** More fundamental changes to improve energy efficiency in the most carbon-intensive sectors (e.g. greater use of recycled steel, major process changes in refineries).
- **Low-carbon space heating.** Moving from fossil fuel sources to low-carbon sources like heat pumps for space heating; also use of waste heat in combined heat and power (CHP) applications.
- **Biomass and biogas.** Using bioenergy resources (e.g. biogas from anaerobic digestion and woody biomass) to meet heat loads where these meet required fuel standards.
- **Carbon Capture and Storage (CCS).** Application of carbon capture equipment to major emission sources, with deployment aligned to capital replacement cycles.

Given the limited availability of low-carbon generation to 2030 and rising demand from other sectors, our original advice for the fourth carbon budget did not assess the potential for widespread application of electricity within industry. However, we did state that electrification in industry may provide an additional abatement opportunity beyond 2030 (see Section 4).

Relatively slow pace and low-cost abatement eases competitiveness concerns, particularly with policies such as free EU ETS allowances (see chapter 4 of our summary report³).

As part of our update for the fourth carbon budget review, we commissioned Ricardo-AEA to review the feasibility of a wide range of abatement technologies across industry⁴. The review focused on the seven most carbon-intensive industries in the UK, accounting for over half of industrial emissions.

² <http://www.theccc.org.uk/publication/the-fourth-carbon-budget-reducing-emissions-through-the-2020s-2/>

³ <http://www.theccc.org.uk/publication/fourth-carbon-budget-review>

⁴ Ricardo-AEA – Updating and extending carbon budget trajectories: A review of the evidence, <http://www.theccc.org.uk/publication/fourth-carbon-budget-review>

The review generally reinforced our previous finding that there is some scope to reduce emissions in industry at low cost to 2030 through improvements to energy efficiency including CHP, use of biogas and biomass, low-carbon heat and potentially application of CCS in later years. The review also identified several areas where more may be possible, but was not able to quantify these on current evidence. In carbon-intensive industry, it raised questions about previously assumed abatement potential in two important areas, which we set out below and consider in our sensitivities in section 4.

Conventional energy efficiency

Our 2010 analysis of emissions reductions in industry to 2020 focused on cost-effective, short pay-back options for abatement, such as improvements to the efficiency of motors (which we refer to here as 'conventional energy efficiency').

There is a limited evidence base and we previously relied predominantly on DECC's ENUSIM model, which under-represents the opportunities for fuel switching and longer payback options within industry. We also highlighted that the accuracy of the data underpinning ENUSIM is reliant on the often limited ability and/or willingness (given commercial considerations) of industry to provide information regarding abatement opportunities.

Based on the review by Ricardo-AEA, we have found that the technologies likely to be available to 2020 are broadly unchanged from those previously modelled using ENUSIM. An exception is 'impulse drying' in the paper, printing and publishing sector where the review found that pilot demonstrations suggest limited energy efficiency improvements. The sector has not therefore taken up the technology and there are no plans to do so by 2030, but this does not materially affect emission abatement (less than 0.5 MtCO₂ per year).

We have therefore kept the conventional energy efficiency abatement options to 2020 broadly the same, with an adjustment for impulse drying.

As a result of our review and updated baseline emission projection to 2020, our assumed abatement from conventional energy efficiency has reduced from 4 MtCO₂ to 3 MtCO₂ in 2020.

Further options within carbon-intensive industry

For our original advice on the fourth carbon budget, we also included a number of new technologies and approaches in carbon-intensive industry which could result in substantial opportunities for abatement. This original advice was based on a study commissioned from AEA⁵ to consider more 'radical' energy efficiency options for the 2020s.

Based on the latest evidence from our review, the energy efficiency potential during the 2020s has been left broadly unchanged.

5 <http://archive.theccc.org.uk/aws2/4th%20Budget/Final%20Report%20ED56369.pdf>

The review did question the potential of the two largest abatement options, in the steel and refineries sectors. The evidence on these, however, is limited. We have therefore decided to retain these abatement options but will review them further when more evidence is available (Boxes 4.3 and 4.4).

Ricardo-AEA did not quantify any further abatement, but identified potential options that will need to be analysed in the future. These include:

- Considerable potential for the use of waste heat from refineries, as is currently done in Scandinavia with wide use of district heating. However, there is currently no market in the UK for the heat, a heat distribution market or significant effort to co-locate users of low-grade heat. Investment from outside the industry would be needed to achieve this.
- Potential for a future range of low-carbon cement types if there were demand from the construction sector.
- Replacement of paint shops with more efficient units in the motor industry (30% of site energy use).
- Further abatement potential if recycling quality and quantity improved for many materials (e.g. glass).

We have therefore broadly kept the same potential abatement options from energy efficiency in carbon-intensive industry to 2030, with a few small adjustments based on new evidence.

As a result of our review and updated baseline emission projection to 2030, our assumed abatement from energy efficiency within carbon-intensive industry has reduced from 12 MtCO₂ to 9 MtCO₂ in 2030.

We consider lower abatement potential for the refineries and steel sectors in our sensitivities (see section 4).

Box 4.3: Abatement potential in the iron and steel sector

The AEA 2010 study identified a switch from integrated blast furnace to electric arc furnace (EAF) melting and increased use of recycled scrap steel as a cost-effective abatement opportunities.

- AEA proposed a technically possible scenario of increasing the recycled content of UK steel from 37% to 52%, a 2.7 Mt shift in steel production to EAF – abating 4.75 MtCO₂ by 2030.
- The Ricardo-AEA review confirmed that this would require a major change to the industry and significant increase in available quality scrap – an extra 2 Mt – where most UK steel scrap is currently exported. Globally, 450 Mt of scrap steel is recycled annually, but scrap is considered and priced as a scarce resource.
- Investment, further R&D and assured access to competitive priced electricity would be needed, but technically it remains a potential abatement option for the UK.
- The AEA 2010 study estimated an alternative ‘realistic’ scenario was an increase to recycled content of UK steel of 41%, with the abatement of 1.2 MtCO₂ in 2030.

The review did not find evidence sufficient to suggest taking this 52% recycled content option out of our abatement scenario.

Recognising the potential barriers of this option and that CCS may be an alternative solution, we have considered the lower 41% recycled content option in our sensitivities scenario (see section 4).

More in-depth research and analysis is needed in the iron and steel sector to provide more certainty about abatement potential in this sector. We will review the potential again after when new evidence becomes available such as DECC’s 2050 Decarbonisation Roadmaps by 2015 and the DECC/BIS Industrial CCS study in 2014.

Box 4.4: Abatement potential from refineries

The AEA 2010 study highlighted that there was significant emissions abatement potential from refineries in the UK by bringing them up to best performing standard globally.

Evidence underpinning our previous advice suggested that ‘whole refinery optimisation’ could bring cost-effective abatement of 3.5 MtCO₂ by 2030.

We highlighted potential barriers to this measure:

- The uncertain future demand for refined fuels given the expected uptake of electric vehicles.
- The competition for capital investment across the whole supply chain for petroleum products.

However, the Ricardo-AEA review concluded that the barriers are mainly economic rather than technical, although the capital cost of meeting them could be high.

When discussing this option with industry, they raised concerns about the estimate of the emissions abated to 2030:

- Some of this optimisation may have occurred already.
- It may not be possible to reduce CO₂ intensity to levels in Benelux/Scandinavian refineries due to the size and complexity of UK refineries.

The review did not find evidence to provide an improved abatement estimate from refinery optimisation. We have therefore maintained the original abatement potential in our abatement scenario.

Recognising the uncertainty in this abatement estimate, we have assumed only half of the abatement potential can be delivered in our sensitivities scenario (section 4).

Further in-depth research and analysis is needed in the refineries sector to provide more certainty about the potential for abatement. We will review the potential again after completion of further studies such as DECC’s 2050 Decarbonisation Roadmaps by 2015.

Low-carbon space heating

For our original advice on the fourth carbon budget, we assumed a total industrial heat demand in 2030 of around 180 TWh, of which 30 TWh was for industrial space heating and 150 TWh for process heat. We assumed that around half of space heating demand could be met through uptake of heat pumps.

We commissioned Frontier Economics and Element Energy to review the feasibility of our heat pump scenarios.

The review suggested changes to our previous heat modelling through higher capital costs from lower learning rates, lower heat pump performance, only partially offset by lower supply-side constraints compared to our previous estimates.

Further details of the Frontier Economics/Element Energy analysis and changes to the heat modelling can be found in Chapter 3.

As a result of our review and updated baseline heat demand of around 120 TWh in 2030, of which 20TWh is for space heating, we assume around half could be met through uptake of heat pumps. Our assumed abatement from low-carbon space heating in industry has therefore reduced from 5 MtCO₂ to 2 MtCO₂ in 2030.

Biomass and biogas

For our original advice on the fourth carbon budget, we assumed that a quarter of total industrial heat demand of around 180 TWh could be generated through biomass and biogas.

We reviewed the suitability of industrial heat loads for biomass. After consulting with industry, we included new evidence of lower biomass suitability for the food, drink & tobacco, cement and lime sectors. Our assumptions about the suitability of biomass for all other industrial sectors remain unchanged from our original fourth carbon budget analysis.

As a result of our review and updated baseline heat demand of around 120 TWh in 2030, we assume around a third could be generated through uptake of biomass and biogas. Our assumed abatement from biomass and biogas has reduced from 14 MtCO₂ to 11 MtCO₂ in 2030.

In total, we have reduced low-carbon heat abatement in our scenario from 20 MtCO₂ to 14 MtCO₂ in 2030.

Carbon Capture and Storage

Carbon Capture and Storage (CCS) technology is most frequently discussed in the context of power generation. However, it is likely that this technology will be feasible in energy-intensive industries including iron and steel, industrial Combined Heat and Power (CHP), refining, cement and chemicals.

We previously commissioned Element Energy in 2010⁶ to assess the viability of CCS in industry. We have continued to use the results of their analysis that suggests that CCS could be both widely applicable in energy-intensive industries and cost-effective. CCS could reduce emissions from energy-intensive industry by 5 MtCO₂ in 2030 and 33 MtCO₂ in 2050.

As discussed in our report on *'The 2050 target'*⁷, CCS in industry is a key option to meet the 2050 target. Given that industrial CCS projects have not been funded under the current UK CCS competition and that there has been limited progress internationally, an approach to developing industrial CCS demonstrations compatible with required deployment in the 2020s is required. This would lay the foundations for deep cuts in industry emissions in the period to 2030 and beyond.

4. Projected emissions with abatement – an updated scenario for the 2020s

In our 2010 fourth carbon budget advice, we developed an abatement scenario involving measures that were likely to be economically-sensible in a carbon-constrained world – measures that are important on the path to the 2050 target and that are cost-effective compared to expected carbon prices over investment lifetimes.

Outlook to 2020

The starting point for our abatement scenario was a projection for emissions in 2020. We have updated our projection based on the new evidence since our original advice.

We have assumed lower industry emissions to 2020, as a result of the new DECC baseline emissions projections for industry and our updated assumptions on abatement potential in section 3.

- Industry direct emissions would reduce by 14% from 2012 to 2020, reaching 92 MtCO₂, 20 MtCO₂ lower than we previously assumed.
- Traded sector industry emissions would reduce by 7% from 2012 to 2020, reaching 67 MtCO₂, 17 MtCO₂ lower than we previously assumed.
- Non-traded sector industry emissions would reduce by 28% from 2012 to 2020, reaching 25 MtCO₂, 4 MtCO₂ lower than we previously assumed.

We have used this updated analysis as an entry point for our path from 2020 to 2030.

The path from 2020 to 2030

We have revisited our assessment for the 2020s based on the latest emission projections and our review of potential abatement. As set out in section 3, we have made a number of small changes to the scenario in terms of implementation of abatement measures.

6 http://archive.theccc.org.uk/aws2/0610/pr_supporting_research_element_Energy_CCS_on_gas_and_industry.pdf

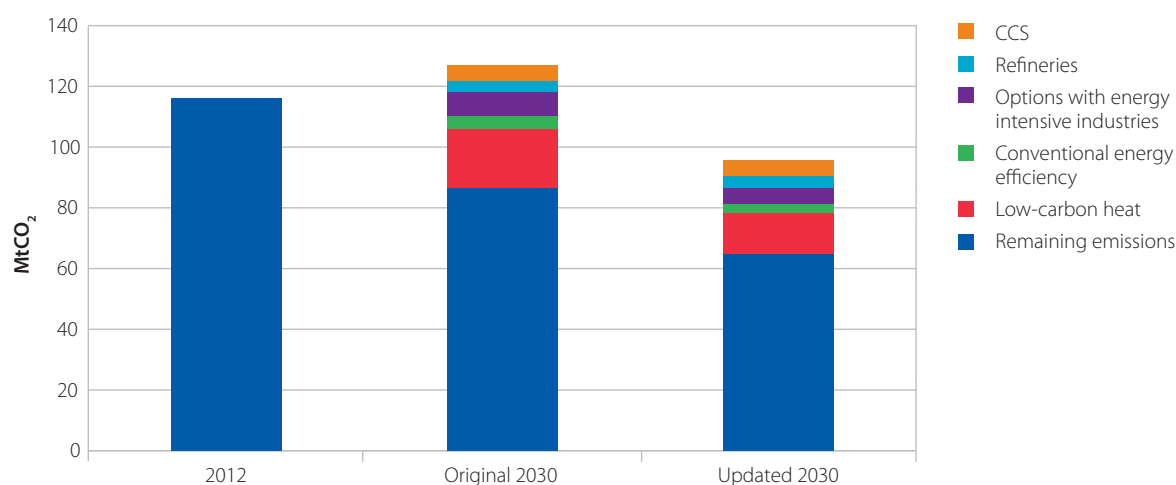
7 <http://www.theccc.org.uk/publication/international-aviation-shipping-review/>

We have therefore assumed reduced industry emissions to 2030 (figure 4.2).

- Industry direct emissions would reduce by 40% from 2012 to 2030, reaching 65 MtCO₂, 22 MtCO₂ lower than we previously assumed.
- Traded sector industry emissions would reduce by 35% from 2012 to 2030, reaching 47 MtCO₂, 14 MtCO₂ lower than we previously assumed.
- Non-traded sector industry emissions would reduce by 50% from 2012 to 2030, reaching 18 MtCO₂, 8 MtCO₂ lower than we previously assumed.

We build this updated assessment into our economy-wide analysis in Chapter 1.

Figure 4.2: Original and updated fourth carbon budget industry abatement scenario for 2030



Source: NAEI (2013), DECC baseline projections, CCC analysis.

Notes: 2012 emission estimates are provisional.

Preparing for 2050

In our 2012 report on *'The 2050 target'*⁸ we highlighted areas in which we could further abate industry CO₂ emissions from 2030-2050.

- Further rollout of industrial CCS across the energy-intensive sectors.
- Further use of bioenergy especially used with CCS, or alternatively the increased use of wood in the construction industry.
- Given low-carbon electricity, there is a significant opportunity for electrification and use of hydrogen options to decarbonise combustion emissions.

⁸ <http://www.theccc.org.uk/publication/international-aviation-shipping-review/>

CCS in industry is a key option to meet the 2050 target and an approach to developing industrial CCS demonstrations compatible with deployment in the 2020s is required. This would lay the foundations for deep cuts in industry emissions in the period to 2030 and beyond. To ensure other options are available, it is important that scarce bioenergy resources are not locked in to use in other sectors. Power sector decarbonisation will also need to proceed in such a way that so that options are developed to further increase use of low-carbon generation after 2030.

Sensitivities and flexibilities

We have also considered various sensitivities around our updated assessment, to reflect potential deliverability barriers.

The measures included in our updated abatement scenario are feasible and cost-effective compared to the carbon price. However, our review has highlighted potential barriers and uncertainty in the estimated abatement for a few of the options included. In addition, given the slow progress in CCS demonstration, there are risks of delay in its use in the industrial sectors. We capture these uncertainties in the following sensitivities.

- **Lower abatement potential in refinery optimisation.** We assume that only half of the abatement potential can be delivered. This would reduce abatement in 2030 by 2 MtCO₂.
- **Lower growth in the use of recycled steel.** We have assumed an increase to recycled content of UK steel from 37% to 41%. This would reduce abatement in 2030 by 2.5 MtCO₂.
- **No industrial CCS by 2030.** We have assumed a 10 year delay in CCS technology development so that there will be no industrial CCS deployed by 2030. This would reduce abatement in 2030 by 5 MtCO₂.

Overall this would mean a reduction in abatement of 9 MtCO₂ (all traded emissions). Direct emissions in industry would be 75 MtCO₂ in 2030, still lower than the 86 MtCO₂ assumed in our original 2010 analysis. However, risks attached to the 2050 target would be increased, particularly if potential to apply CCS to industry is reduced.

As set out in Chapter 1, the budget involves flexibility to accommodate these sensitivities. Lower delivery in some areas could be offset by increased delivery elsewhere. Additionally, the cost-effective path would reduce emissions by more than required under the legislated budget, so that some under-delivery overall can be accommodated within the economy-wide budget.

5. Benefits of delivering the measures in our scenario

The measures in our scenario are cheaper than the expected carbon price 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:

- Overall, the benefits of the fourth carbon budget abatement in industry versus a ten-year delay are around £20 billion. This includes benefits of £10 billion from energy efficiency improvements, around £5 billion from low-carbon heat and around £5 billion from deployment of CCS. See table 4.1 below for abatement cost of options and importance to 2050.
- Benefits of abatement would be higher if fuel costs or the carbon price would be higher. Even with low fuel costs or carbon prices there would still be cost savings of acting in the 2020's, so pursuing the cost-effective path is a low-regret strategy. See table 4.2 below for estimates.
- Section 4 highlighted that delaying action on technologies like industrial CCS in the 2020's will increase risk of delivery to meet the 2050 target.

It is therefore appropriate to aim to deliver significant abatement in the industry sector, as included in our abatement scenario. This will require policy strengthening to ensure that incentives for investment are in place and that barriers to deployment are addressed. We will consider policy options in more detail in our 2014 progress report to Parliament, as part of our review of progress over the first budget period.

Table 4.1: Abatement costs of options and importance to 2050

Measure	Cost per tonne CO ₂ in 2025 (weighted average)	Importance to 2050
Further options within carbon-intensive industry	-£115	Further energy-efficiency of carbon-intensive industry is essential to meet the 2050 target. The measures included are also significantly cost-effective.
<i>Of which refinery optimisation</i>	-£132	
<i>Of which increased use of scrap in electric arc furnace</i>	-£73	
Low-carbon heat	-£12	Decarbonising heat in industry to 2050 requires building up capacity and supply-chains through the 2020s, particularly in the case of heat pumps
<i>Of which low-carbon space heating</i>	-£16	
Carbon Capture and Storage	£36	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 modelling. Notes: Abatement costs are calculated for measures taken up in the 2020s.

Table 4.2: Net present value under different carbon price and fossil fuel price assumptions

Central assumptions	Low carbon prices	High carbon prices	Low fossil fuel prices	High fossil fuel prices
£20 billion	£10 billion	£30 billion	£15 billion	£25 billion

Source: CCC modelling

Chapter 5: Reducing emissions from transport

Introduction and key messages

In 2012 domestic transport CO₂ accounted for 20% (116 MtCO₂) of UK emissions covered by carbon budgets.

In our original 2010 advice on the fourth carbon budget we proposed a scenario in which domestic transport emissions were reduced by 24% by 2025 relative to 1990 levels, and 34% by 2030, based on improving efficiency of conventional vehicles, a shift to ultra-low emissions vehicles (e.g. plug-in hybrid electric vehicles) and some moderation of demand growth. This was our best estimate of the cost-effective path to the UK's target of an 80% emissions reduction by 2050, involving those measures that were cost-effective compared to our carbon price assumptions and/or required to prepare for meeting the statutory 2050 target.

In this chapter we set out new evidence on transport emissions and abatement options and update our assessment of abatement potential accordingly. Specific changes in the evidence base include: new emissions projections produced by DfT; updated projections for the costs of all vehicle types; analysis we have commissioned on consumer barriers to take-up of electric vehicles.

Our updated scenario leads to slightly greater reductions in emissions in the fourth carbon budget period (to 82 MtCO₂ in 2025, a 31% reduction compared to 1990 levels). Relative to a path with no progress during the 2020s, this scenario offers a saving of £30-35 billion in present value terms under central case assumptions for fossil fuel and carbon prices.

This reflects the specific conclusions from our new analysis:

- Demand growth has been slightly slower than we expected as the economic slowdown continues to affect travel demand. The latest baseline emissions projections reflect this and have been revised down by 13% in 2030 relative to assumptions in our original advice.
- There is considerable scope for improving conventional vehicle efficiency in cars, to 110 gCO₂/km in 2020 and to 80 gCO₂/km in 2030, as we assumed in our original advice. Recent progress in this area has been strong, and an agreement to limit emissions from all new cars to 95 gCO₂/km by 2021 (95% of cars by 2020), has recently been reached at EU level (to be ratified by the EU Parliament and Member States).
- It remains appropriate to aim for a significant penetration (e.g. 60% of new car purchases) of plug-in hybrid vehicles (PHEVs), battery electric vehicles (BEVs) and hydrogen fuel cell vehicles (HFCVs) by 2030. Our new analysis gives us more confidence that this can be delivered, albeit with a slightly slower trajectory relative to our previous assessment, reflecting projected production capacity.

- There is scope for some use of biofuels in surface transport but, given continued uncertainty over sustainability issues and technologies for advanced biofuels, we continue to limit the take-up of biofuels in the 2020s to a level indicated by the Gallagher Review¹ of between 5-8% by energy in 2020.
- It continues to be appropriate to include cost-effective abatement from measures aimed at reducing demand through eco-driving, modal shift and streamlining freight operations. Together, these measures offer emissions reductions of around 4.5 MtCO₂ in 2030.

We set out the analysis underpinning these conclusions in five sections:

1. Current emissions
2. Latest projections for emissions before abatement action
3. Updated evidence on abatement options and cost
4. Projected emissions with abatement – an updated scenario for the 2020s
5. Benefits of delivering the measures in the fourth budget period

1. Current emissions

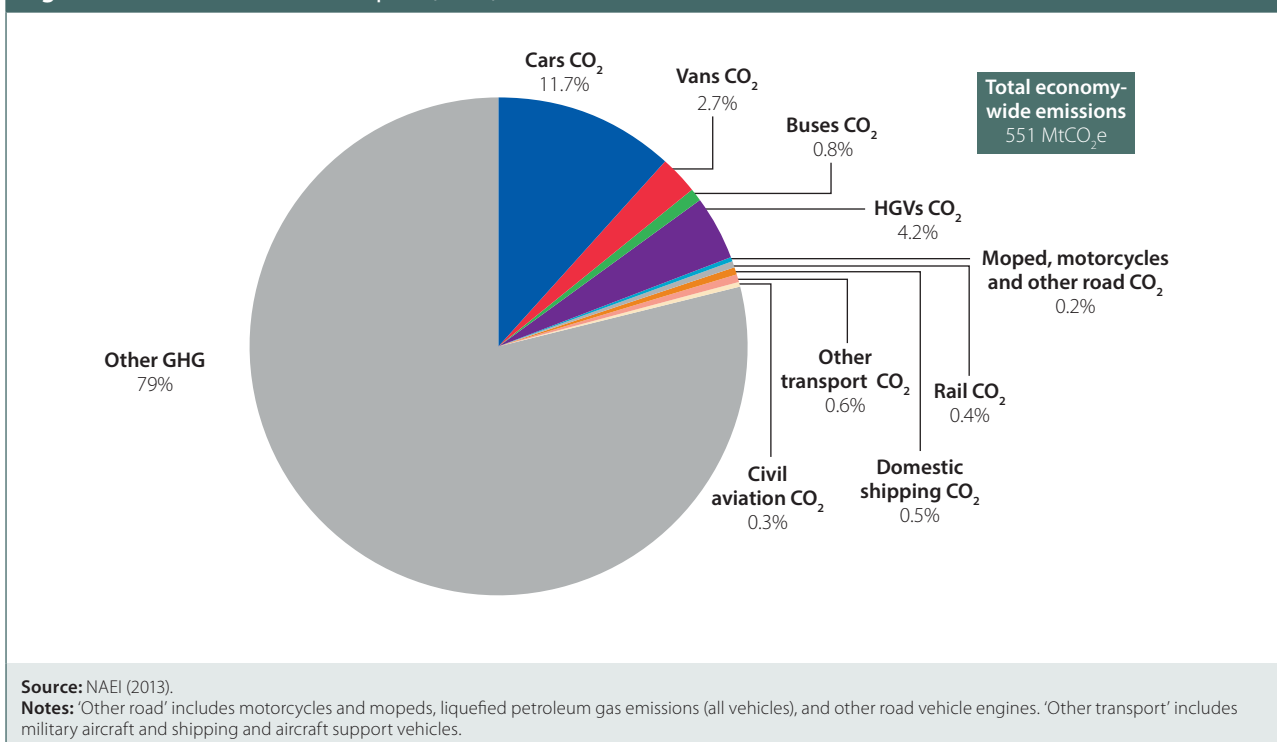
Domestic transport CO₂ emissions were 116 MtCO₂ in 2012, down from 117 MtCO₂ in 2011, and accounting for 20% of total UK GHG emissions covered by carbon budgets. A breakdown of emissions by mode is not yet available for 2012. However in 2011 (Figure 5.1):

- **Surface transport** emissions were 110 MtCO₂. Cars accounted for the majority of these emissions (59%), followed by HGVs (21%), vans (14%), buses (4%), mopeds and motorcycles (0.5%); rail accounted for the remaining 2%.
- **Domestic aviation and shipping** emissions were 4.2 MtCO₂ in total.
- **Other** domestic transport emissions were 3.2 MtCO₂.

Emissions from international aviation and shipping were 42.5 MtCO₂ in 2011. These are not currently included in carbon budgets, but are covered by the UK's 2050 target to reduce emissions by 80% relative to 1990.

¹ Gallagher (2008) *The Gallagher review of the indirect effects of biofuels production*.

Figure 5.1: Emissions from transport (2011)



Given transport's high share of total emissions and the availability of options to reduce and possibly eliminate emissions, we concluded in our original fourth budget advice that the aim should be 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.

2. Latest projections for emissions before abatement action

Our starting point when developing a trajectory to meet our longer-term targets is to assess demand and emissions projections without any action to reduce emissions. To develop this 'baseline', we use road travel demand projections from DfT's National Transport Model (NTM). This allows for changing fossil fuel prices, economic growth and demographics.

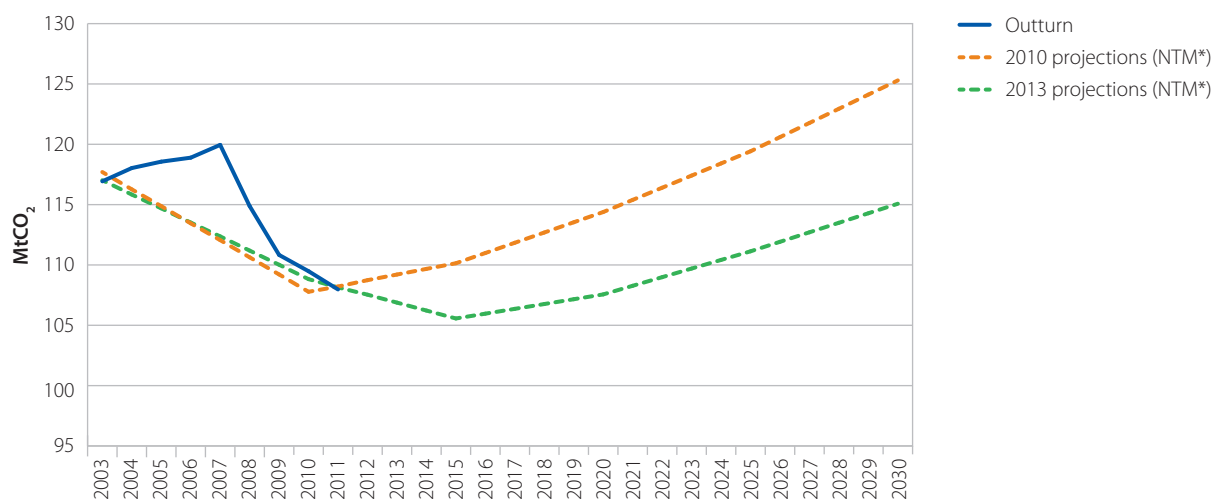
Since our original advice, assumptions for the drivers of travel demand have changed, with slower expected economic growth and a higher projection for the oil price (see Chapter 1). As a result, the NTM now projects lower baseline growth in travel demand for cars and vans, with growth of 13% in car vehicle-kms (previously 18%) and 49% in van vehicle-kms (previously 59%), but slightly higher growth in HGV vehicle-kms (9% versus 7% previously) between 2010 and 2030.

To project emissions, these increases in travel demand are combined with modelled carbon intensities (which are a function of vehicle efficiencies at different speeds, and carbon content of fuels used). Since our original advice, there have been some updates to the assumptions for vehicle efficiencies used in the baseline, reflecting the latest evidence. Greater improvements in vehicle efficiency between 2010 and 2030 are assumed for cars (13% compared to 9% previously) and vans (13% compared to no improvement previously), while smaller improvements are assumed for HGVs (2% compared to 7% previously).

Given these assumptions, the NTM projects growth in road transport emissions of 6% (previously 16%) between 2010 and 2030 in the absence of any abatement policies (Figure 5.2).

However, as we set out in section 4 below, policies to which the Government have already committed will reduce emissions below this level by 2020 and options exist to continue emissions reductions through the 2020s. We now turn to these options.

Figure 5.2: UK road transport emissions, outturn and baseline projections (2003-2030)



Source: NAEI (2013), NTM for CCC (2010, 2013), CCC estimates.

Notes: *Includes projected car, van, HGV and PSV emissions from the NTM plus CCC estimates of emissions from other road transport modes not covered by the NTM, based on their historic share. The NTM projects emissions from a base year of 2003, at five-yearly intervals starting in 2010; intermediate years have been interpolated.

3. Updated evidence on abatement options and costs

In our original advice on the fourth carbon budget we set out detailed assessments of the options for reducing emissions from surface transport. Since then, we have reassessed their costs and potential for deployment. This section sets out that updated evidence.

There is scope for significant reduction in surface transport emissions over the next two decades and beyond, through a range of measures relating to technology and behaviour change. The majority of these measures are either negative cost, or are likely to become cost-effective compared to the projected carbon price over this period. They include:

- Improvements in conventional vehicle efficiency, for example through increased hybridisation, downsizing of engines with turbocharging and use of advanced lightweight materials.
- Uptake of ultra-low emission vehicles, including battery electric, plug-in hybrid and hydrogen fuel cell vehicles.
- Penetration of biofuels, provided these offer emissions reductions on a lifecycle basis, and meet other sustainability criteria.
- Roll-out of Smarter Choices programmes, which aim to reduce car trips through encouraging modal shift, car sharing, remote working etc.
- Uptake of eco-driving, a more efficient driving style which maximises fuel efficiency through more gradual acceleration and braking etc.
- Enforcement of the speed limit on motorways, which helps to improve fuel efficiency.
- Improvements in freight operations to reduce mileage from HGVs for a given amount of haulage.

Additional options which we have identified but not previously incorporated in our scenarios for meeting carbon budgets include road pricing, electrification of rail, reduction of the speed limit on motorways and use of natural gas in HGVs.

In domestic shipping, since 2010 we have published detailed evidence on potential for reducing UK shipping emissions². We have updated our scenarios to take account of the latest evidence and policy developments (see section 4).

Improvements in conventional vehicle efficiency

New evidence on potential to improve conventional vehicle efficiency generally reinforces our previous conclusion that significant improvement is feasible and desirable:

- New car and van efficiency has continued to improve in recent years, largely a result of EU legislation which sets targets for the average emission of new cars and vans sold. As set out in our 2013 progress report, average new car CO₂ in the UK fell by 3.6% to 133 gCO₂/km in 2012, while new van CO₂ fell by 4.9% to 188 gCO₂/km.

² CCC (2011) *Review of UK Shipping Emissions*, CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*.

- In 2012, we commissioned AEA Technology to review the potential and costs of increasing vehicle efficiency³. This analysis confirmed previous estimates that by 2030 average test-cycle emissions from conventional new vehicles could reach 80 gCO₂/km for cars, 120 gCO₂/km for vans and around 600 g/km for HGVs (410–665 gCO₂/km depending on size). Moreover, the analysis suggested that this could be achieved at lower cost than previously estimated (–£80/tCO₂ versus +£65/tCO₂ previously for cars, £-110/tCO₂ versus £-90/tCO₂ previously for vans and -£150/tCO₂ versus -£110/tCO₂ for HGVs).
- Subsequent work by Ricardo-AEA for the European Climate Foundation⁴, building on their modelling for CCC, suggested that costs for light duty vehicles could be even lower (e.g. as a result of revised cost estimates for light-weighting), and that there may be scope for emissions to fall further in the long term. They set out a scenario in which increasing penetration of hybridised cars leads to average test cycle surface emissions of 60 g/km by 2030 required in the longer term.

These efficiency improvements could potentially make a useful contribution to meeting the fourth and subsequent carbon budgets. However there are limits to the emissions reductions available for conventional vehicles. New technologies will be required to achieve the deep cuts in transport emissions.

Take-up of ultra-low emission vehicles

Coupled with decarbonisation of power generation, battery electric and plug-in hybrid electric vehicles (BEVs and PHEVs) are very promising options for cutting surface transport emissions in the 2020s. The latest evidence on potential battery cost reductions and increased range confirms our previous finding that EVs can be a cost-effective option in the longer term (Box 5.1):

- Work we commissioned from Element Energy on battery costs, combined with analysis by Ricardo-AEA on wider vehicle efficiencies and costs, confirmed that by 2030, from an economic resource cost perspective, EVs would be a cost-effective abatement option against projected carbon prices.
- This would be true even for BEVs with a larger battery and range of 150 miles, compared to the 100 miles we assumed in our original advice on the fourth carbon budget⁵.

In addition to cost-effectiveness, however, it is important to consider whether consumers will actually be prepared to adopt the new technology, particularly while it is still developing. For this review, we commissioned a consortium led by Element Energy to assess potential barriers to EV uptake and measures required to overcome them.

³ AEA Technology (2012) *A Review of the Efficiency and Cost Assumptions for Road Transport Vehicles to 2050*.

⁴ Cambridge Econometrics, Element Energy, Ricardo-AEA (2013) *Fuelling Europe's Future*.

⁵ At a higher carbon price (e.g. £220/tCO₂, as assumed in Government values for 2050) higher battery capacity would be economic, such that BEVs with a range of 320 km (200 miles) would be cost-effective, and cheaper than PHEVs.

This analysis showed that achieving a high uptake of EVs by 2030 is possible given a good supply of models, and a package of measures to address current financial and non-financial barriers. These could include battery leasing to reduce purchase price premiums, a modest national rapid charging network to complement overnight home/depot-based charging, marketing to improve consumer awareness and acceptance, and provision of financial and/or non-financial 'cost-equivalent' support (Box 5.2).

Box 5.1: Cost-effectiveness of EVs

For our 2012 advice on meeting the UK's 2050 emissions reduction target⁶, we commissioned Element Energy to assess scope for reduction in EV battery costs. Element Energy concluded that there was scope for significant reduction, with the implication that both PHEVs and lower-range BEVs are likely to be cost-effective abatement options by 2030:

- Element Energy forecast that battery pack costs for BEV cars could fall from around \$725/kWh currently to around \$210/kWh by 2030, through improvements in energy densities and economies of scale. PHEV battery pack costs could fall to around \$1,325/kWh currently to around \$425/kWh by 2030.
- For a C/D segment BEV with a range of 240 km (150 miles), this implies a capital cost premium of £5000 relative to a comparable conventional vehicle. For a PHEV with a range of 30 km (20 miles), it implies a capital cost premium of £3500.
- However, electric cars are cheaper to run than conventional cars, given their significantly greater efficiency. We estimate a cost differential of around 2.4 pence/km for a C/D segment BEV car (1.9 pence/km for a PHEV), assuming EV charging takes place largely overnight using off-peak low-carbon generating capacity.
- The resulting abatement costs are £4/tCO₂ for new C/D segment BEV cars in 2030 and £-20/tCO₂ for new PHEVs, with ranges between £-115/tCO₂ to £+125/tCO₂ for BEVs and £-130 to £+90/tCO₂ for PHEVs depending on assumptions about technology costs, fossil fuel prices and time of day of charging (i.e. peak vs. off-peak).
- This compares to projected carbon prices over vehicle lifetimes of £130/tCO₂.

Looking beyond 2030, rising carbon prices would justify higher battery capacity, such that BEV cars with a longer range of 320 km (200 miles) would be cost-effective by 2050 (and cheaper than PHEVs facing a carbon price).

Energy system modelling for our previous advice on carbon budgets suggests that all cars and vans could need to be ultra-low emissions by 2050 as part of a cost-effective solution to meeting the UK's 80% emissions reduction target relative to 1990. Given stock turnover rates, this implies the need for significant penetration of ultra-low emissions vehicles (e.g. 60% of new sales) by 2030.

Source: Element Energy (2012) *Cost & Performance of EV Batteries*, CCC analysis

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

Box 5.2: New evidence on EV uptake

We commissioned Element Energy, with Ecolane Consultancy and Dr Jillian Anable from the University of Aberdeen, to review our uptake scenarios for electric vehicles. The key findings were:

- **Costs.** Capital costs are likely to remain a key barrier to the uptake of electric vehicles in the period to 2030. The lower running costs of EVs are not sufficient to offset higher purchase costs over required consumer pay back periods (which are much shorter than vehicle lifetimes). However battery leasing could be used to spread the purchase cost premium of EVs.
- **Supply.** A good supply of EV models and brands across vehicle segments is key to delivering high uptake. Automotive manufacturer announcements on planned releases and production capacity give confidence that this is achievable by 2030. We scale back our assumption on EV uptake in the UK in 2020, however, to better reflect likely share of projected overall EU production.
- **Consumer acceptability.** Consumer awareness and acceptance of EVs is currently low. A well-designed marketing campaign, complemented with direct exposure to EVs (e.g. through test drives), is needed to ensure all consumers understand EV capabilities. The 'neighbour effect' should also reduce bias against EVs among some consumer segments, as the technology becomes more familiar with increased sales.
- **Overnight charging.** Certainty of access to charging is a pre-requisite for BEV purchase, and best delivered overnight at home/depot. 70% of vehicle buyers currently have access to off-street parking where this could take place.
- **Public charging infrastructure.** A public rapid charging network would offer a number of additional benefits: increases the proportion of fleet vehicles for which BEVs are range-compatible, addresses perceived need for public charging among private buyers and reduces minimum charging times which currently act as a barrier to EV deployment.

These interventions can help deliver a high uptake of EVs. Nevertheless, it is possible that 'cost-equivalent' support for EVs may be required to 2030. This could be financial (e.g. grants) and/or non-financial (e.g. preferential access to parking). We will return to policy options for EVs in our 2014 progress report to Parliament.

These findings reinforce our previous conclusion that with appropriate support, high levels of EV penetration can be achieved by 2030, keeping open the option of a near-zero emissions transport fleet by 2050.

Source: Element Energy et al (2013) *Pathways to high penetration of electric vehicles*

Role for hydrogen

New evidence points to greater potential for hydrogen fuel cell vehicles (HFCVs) in the period to 2030 than we assumed in our original advice on the fourth carbon budget:

- Work by Ricardo-AEA, for our 2012 advice on meeting the UK's 2050 emissions target, suggested HFCV costs could be lower than we previously estimated (e.g. around £125/tCO₂ rather than £220/tCO₂ for a medium car).
- Phase 1 of the H2Mobility project, a joint industry and government project to evaluate the potential role for hydrogen in road transport, identified potential early adopters among car and van drivers, and suggested feasible uptake of around 10% of new sales by 2030 (Box 5.3).
- The Element Energy analysis we commissioned for this report suggests a 10% market share of HFCVs in 2030 could make an overall share of 60% for ultra-low carbon cars and vans more achievable, though with caveats around vehicle supply and competition for infrastructure support.

Nevertheless, in the near term, HFCVs do not appear to be as promising as a *mass market* proposition as plug-in electric cars and vans, partly due to higher purchase prices and also because of the challenges relating to a full-scale infrastructure for low-carbon production, transportation and storage of hydrogen⁷.

In the longer term, however, hydrogen vehicles could be useful as a complement to plug-in electric vehicles for the long-term decarbonisation of light vehicles. The Element Energy analysis we commissioned for this report suggests two areas where HFCVs could be particularly useful:

- For more demanding duty cycles where even longer-range BEVs may not be suitable.
- For new car buyers without access to off-street parking and hence readily available overnight charging.

In addition to cars and vans, we have previously recognised the potential in the longer term for hydrogen to reduce emissions from buses and HGVs, where battery electric vehicles may be unsuitable (e.g. due to size, weight and cost of the battery required), and if current significant challenges can be overcome (e.g. around hydrogen storage technology).

Meanwhile, there may be an opportunity to reduce emissions through use of natural gas in HGVs, depending on the source of the gas, and provided this does not 'lock out' the option of moving to hydrogen.

- A recent report for the Task Force on Fuel Efficient, Low Emission HGV Technologies⁸ identified well-to-wheel (WTW) emissions reductions (relative to diesel) of up to 65% for vehicles using biogas, and between -11% and 16% for vehicles using gas from fossil sources. There may be further benefits in terms of air quality, as particulate emissions from gas-fuelled vehicles are lower than from diesel vehicles.
- Further work is required to assess the overall benefits of switching from diesel to gas in HGVs in the longer term (e.g. if barriers to hydrogen fuel cell vehicles cannot be overcome), given some residual gas demand is likely in 2050 and that biomethane is expected to remain a fraction of overall gas supply.

⁷ See for example Box 4.4 in CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*.

⁸ Ricardo-AEA (2012) Opportunities to overcome the barriers to uptake of low emission technologies for each commercial vehicle duty cycle.

Box 5.3: H2Mobility

H2Mobility is a collaborative project between car manufacturers, utility companies and government departments to assess the potential for hydrogen fuel cell vehicles (HFCVs) and to develop an industry roadmap. Findings from Phase 1 of the project were published in April 2013.

- The findings, based on OEM cost and supply data and consumer decision making suggest that annual sales of 300,000 per year or a 10% market share could be achieved by 2030 as vehicles become cost-competitive and the hydrogen refuelling network develops.
- The cost premium, supply of HFCVs and refuelling infrastructure were found to be the biggest barriers to uptake.
 - The purchase price premium of HFCVs relative to diesel is high in initial years but is forecast to decline to near parity by 2030 as global production volumes increase. The study assumes that hydrogen will be offered at a lower price than diesel so that by 2030, total costs of ownership over a four year period are equivalent.
 - The volume and diversity of HFCVs is expected to increase as consumer take-up grows. OEMs are likely to focus on the high mileage, premium market segment where BEVs are less attractive due to battery weight constraints and where consumers are less price-sensitive. HFCVs could also be well suited to vans, many of which require a long range and value the fast charging that H2 offers.
 - To achieve the level of uptake identified, a refuelling network comprising 65 stations in 2015 would need to be developed and expanded over time as demand grows, rising to 1,150 stations by 2030. This would give all the UK access to at least one hydrogen refuelling station within their local authority district and would require funding of £420 million before stations become self-financing.
- There are different methods of producing hydrogen with different implications for emissions savings. The mix of processes used in the project implied 60% CO₂ emissions savings in 2020 relative to diesel and 75% in 2030 on a well-to-wheel basis.

Source: UK H2 Mobility (2013) *Phase I results*

Scope for increased use of biofuels

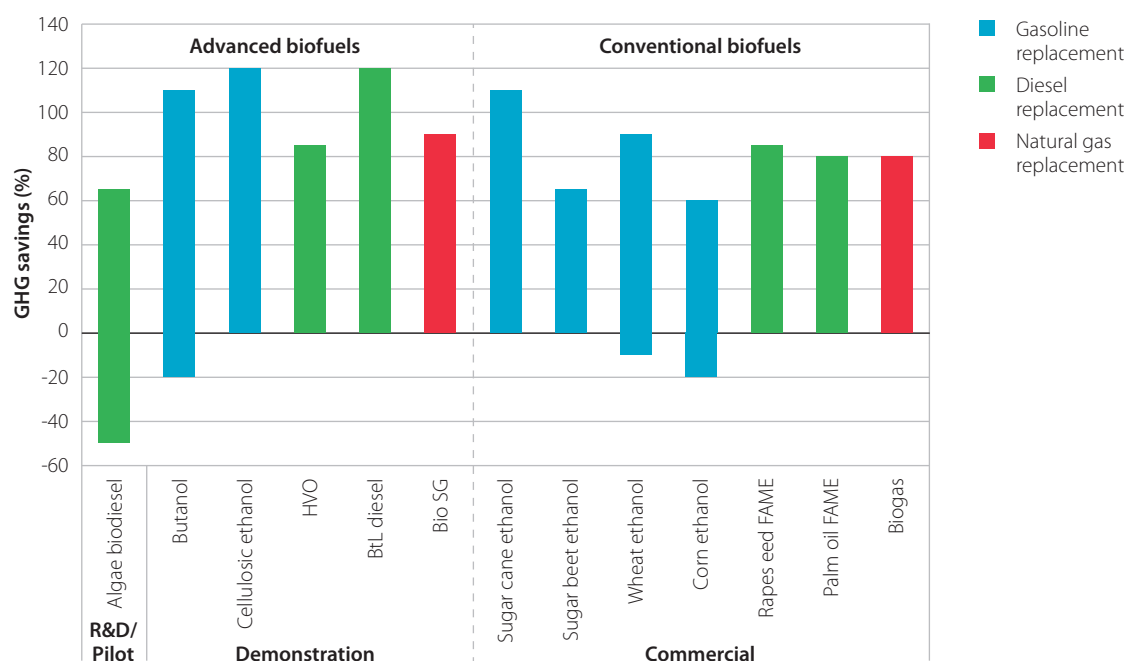
Since our original advice we have further investigated the potential of bioenergy to contribute to carbon budgets and the European Commission has clarified how biofuels will contribute to the EU's 2020 renewables targets:

- We considered feasibility and sustainability constraints on increasing biofuels use in more detail in our 2011 Bioenergy Review. We concluded that biofuels' role in transport should be limited in the long term, but that they could make important contributions during the transition, provided sustainability criteria are met.
 - Land constraints and competition with food are likely to limit the total available supply of sustainable bioenergy in the longer term. Biofuels available for transport are likely to be limited by competition with other sectors, particularly those with few alternatives for decarbonisation.
 - Calculations of emissions reductions from biofuels must consider land use change and be calculated on a lifecycle basis (Box 5.4). Advanced biofuels from wastes and residues offer greater lifetime savings but require significant investment to reduce costs. Reflecting this, the European Commission recently proposed to restrict the contribution of first generation biofuels in transport to 6% with advanced biofuels representing at least 2.5% by 2020.

Box 5.4: Biofuels lifecycle emissions and land use change

Biofuels are counted as zero carbon at the point of combustion (as the carbon released equates to that taken up from the atmosphere during crop growth). However, lifecycle emissions occur in the supply chain of biofuel production through fertilisers used for growing crops, the transport of the crops/fuels, and processing of the fuel. Analysis for our Bioenergy Review suggests that these could significantly erode emissions savings (Figure B5.5).

Figure B5.4: Range of GHG savings of different biofuels compared to fossil fuel



Source: OECD/IEA (2011).

Notes: Exhibit based on 60 "well-to-wheel" lifecycle emissions studies and shows a large range for each biofuel. Excludes land use change emissions.

Bioenergy feedstocks can also lead to emissions released through land use. Land use change (LUC) emissions occur when a portion of land is diverted from other uses to the growing of biofuels. Indirect land use change (ILUC) occurs when the growth of bioenergy crops displaces an existing economic activity to new land which leads to additional emissions being released.

Taking account of these factors can further reduce GHG emissions savings associated with biofuels.

- The extent of direct LUC impact depends on the type of land and crop grown. Where land used for crops was formerly carbon-rich (e.g. tropical rainforest or grassland), resulting emissions can dwarf any savings from bioenergy replacing fossil fuels.
- ILUC emissions are harder to measure and result in a wide range of estimates. Wheat bioethanol can perform well due to the potential for co-products to be used in animal feed. Palm biodiesel can have very significant negative impacts where plantations replaced previously forested areas or peatland.

Source: CCC (2011) *Bioenergy Review*

While there is still considerable uncertainty surrounding biofuel potential, these considerations support our previous assumptions on availability of sustainable biofuels for surface transport that, in line with the Gallagher Review, biofuels could meet 8% by energy of transport liquid fuel demand in 2020.

Cost of biofuels

Biofuel costs are a function of production and feedstock costs and need to be considered relative to the cost of conventional petrol and diesel.

- Biofuel production costs vary by the conversion process used. Current processes such as fermentation and anaerobic digestion are mature technologies which are already widely deployed to produce biofuels at scale. Advanced technologies are currently being developed but they are not yet widely deployed. Given their infancy these technologies are currently more costly than first generation processes and although costs are expected to fall, the degree and pace of any cost reductions are uncertain.
- It is expected that the price of fossil fuels will continue to rise in real terms towards 2030 as declining conventional oil resources force a move toward harder to exploit, and unconventional sources.

Recent evidence supports our previous assumption that biofuel and fossil fuel costs are likely to converge around 2030. However in the nearer term, while bioethanol production costs, can be cheaper than petrol, other fuels such as biodiesel and advanced biofuels are likely to remain more expensive than conventional fuels for most of the 2020s (Box 5.5).

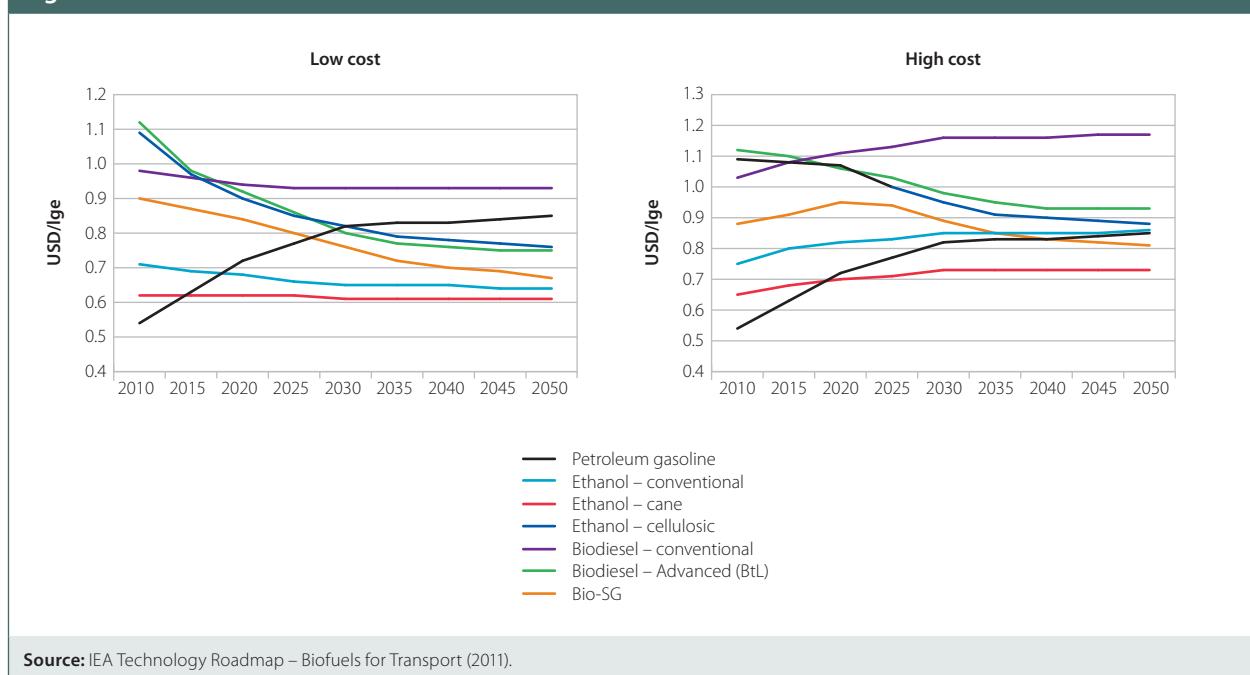
Box 5.5: Biofuel costs

In their Biofuels Technology Roadmap (2011) the IEA present two scenarios for biofuels uptake:

- **Low cost** where rising oil costs have little upward impact on biofuel costs, while economies of scale in biofuel production serve to provide downward price pressure.
- **High cost** which assumes a greater impact of rising oil prices on biofuel costs, and lower economies of scale in biofuel production.

Under the low cost scenario both advanced bioethanol and biodiesel production reach cost parity with petrol and diesel at around 2030. The high cost scenario is less optimistic and predicts biofuels to be marginally more expensive than conventional fuels in 2050 (Figure 5.6).

Figure B5.5: Cost of biofuels to 2050



Source: IEA Technology Roadmap – Biofuels for Transport (2011).

Source: IEA (2011) Biofuels Technology Roadmap, IEA (2013) Production Costs of Alternative Transportation Fuels

Demand-side measures

As we assumed in our original advice, there is significant potential to reduce demand for travel in order to deliver emissions reduction at low cost.

- **Smarter Choices:** Smarter Choices refers to a range of measures promoting voluntary reductions in levels of car use, achieved through a reduction in trips or modal shift to public transportation, walking and cycling. In our original advice we assumed that wide-spread implementation of Smarter Choices had the potential to reduce vehicle-km by 5%. Many of these schemes have just started and evaluation is on-going but initial results do not point to a change in our assumption at this stage (Box 5.6).

- **Eco-driving:** Eco-driving refers to a range of techniques to reduce fuel consumption, for example ensuring that tyres are properly inflated and sharp acceleration and braking is avoided. In our original advice we assumed that 20% of car and van drivers and 100% of HGV drivers would undergo training in eco-driving techniques by 2030, with fuel savings of 3% for cars/vans and 4% for HGVs compared to untrained drivers. Updated evidence suggests there is no basis to change our original assumption (Box 5.7).
- **Speed limiting:** Data shows that around 50%⁹ of car and van drivers exceed the motorway speed limit. This offers an opportunity for reducing emissions through enforcing the speed limit given the significant decline in fuel efficiency as speeds increase from 70 to 80 mph. Our data suggests that if the 70 mph speed limit for cars and vans were more strictly enforced this could lead to emissions savings of 1.4 MtCO₂ in 2020.
- **Freight operations:** Emissions reductions from freight can be achieved through modal shift, supply chain rationalisation and better vehicle utilisation, with many measures resulting in cost-savings for operators. Evidence supports our previous assumption of a feasible reduction in vehicle-kms of 6.5% by 2030 relative to baseline projections (Box 5.8).

Box 5.6: Evidence on effectiveness of Smarter Choices

The Local Sustainable Transport Fund (LSTF) set up by DfT in 2011 provides funding for Local Authorities to operate Smarter Choices schemes in England. There are currently 96 LSTF funded schemes across 77 Local Authorities, with similar measures in place across the Devolved Administrations.

Evidence on the effectiveness of Smarter Choices funded via the LSTF is currently being gathered through a small number of case studies, but is not yet available. Other new evidence suggests these schemes have the potential to reduce driving.

- A report by the Scottish Government on their *Smarter Choices, Smarter Places* pilot schemes implemented in seven regions found those using car driving as their principal mode of transport fell in all regions, with reported decreases ranging from 6% to as high as 40%. This coincided with an increase in cycling and walking in five of the seven regions.
- Centro's Smarter Choices scheme, to be rolled out across the West Midlands, is expected to deliver a reduction in the number of car driver trips of between 4 and 10% by 2015.

Source: Scottish Government (2013) *Monitoring and Evaluation of the Smarter Choices, Smarter Places Programme*, Centro (2011) *Smarter Network Smarter Choices*.

⁹ DfT (2012) *Free-flow vehicle speeds on non-built-up roads by road type and vehicle type in Great Britain*.

Box 5.7: Evidence on eco-driving

The application of efficient driving techniques can be an effective means of reducing fuel consumption. The effectiveness of eco-training is difficult to measure but evidence suggests cost savings can accrue to drivers when implemented over a long period. Up-take among fleet drivers could lead other groups and there is a role for technology to reinforce good practice.

- The effectiveness of eco-driving depends on a range of factors such as driving conditions, the vehicle and types of road being tested. The RAC suggest that savings of 5-10% are possible, but that there is evidence of a reduction in effectiveness over time (for example one study suggested a reduction from 10% to 3% in fuel saved after one year). It is therefore important that behaviour is reinforced at regular intervals.
- Fleet managers are a good case group for demonstrating the benefits of eco-training as they are particularly sensitive to potential cost savings and they often use more advanced driver training. Employers are in a strong position to compel driver training and there are examples (e.g. UK bus firm Stagecoach) of companies operating financial rewards and other means to maintain performance over time.
- There are simple technology solutions that could help reinforce behaviour and help deliver fuel savings:
 - Gear shift indicators and fuel performance monitors can prompt effective driving.
 - Telematics collect data such as the location, speed and other characteristics of driving and can be fed back to drivers in real time.
 - Tyre pressure monitors help ensure optimal tyre condition.

Source: RAC (2012) *The Effectiveness of Eco Driving*

Box 5.8: Evidence on freight operations

Key measures aimed at reducing freight distance travelled include:

- Modal shift – from HGV road travel to rail or water.
 - Network Rail¹⁰ forecast an increase in rail freight of around 17 billion tonne-kms to 2030. This is more than the equivalent reduction in road freight demand we expect in the fourth carbon budget, suggesting there would be enough additional freight capacity if all of this were to shift to rail.
 - Current investment planned by Network Rail could lead to rail becoming a more attractive option for freight. This includes: provision of longer and heavier trains; increased operating hours; expansion of rail-connected warehousing sites; improvements in ports logistics and connections (e.g. the London Gateway and the Barking rail freight terminal); and delivering new freight capacity.
 - Waterways have the potential to displace some road freight and offer economies of scale particularly for bulk goods and abnormal loads such as waste and aggregates.
- Supply chain rationalisation and better vehicle utilisation – these include use of computerised vehicle routing and scheduling systems (CVRS), better back-loading and optimising distribution centre locations.
 - A survey of Freight Transport Association¹¹ members using CVRS reported benefits of reduced mileage and fleet size as well as lowering costs to operators.
 - A case study of Alstons Cabinets¹¹ found better routing enabled the company to reduce its fleet size by 20%.
 - Better siting of distribution centres, double decker trailers and a reduction in empty driving has led to significant reduction in travel demand at Tesco; Asda has improved fuel efficiency by a half since 2005 by investing in measures such as in-cab technology, driver training and double decker lorries¹².

Source: DfT and Network Rail

10 Network Rail (2013) Long Term Planning Process: Freight Market Study.

11 DfT (2005) Computerised Vehicle Routing and Scheduling (CVRS) for Efficient Logistics.

12 <http://your.asda.com/sustainability-transport/17-million-miles-better>

4. Projected emissions with abatement – an updated scenario for the 2020s

In our previous advice we developed a trajectory of emissions through the 2020s that represented the cost-effective path to the 2050 target. This contained the set of measures that are important on the path to the 2050 target and that are cost-effective compared to expected carbon prices over investment lifetimes. It included improvements in conventional vehicles efficiency, uptake of electric vehicles and emissions reductions from demand side measures. We expected it to reduce transport emissions to 91 MtCO₂ in 2025 and 79 MtCO₂ in 2030.

Outlook to 2020

In developing our new scenario we follow the same methodology as our original advice. The starting point is a projection of baseline emissions from transport as set out in section 2. We then add measures which the Government is aiming to deliver or has committed to deliver, and our set of cost-effective abatement measures. Compared with our original advice, the new scenario now involves:

- The updated reference projection from the National Transport model.
- Lower EV uptake by 2020 (9% of new car sales and 12% of new van sales, compared to our previous assumption of 16%), reflecting an assessment of the UK's share of projected EU production.
- Updated costs for some measures (see section 3):
 - Updated vehicle technology and battery costs, reflecting the work by Ricardo-AEA and Element Energy for our 2012 advice on meeting the UK's 2050 emissions reduction target.
 - Updated biofuel costs, reflecting latest evidence from the IEA.
- A refined modelling approach, which disaggregates small, medium and large cars, and better accounts for real world vehicle efficiencies¹³ and for the 'rebound' effect (i.e. a change in vehicle-km as a result of changes in purchase and running costs of vehicles).

Other assumptions underlying our projection remain unchanged:

- New car CO₂ – we continue to assume new conventional car CO₂ will reach 110 gCO₂/km in 2020.
- Biofuels – we continue to assume, in line with the Gallagher Review, that biofuels will meet 8% by energy of transport liquid fuel demand in 2020.
- Smarter Choices – we continue to assume a 5% reduction in vehicle-km (relative to the baseline) as a result of nationwide roll-out of Smarter Choices programmes.
- Freight logistics – we continue to assume a 6.5% reduction in HGV-kms in 2030 through improved freight operations

¹³ As we set out in our 2013 progress report, there is evidence to suggest that efficiencies under real-world driving conditions can be significantly lower than measured under the current test cycle, with a larger discrepancy for more efficient vehicles. See for example ICCT (2013) From laboratory to road.

- Eco-driving – we continue to assume that by 2020, 12% of cars drivers and 100% of HGV drivers have been trained, and use 3-4% less fuel.
- Enforcing the speed limit– we continue to assume that the 70mph speed limit for cars and vans is enforced on motorways and major roads, saving 1.4 MtCO₂ in 2020.

As a result we now assume emissions from road transport are 83 MtCO₂ in 2020. We add to this projected emissions from rail, domestic aviation and shipping, bringing total domestic transport emissions to 93 MtCO₂. This would be a 22% reduction on 2010 and is 7% lower than the level than we assumed in our original advice (101 MtCO₂).

The path from 2020 to 2030

We have revisited our scenario for the 2020s based on the latest evidence. This has generally confirmed our previous analysis, with a small number of updates. In terms of road transport, our scenario now involves:

- The updated reference projection from the NTM (see section 2).
- A slightly revised trajectory for ultra-low emissions vehicles, with only a small net impact on emissions:
 - **Market share of EVs.** We assume the same market share of new car and van sales by 2030 (i.e. 60%). However, the lower market share for 2020 described above leads in turn to slightly lower uptake in 2025, tending to increase emissions.
 - **Balance of BEVs/PHEVs.** We previously assumed that, given expected range constraints in 2030, 70% of people buying an EV would choose a PHEV rather than a pure BEV, based on an analysis of trip patterns; BEVs would be suitable for drivers who rarely make longer trips, or in multi-car households. However, the consumer choice modelling we commissioned from Element Energy for this report suggests, based on stated consumer preferences, that BEVs may achieve a higher market share than we previously assumed (around 40% of EV car purchases and 65% of EV van purchases in 2030), tending to reduce emissions.
- Updated vehicle technology and battery costs, and biofuels costs (see section 3).
- As for 2020, a refined modelling approach, which disaggregates small, medium and large cars, and better accounts for real world vehicle efficiencies and for the 'rebound' effect (i.e. a change in vehicle-km as a result of changes in purchase and running costs of vehicles).

Other assumptions underlying our scenario remain broadly unchanged:

- We continue to assume that emissions from conventional new cars will fall to 80 gCO₂/km by 2030, emissions from conventional new vans will fall to 120 gCO₂/km and emissions from conventional new HGVs will fall to around 600 gCO₂/km on average on a test cycle basis.

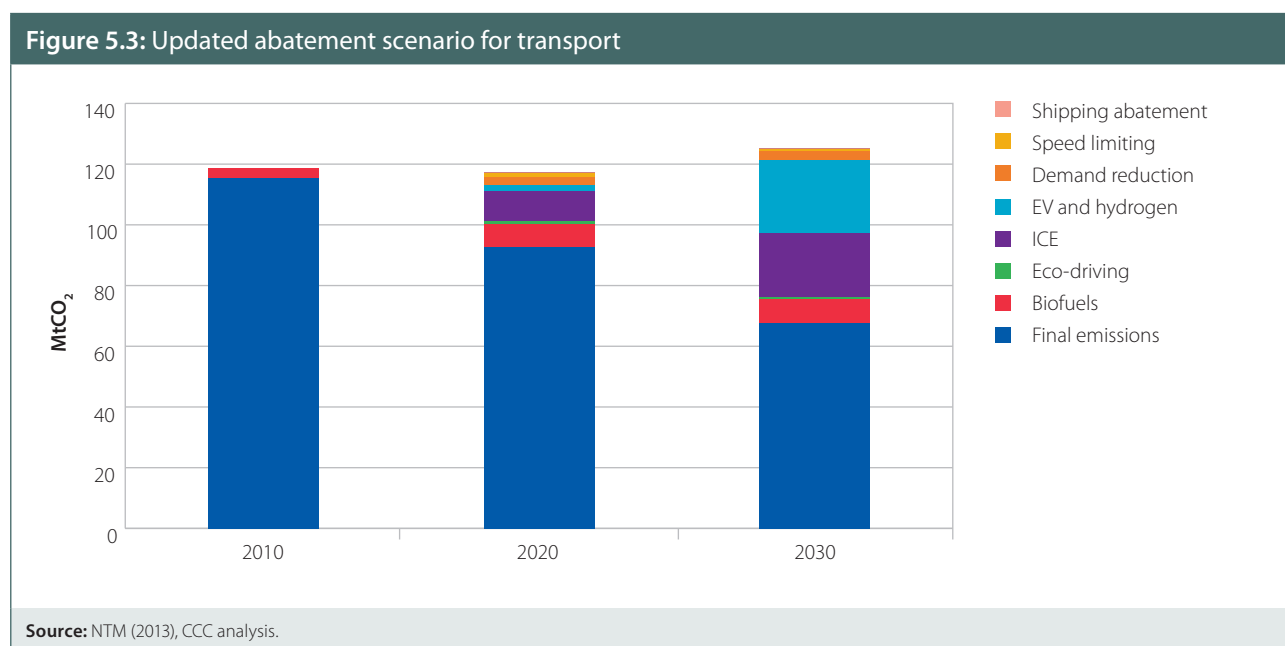
- We continue to assume that 50% of new buses are hydrogen fuelled by 2030.
- We continue to assume that the quantity of biofuels implied by an 8% share by energy in 2020 is held constant through the 2020s, reflecting uncertainties around sustainability.
- We continue to assume that the demand side measures delivered in 2020 persist (i.e. we assume a 5% reduction in vehicle-km due to Smarter Choices measures, a reduction in HGV-kms due to improved freight operations on rising trajectory to 6.5% reduction by 2030, and emissions reductions from eco-driving and enforcing the speed limit).

We have also updated our scenario to reflect latest evidence for domestic shipping:

- In 2011 the International Maritime Organisation agreed a global policy to improve energy efficiency of new ships by 30% by 2025. Our emission scenario for domestic shipping reflects this policy development, based on our previous detailed assessments of UK shipping emissions¹⁴.

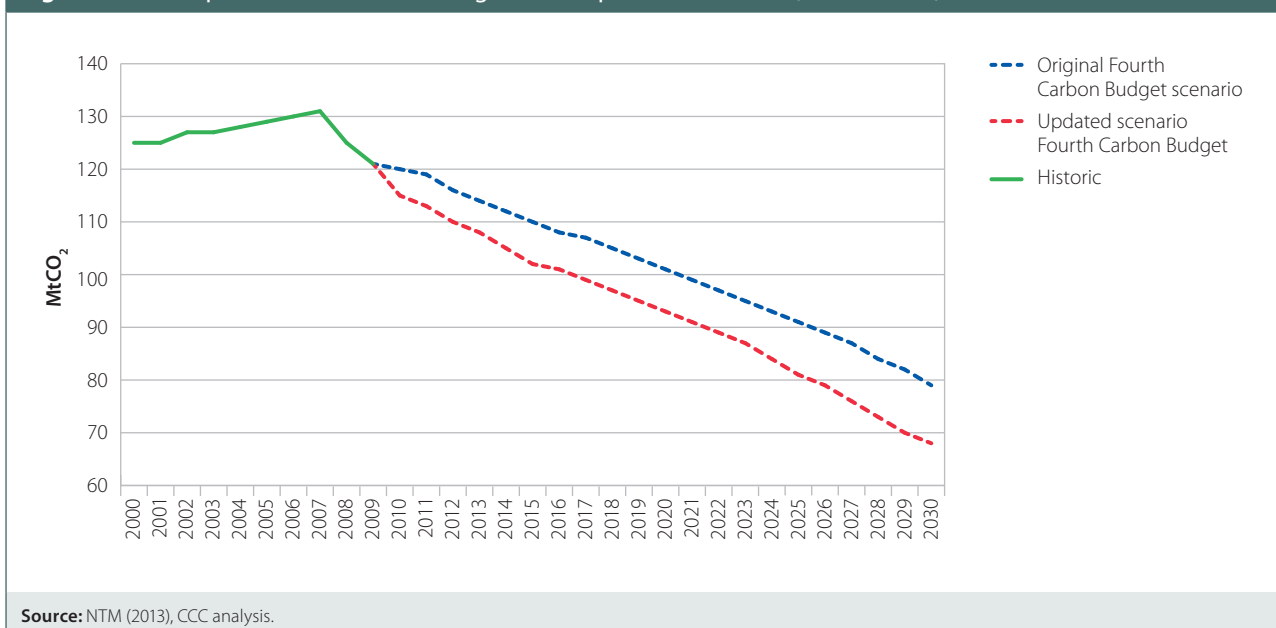
This scenario now results in domestic transport emissions of 82 MtCO₂ in 2025 (i.e. 9 MtCO₂ below our previous estimate) and 69 MtCO₂ in 2030 (11 MtCO₂ below our previous estimate) (Figures 5.3 and 5.4).

We build this updated scenario into our economy-wide analysis in Chapter 1.



¹⁴ CCC (2012) *Scope of carbon budgets: Statutory advice on inclusion of international aviation and shipping*, CCC (2011) *Review of UK Shipping Emissions*.

Figure 5.4: Transport emissions in our original and updated scenarios (2000 – 2030)



Preparing for 2050

Beyond 2030 this scenario would keep open the option of reaching close to zero emissions from surface transport by 2050, which we judge to be feasible given:

- Further uptake of electric vehicles (battery or fuel cell). A zero-emissions light vehicle fleet by 2050 would require all new cars and vans to be zero emissions by around 2035. This is plausible given a high share of sales by 2030 as in our abatement scenario. Rising carbon prices will justify larger batteries and longer ranges for BEVs, while fuel cell vehicles could help address market segments which are the most difficult to electrify, in terms of both range and access to overnight charging.
- Hydrogen and biofuels/biogas for HGVs. Deployment of hydrogen fuel cells in buses offers a stepping stone to potential deployment in goods vehicles in the longer term. While currently there are a number of challenges, it is plausible that these could be addressed, at least for some applications, given ongoing research and investment. Should challenges prove insurmountable in some cases (e.g. for heavy, long-distance goods vehicles) sustainable biofuels and/or biogas could offer a solution, though use of limited bioenergy resources here would need to be traded-off against use in other applications which may offer greater emissions reduction potential (e.g. industrial heat with CCS).

Sensitivities and flexibilities

We have also considered various sensitivities around the updated scenario:

- **Higher fuel or carbon prices.** Under high assumptions for carbon prices or fossil fuel prices, the costs of measures in our scenario would be lower, implying some scope to go further in terms of deployment. For example, under high fossil fuel prices, the difference in lifetime cost of a C/D segment BEV car compared to relative to a conventional car with today's technology would fall from around £+1500 to £-600 in 2025, making it easier to achieve higher consumer uptake. Further improvements to conventional vehicle efficiency would also become more cost effective, although lead-times in product development may mean some delay in bringing more efficient vehicles to market. Were the share of EVs in new car and van sales to reach 70% in 2030, and conventional new car efficiency to reach 60 g/km on a test cycle basis, emissions from domestic transport would be 4 MtCO₂ lower over the fourth carbon budget period than in our core abatement scenario.
- **Low oil or carbon prices.** Under low assumptions for fossil fuel prices or carbon prices, abatement costs associated with our updated scenario would increase. However, efficiency improvements, demand-side measures and biofuels would all remain negative or low-cost. EVs may no longer be cost-effective in the 2020s, but their deployment would still be required in order to prepare for a near-zero emissions light vehicle fleet by 2050. Deployment of measures in our updated scenario, and resulting domestic transport emissions, would therefore be largely unaffected.
- **Deliverability barriers.** Uptake of EVs is a key area of our updated scenario where there are delivery risks, reflecting the barriers to consumer uptake described in section 3 above. For example, there may be constraints on access to overnight charging for tenants, consumer acceptance of EV capabilities may be slower than anticipated, or battery cost reductions may be more gradual than expected. We have therefore considered an illustrative sensitivity where the share of EVs in new sales reaches only 30% in 2030. Emissions in this case would be 14 MtCO₂ higher over the fourth carbon budget period compared to our abatement scenario.

As set out in Chapter 1, the fourth carbon budget involves flexibility to accommodate these sensitivities. Firstly, lower delivery in some areas could be offset by increased delivery elsewhere. Secondly, there is some 'headroom' in the budget, such that some under-delivery overall can be accommodated within the economy-wide budget.

3. Benefits of delivering the measures in the fourth budget period

The measures in our updated abatement scenario are cheaper than the expected carbon price or are required to prepare for 2050 (Table 5.1). A delay in their deployment would therefore increase costs. We have quantified the cost for such a delay:

- The improvements in conventional vehicle efficiency in our updated scenario save money even before carbon savings are included.
- Deployment of electric vehicles in the 2020s is needed to prepare for a near-zero emissions light vehicle fleet by 2050. In addition, EVs are expected to be cost-effective relative to the carbon price by 2025, with electric vans offering emission reductions at negative cost.

- Overall, our updated scenario delivers a net present value of £30-35 billion compared to a scenario where deployment of measures through the 2020s is delayed to 2030¹⁵. To the extent that carbon prices or fossil fuel prices are higher than our central assumptions, this benefit would increase. Even under low assumptions for carbon prices, our updated scenario would still offer benefits relative to delayed action, and under low fossil fuel prices would be low to zero cost. It is therefore a low-regrets option (Table 5.2).

Table 5.1: Benefits of measures in our updated abatement scenario

		Average £/tCO ₂ in 2025	Importance to 2050
Conventional efficiency improvements	Cars	3	
	Vans	-51	
	HGVs	-123	
Electric vehicles	Cars	156	Significant deployment required by 2030 to allow full penetration of the fleet by 2050, given stock turnover rates. A zero emission car fleet is likely to be part of the cost-effective solution to meeting the UK's 80% reduction target.
	Vans	-57	
Biofuels		42	
Demand side measures		Likely to be cost-effective given low costs of implementation and resulting fuel savings.	

Source: CCC analysis.

Note: unit abatement costs are average across measures deployed up to and including 2025; abatement costs are generally higher for measures deployed in earlier years.

Table 5.2: Net present value under different carbon price and fossil fuel price assumptions

	Central assumptions	Low carbon price	High carbon price	Low fossil fuel price	High fossil fuel price
NPV of our updated scenario versus delayed action £bn (2012)	30-35	15-20	40-50	-15-0	55-70

Source: CCC analysis.

It is therefore appropriate to aim to deliver significant abatement in the transport sector, as included in our updated abatement scenario. This will require policy strengthening to ensure that incentives for investment are in place and that barriers to deployment are addressed. We will consider policy in more detail in our 2014 progress report to Parliament, as part of our review of progress over the first budget period.

¹⁵ The range reflects different assumptions for the extent to which deployment of EVs is delayed. The upper end of the range corresponds to the share of EVs in new car and van sales remaining fixed through the 2020s. The lower end of the range corresponds to the share of EVs increasing to 26% for cars (22% for vans) in response to falling technology costs but in the absence of policy measures.

Chapter 6: Reducing emissions from agriculture and land use, land use change and forestry

Introduction and key messages

In 2011, agriculture accounted for 9% (51 MtCO₂e) of UK greenhouse gas (GHG) emissions. In our original advice for the fourth carbon budget we proposed measures to reduce agriculture non-CO₂ emission by 4.5 MtCO₂e in 2020, 7 MtCO₂e in 2025 and by 10 MtCO₂e in 2030. Key measures to achieve these include nutrient management, livestock breeding and anaerobic digestion.

The land use, land use change and forestry (LULUCF) sector is a net carbon sink, absorbing 3.3 MtCO₂e in 2011. We have identified abatement measures in this sector amounting to 1 MtCO₂ by 2030 through increased tree planting.

There is no new evidence to suggest that our previous assessment of future emissions from agriculture should be changed and so we continue to use our previous scenario for this report. Further work is being undertaken to analyse on-farm abatement options in Defra's Farmscoper tool, but results are preliminary and have not yet been published. We will continue to monitor development of these options and update our advice as appropriate.

We set out the analysis underpinning these conclusions in five sections:

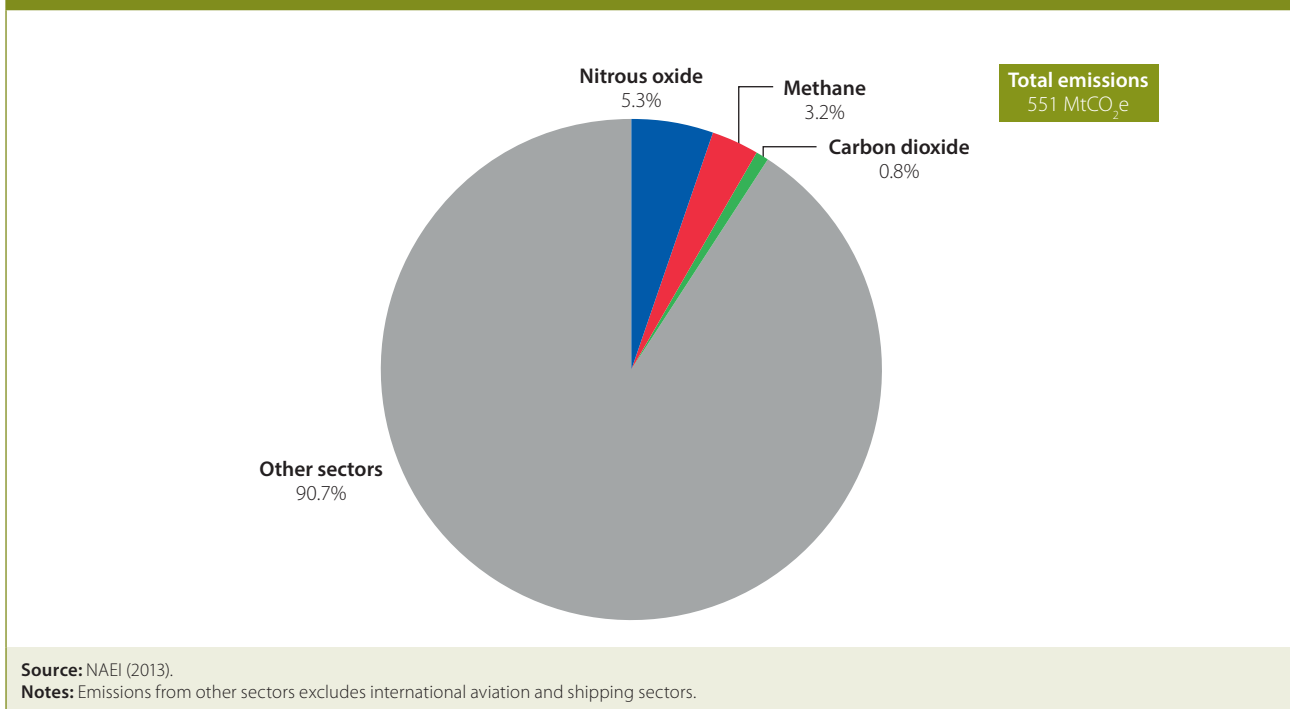
1. Current emissions
2. Projected agriculture emissions before abatement action
3. Updated evidence on abatement options and costs in farms
4. Projected agriculture emissions with abatement – an updated scenario for the 2020s
5. Land use, land use change and forestry

1. Current emissions

Agriculture emissions totalled 51 MtCO₂e in 2011, accounting for 9% of UK territorial GHG emissions (Figure 6.1). Agriculture emissions are comprised of: nitrous oxide (57%) from crops and soils, largely resulting from the application of organic and inorganic fertiliser; methane (35%) from enteric fermentation and waste and manure management and carbon dioxide (8%) from stationary and mobile machinery. The LULUCF sector is a net carbon sink, and in 2011 it absorbed 3.3 MtCO₂e.

Since 1990 agricultural emissions have declined by 20% due primarily to a reduction in livestock numbers and a decline in fertiliser use. However, the absolute level of non-CO₂ emissions in agriculture remains highly uncertain and could be considerably higher or lower than calculated in the current inventory given they use standard rather than UK-specific emission factors. The launch of an improved inventory in 2015 will provide more robust estimates and a firmer foundation for considering abatement options.

Figure 6.1: GHG emissions from agriculture in the context of total UK emissions (2011)



2. Projected agriculture emissions before abatement action

The starting point for our scenario is DECC's updated emissions projections (UEP), which projects 'baseline' emissions to 2030 without the impact of policies implemented since the 2007 Energy White Paper.

Since our original advice on the fourth carbon budget, baseline projections of agricultural emissions have been updated for new assumptions on key drivers (e.g. livestock numbers, crop area and GDP) and to better reflect the past trend in agricultural activity and changes in emissions factors. Baseline emissions are projected to fall by 5.2% to 2020 and reach 48 MtCO₂e by 2030, which is 1 MtCO₂e (2.2%) lower than the projection at the time of our previous recommendation for the fourth carbon budget (Figure 6.2). Disaggregated by GHG, the changes are:

- N₂O emissions are expected to decline by 2.1% between 2011 and 2030, reaching 29 MtCO₂e by 2030 1 MtCO₂e higher than previously projected.
- Methane emissions are expected to decline by 1.4% by 2030, reaching 18 MtCO₂e by 2030, slightly lower than our previous projections.

- CO₂ emissions are expected to decline by nearly 2 MtCO₂ between 2011 and 2030 driven by reductions in off-road transport energy-use¹ (e.g. gas oil) and reach 2.4 MtCO₂ by 2030.

There is scope for further abatement policies, such as the Industry GHG Action Plan in England, to reduce emissions below the baseline projection. We consider the latest evidence on abatement measures in the next section.

Figure 6.2: Agricultural baseline emissions projections to 2030



3. Updated evidence on abatement options and costs in farms

Options for reducing emissions are focused on on-farm abatement through the employment of best practice and technology:

- **Non-CO₂:** In 2010, our analysis identified a range of options to reduce emissions from soils and livestock: nutrient management, livestock breeding, livestock feeding, anaerobic digestion and manure management
- **CO₂:** Options include: efficient engine technology and alternative vehicle fuels for mobile machinery, and more efficient and biomass boilers for stationary machinery.

Overall, we identified a low scenario of non-CO₂ abatement potential by 2030 of 8.3 MtCO₂e and a high scenario of 11.6 MtCO₂e. We selected the centre of the range, equivalent to 10 MtCO₂e and our analysis suggested that these abatement options are mainly cost-saving, with only three measures entailing a positive cost (new species of nitrogen fixing plants, anaerobic digestion on pig farms and the installation of covers on slurry lagoons and tanks on beef and dairy farms) (Table 6.1).

¹ Modelling previously assumed flat gas oil demand.

Our projection for the fourth carbon budget excluded abatement of CO₂ emissions due to the lack of evidence that existed on the abatement potential of various mitigation options (e.g. use of efficient engine technology and alternative vehicle fuels). A subsequent report for Defra by AEA² in 2011 did identify 0.5 MtCO₂ of abatement potential by 2030, but as this did not consider the impact of changes in farm practices and electrification of farm machinery, more work is required in these two areas in order to better understand CO₂ abatement potential.

There is no significant new evidence to adjust our abatement potential or to include significant abatement from CO₂. It is possible that the development of the Farmscoper tool³ by Defra will in due course identify additional non-CO₂ abatement from new and existing farming practices. We will consider the outputs of the Farmscoper tool when they are available. Looking further ahead to 2015, completion of Defra's Agricultural UK GHG Platform will enable us to consider, amongst other things, the effectiveness of mitigation measures.

Table 6.1: Non-CO₂ annual abatement by mitigation measure in 2030

Category	Measure(s)	MtCO ₂ e
Nutrient management	Improved timing of fertiliser application, avoiding excess application etc.	2.6
Use of more nitrogen efficient plants	Species introduction	2.4
	Improved nitrogen use plants	0.4
Livestock breeding	Breeding to improve genetics in beef and dairy; improved fertility in dairy	1.4
Livestock feeding	Propionate precursors for beef and dairy	2.0
	Maize silage for dairy	0.2
Anaerobic digestion	Pigs and poultry farm units	0.6
Manure management	Covering lagoons and slurry tanks	0.2

As we noted in our report on the 2050 target,⁴ there is scope for further abatement from:

- On-farm abatement with the use of nitrification inhibitors (1 MtCO₂e annually) and drainage (2 MtCO₂e). Measures to reduce CO₂ emissions from machinery could ultimately reduce emissions to zero, implying a reduction of 2.4 MtCO₂e.
- Inclusion of demand-side measures – these have the potential to deliver an additional 5 MtCO₂e comprising food waste reduction (2 MtCO₂e) and diet change away from less carbon-intensive foodstuffs (3 MtCO₂e).

As in our original advice we do not include potential abatement from these measures. However, these measures could provide an option to go further than we have assumed in agriculture or to compensate for reduced delivery in other measures.

² AEA (2011), Energy Marginal Abatement Cost Curve for English agriculture.

³ The Farm Scale Optimisation of Pollutant Emission Reduction (Farmscoper) decision support tool evaluates the impacts of specific mitigation methods on a wide variety of environmental pollutants.

⁴ CCC (2012), *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*.

4. Projected agriculture emissions with abatement – an updated scenario for the 2020s

We previously developed an abatement scenario involving measures that were likely to be economically sensible in a carbon-constrained world, that are cost-effective with a carbon price and are important for preparing to meet the 2050 target. The measures included those in Table 6.1 (e.g. improved timing of fertiliser application, breeding to improve genetics in beef and dairy, and using more nitrogen efficient plants). Under this scenario we expected sector CO₂e emissions to fall to 42 MtCO₂e in 2025 and 40 MtCO₂e in 2030.

Reflecting the lack of significant new evidence since 2010, we retain the same abatement options as set out in our original advice. Combining these with the latest baseline projections implies the same level of emissions in 2025 and a marginally larger reduction than we previously assumed in 2030, with emissions falling to 39 MtCO₂e.

While the vast majority of measures in our scenario represent cost-savings, just over a quarter (10 MtCO₂e) of the abatement potential identified for the whole fourth carbon budget period entail a cost of up to £69/tCO₂, which may be less desirable in a low carbon price scenario or where barriers related to costs are greater than we have assumed. For example, the costs of introducing new species of nitrogen fixing plants (costs associated with reduced yields, learning, consultancy & contractors) may not be offset by reduced fertiliser use. While we do not formally model this as a sensitivity, we recognise that it would constitute a very small proportion of the overall abatement total, and that other options exist to compensate for it.

The measures in our scenario are generally cost saving so it follows that any delay to their implementation will increase costs and should therefore be avoided.

However, the emphasis on a voluntary approach to achieve delivery rather than measures and incentives could prove challenging.

We will return to this in our annual progress report to Parliament next year.

5. Land use, land use change and forestry (LULUCF)

The LULUCF sector has been a carbon sink since 2001, absorbing a net 3.3 MtCO₂ in 2011. However, since 2010 net emissions have been increasing, and the sector is projected to be a net carbon emitter in 2022. Net baseline emissions are projected to reach 2.2 MtCO₂e by 2030.

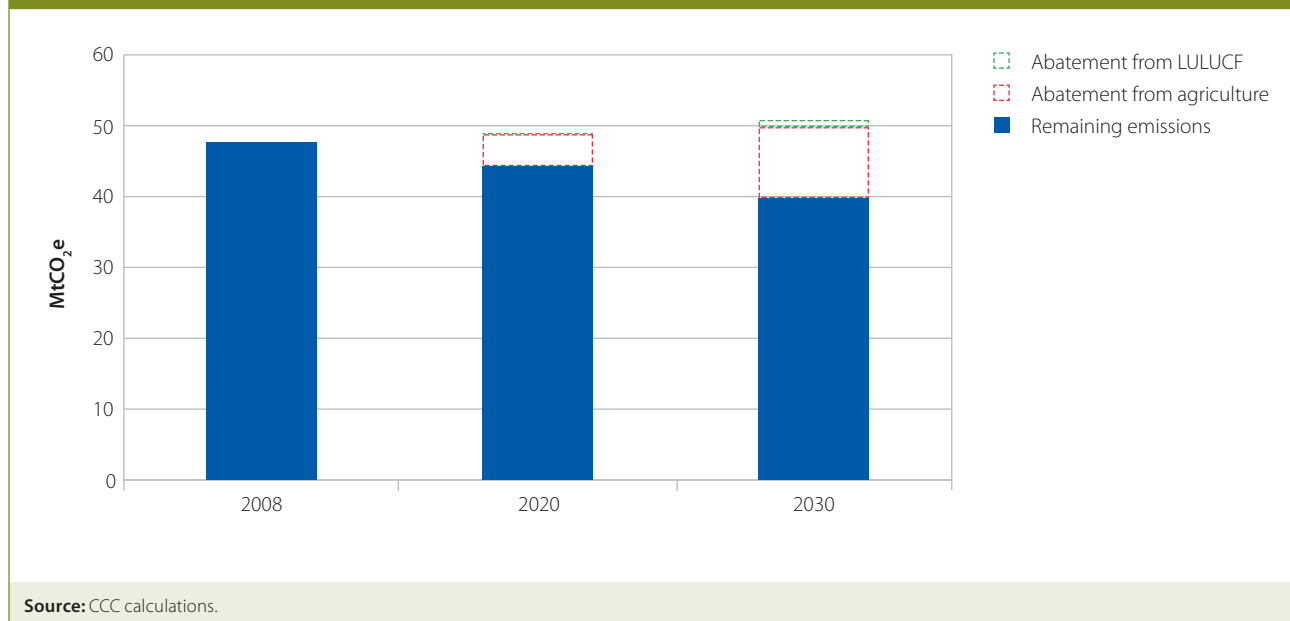
In our previous advice in 2010, we identified an increase in the rate of tree planting of an additional 10,000 ha/year to be the main abatement option. By 2030 this could deliver 1 MtCO₂e savings. Our updated abatement scenario remains unchanged.

Beyond 2030, continuing the same planting rate could deliver an additional 1 MtCO₂e of abatement by 2050.

There is also scope for further abatement through the restoration of upland peat. Two-thirds of upland peat is degraded and accounts for about 0.35 MtCO₂e in England. However, this would require Government to include upland peat in the inventory⁵, strengthen the policy framework to enable further restoration effort across the uplands and the enforcement of existing regulations that prevent damaging practices on protected sites. This is in line with the Adaptation sub-Committee's recent recommendations⁶.

Combined with abatement in agriculture, residual emissions by 2030 from agriculture and the LULUCF sectors are projected to decline under our scenario to 39.8 MtCO₂ (Figure 6.3).

Figure 6.3: Central scenario emissions abatement in the agriculture and the LULUCF sectors



⁵ The IPCC is developing a methodology to capture changes (avoided emissions) due to restoration and drainage (release) for 2013 using Tier 1 emissions factors, and inclusion into the inventory by member states is voluntary.

⁶ CCC (2013), *Managing the land in a changing climate – Adaptation Sub-Committee progress report 2013*.



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